

April 14, 1936.

G. H. ZENNER

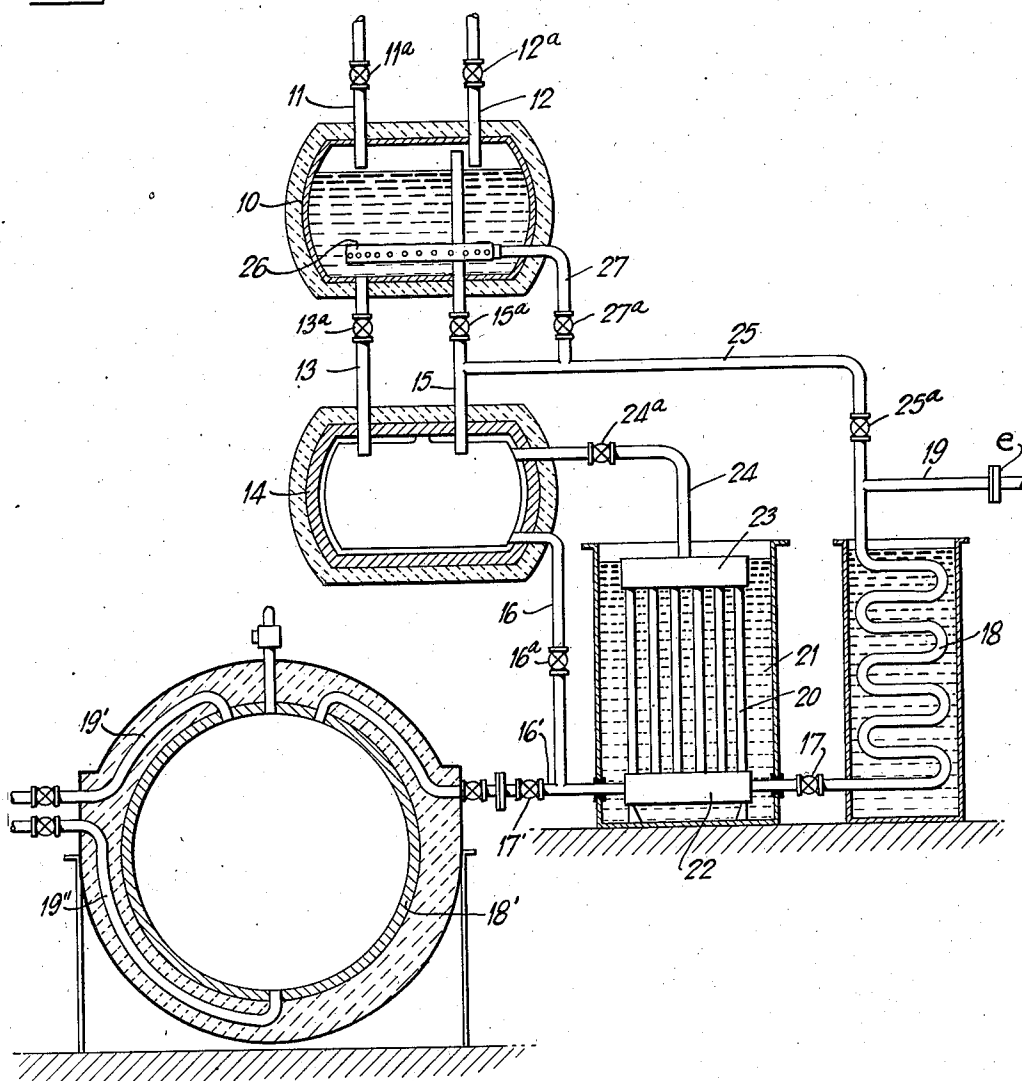
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METHOD AND APPARATUS FOR EFFECTING THE DISCHARGE OF A VOLATILE LIQUID

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2 Sheets-Sheet 1

Fig. 1.



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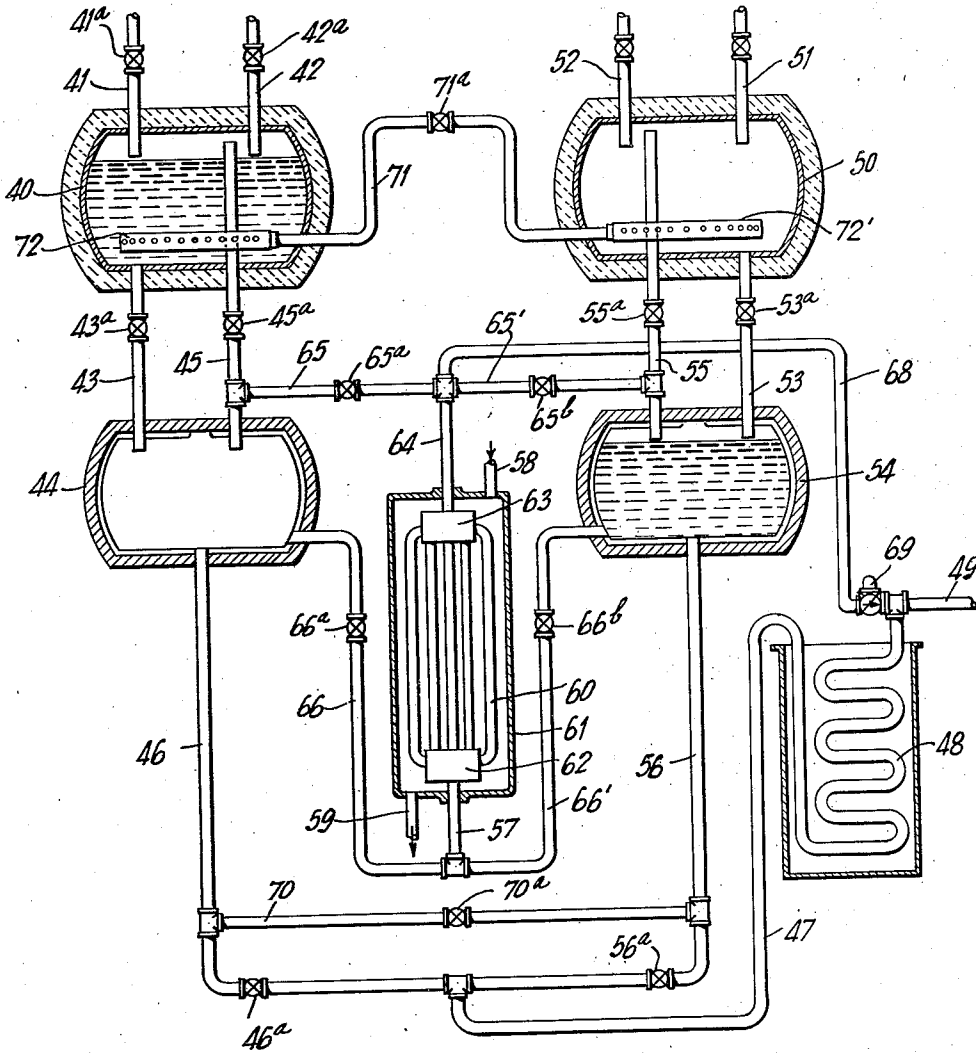
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2 Sheets-Sheet 2

Fig. 2.



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2,037,673

METHOD AND APPARATUS FOR EFFECTING
THE DISCHARGE OF A VOLATILE LIQUID

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Application January 24, 1935, Serial No. 3,249

15 Claims. (Cl. 62—1)

This invention relates to a method and apparatus for effecting the discharge of a volatile liquid from a vessel in a closed system against a head of pressure, and particularly of a volatile liquid, from a final vessel in a system of vessels connected in cascade.

The invention has for its object generally the provision of an improved procedure and suitable apparatus for effecting quickly the desired discharge of very cold volatile liquid which is obtained with difficulty and at some expense, such as certain liquefied hydrocarbons, liquid oxygen, liquid nitrogen, and the like, from a vessel, such as a transfer vessel, to a receiving vessel against a head of pressure.

In transferring volatile liquids of the character indicated which may be partly in the liquid phase and partly in the gas phase, from a supply vessel at a relatively low pressure to a receiver at a relatively high pressure in a manner which reduces losses of the gas phase, such as occur when "blowing-down" initially to receive a charge, a system of transfer vessels, for example, as set forth in copending application of John J. Murphy, Serial No. 752,993, is interposed between such supply vessel and the receiving vessel. By means of such a system, the material being transferred is advanced through a succession of stages of increased pressure from the low pressure region to the high pressure region accompanied with condensations of material from the gas phase into the liquid phase so as to reduce the material in the gas phase, that is ultimately blown-down to the atmosphere, to a relatively low value; the resulting condensate augmenting the liquid ultimately discharged. In such cascade system, the discharge of liquid from the vessel operating at highest pressure may become sluggish, particularly at pressures approaching the critical pressure. In the present commercial practice, when transferring liquid oxygen, liquid nitrogen, and the like, the receiving vessel to which the liquid is transferred may have a pressure considerably in excess of the critical pressure, for example, the receiver may be at 2100 psi gage.

Specifically, it is an object of the present invention to accelerate the discharge of a low boiling point liquefied gas, such as from a vessel in a cascade system where the pressure imposed on the liquid passes through or exceeds the critical pressure, in a manner which achieves the transfer of a desired quantity of liquid in a relatively short period of time.

It is also an object to provide a cascade system of the character indicated with means for con-

trollably supplying heat in a manner which brings the total internal energy of the contents remaining in a selected vessel after discharge to a relatively low value while maintaining the refrigerating capacity of the material discharged at a relatively high value.

It is a further object to provide vessels in a cascade system with means comprising a connection arranged to absorb heat whereby the energy for effecting the desired discharge is supplied solely as thermal energy, the input thereof being at a rate such as to accelerate the discharge up to substantially any desired value. A connection thus arranged to absorb heat is herein-after referred to as a "thermal leg".

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 the 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 section and partly in elevation showing a simple cascade system having a thermal leg associated therewith for accelerating the discharge of gas material from the system in accordance with the invention; and

Fig. 2 is a similar view showing a modified form of cascade connected transfer vessels employing a thermal leg connected to the transfer vessel in a manner which is independent of the liquid withdrawal connection.

Where liquefied gas is transferred through liquid transfer vessels connected in cascade at successively higher pressures to or beyond the critical pressure the flow of the liquid is much retarded owing to the fact that the forces acting mechanically on the liquid material, such as the force of gravity, for effecting the transfer become less effective. This results because the densities of the material in the gas and liquid phases become equal at the critical point.

The connection or thermal leg, provided in accordance with the present invention, overcomes this difficulty and communicates with a selected vessel in the transfer system and is ar-

ranged to absorb heat from a suitable heat supplying medium, such as water or atmospheric air, in a manner which quickly heats a portion of the liquid being transferred and elevates its temperature to a value above the critical temperature. Such heated material is applied so as to overcome the condition of equal densities of gas and liquid phases; whereby the transfer and discharge of the material is made to take place at a desired rate. Since the gas remaining after discharge is to be recondensed it is advantageous that the internal energy contained in it be reduced to a relatively low value, at the same time it is desired to maintain the refrigeration of the major part of the discharge relatively unimpaired which is particularly desired when said refrigeration is to be utilized, as for example, when the material transferred is to be held in the receiving vessel in the liquid phase or when the refrigeration is to be used for cooling portions of gas.

It is also desired that the heat absorbing element be so arranged that the material is heated to a relatively high temperature in one pass therethrough, the heat being supplied at the appropriate temperature and rate required for accomplishing the heating. When so heated the desired discharge is accomplished and the residual contents of the vessel have a total internal energy of relatively low value, which results from raising the temperature of the residual contents to a relatively high value. The high temperature produces a low density of the residual contents which more than overcomes the increased internal energy per unit of mass, so that the total internal energy of the residual contents has a satisfactory low value.

The attainment of a low value for the total internal energy of the residual contents of the vessel is an important object of this invention. The pressure in the vessel after discharge is substantially the same, regardless of the residual gas temperature, so that if this temperature be low the density is high, and vice versa. An increase in temperature of the residual gas not only causes an increase in the internal energy per unit weight, but also causes the more important decrease in density. As a consequence of this decrease in density, the total internal energy of the residual contents is lower the higher the temperature. By controllably heating the residual gas to a relatively high temperature, a satisfactory low value for the total internal energy is attained.

An advantageous form of thermal leg adapted to this end comprises a heat absorbing element which is in pressure communication at points both above and below the normal liquid level with the vessel from which the material is to be discharged, whereby the material in the liquid phase which flows into the thermal leg is quickly heated, a volumetric expansion ensues, and a syphonic action takes place.

Referring now to the drawings and particularly to Fig. 1, 10 denotes a transfer vessel in a cascade system which is provided with an inlet connection 11 adapted to receive gas material of low boiling point in the liquid phase, for example, liquid oxygen, from a source of liquid supply at a relatively low pressure. This vessel has a gaseous discharge connection 12 leading from the top and a liquid discharge connection 13 leading from the bottom to another vessel 14 of the system, which, in the arrangement shown, comprises the final transfer ves-

sel of the series transferring the material to a region of high pressure. This second vessel has a gaseous discharge connection 15 communicating with the upper portion of vessel 10 and liquid discharge connection 16 controlled by valve 16a leading from the lower portion. This connection communicates with a suitable liquid receiving and/or vaporizing device. One form of device adapted for high pressure service is shown at 18 and discharges material in the gas phase through a service connection 19 to gas storage or consuming apparatus; ingress of material to be vaporized being controlled by an inlet valve as shown at 17.

A receiving device that may be used with or without the high pressure device described and adapted to service at relatively low or intermediate pressures is shown at 18', the admission of liquid material thereto being controlled by a valve such as shown at 17' placed in a suitable branch 16' of the liquid-discharge conduit 16 leading from vessel 14. This receiving device has a gas phase discharge conduit 19' and a liquid phase discharge conduit 19''.

The transfer vessels 10 and 14 of the cascade system through which the liquid transferred passes are constructed so as to preserve the refrigeration of the liquid and to this end are provided with means for rigorously excluding heat from the liquid during transfer. Any suitable means adapted for this purpose may be employed, for example, a heat insulating envelope may be provided as shown on the exterior of each of the vessels; a spaced thin-metal lining or "basket" may also be employed as shown on the interior of vessel 14. The pipe connections employed are also preferably insulated; the showing of any such insulation in the drawing has been omitted in the interests of clearness of illustration.

In order that the receiving device may receive liquid material at a desired rapid rate, in accordance with the invention, a thermal leg is connected with the vessel 14 for controllably heating a portion of the liquid therein and raising the pressure of the vessel quickly. The heating thus practiced is seen to introduce relatively little heat into the discharged material but heats the vaporized material to a temperature such that the total internal energy of the residual contents of vessel 14 after discharge at the desired pressure is lowered. The thermal leg here provided is shown as comprising a heat absorbing element 20 disposed in a heating agent or bath 21 which element preferably has a relatively extensive heating surface; a suitable form comprises a plurality of liquid containing tubes, adapted to be immersed in the heating medium of bath 21, that are joined together by lower and upper headers as shown at 22 and 23. Any arrangement by which the lower header communicates with the lower portion of the vessel 14 may be employed; for example, the header 22 may be directly connected with connection 16 in order to provide relatively free communication with the liquid space of vessel 14. The upper header 23 is similarly connected to the upper portion of vessel 14, for example, by means of the conduit 24 which provides substantially unobstructed communication with the upper portion of the vessel 14 although the conduit preferably has a valve 24a disposed therein. The flow of liquid from the vessel 14 to the heat absorbing element is controlled by manipulating valves 16a and 24a. It should be noted that the heat absorbing element 20 is so arranged in relation to

the vessel 14 that flow due to the influence of gravity is assured. Thus the column of cold material in conduit 16 is more dense and heavier than the column of heated material in element 20 and conduit 24, the difference in density being great enough to cause flow to occur at the desired rate.

A gas phase connection is also preferably associated with the gaseous discharge connection 15 that leads to the service connection 19 and is shown at 25. This connection thus has communication at one end with the upper portion of vessel 14 and at the other end with a high pressure source of supply and is controlled by a suitably placed valve 25a. Thus arranged the connection 25 serves the twofold purpose of relieving, when desired, the high pressure in the vessel 14 and of initially priming the vessel 14 to permit flow in receiver 18 when valve 16a is opened. For example, if an excessive pressure be attained in vessel 14 which is above that in service connection 19, valve 25a may be opened to permit the passage of material in the gas phase thereinto. If the pressure in vessel 14 be less than that in conduit 19 and valve 25a be opened, the vessel 14 receives gas material in the gas phase which may be used in priming.

A distributor 26 is preferably placed in the vessel 10 for introducing heated gaseous material from the vessel 14 when desired. This is accomplished through the branch connection 27 here shown as connected to the relief connection 25 in order to be in communication with the upper part of vessel 14. The admission of gas to the distributor is controlled by means of a valve 27a which is disposed adjacent to the valve 15a in the connection 15 that provides for communication between the upper portions of the transfer vessels.

The arrangement shown in Fig. 1 operates as follows:

Gas material in the liquid phase from a low pressure source, for example, from a stand tank or transport container, is introduced in predetermined amounts through the connection 11 into the vessel 10, the connection 12 being open during the filling period. The introduction of only a predetermined amount of liquid is secured by associating a suitable metering device with the vessel 10. As shown, this is provided by extending connection 12 into vessel 10 a distance such that it is sealed by the liquid when the predetermined amount has been introduced.

The transfer of liquid from the vessel 10 to the vessel 14 against whatever pressure there may be in the vessel 14 is effected by first opening the valve 27a to equalize the pressures by condensation of gas into the liquid charge in vessel 10 and then opening the valves 13a and 15a. This permits displacement of liquid from the vessel 10 through the connection 13 and the displacement of gas from the vessel 14 into vessel 10 through the connection 15. When the transfer is complete, the valves 13a, 15a, and 27a are closed.

The operation of valve 27a is practiced in order to accomplish the transfer of liquid material into the vessel 14 with a reduction of the net blow-down loss in accordance with the principle of cascade operation disclosed in copending application of John J. Murphy, above referred to. Condensation of gas material and equalization of pressures in the vessels 10 and 14 is effected prior to the opening of valves 13a and 15a for transferring the material under the force operative in the cascade system, this operative force being

any convenient mechanical force, such as gravity. In the application above referred to, it is shown that it is desirable to have at a substantially low value the internal energy of the gas which is to be brought into heat exchanging relation with fresh charges of liquid in accordance with the cascade principle. The means of discharging the gas material from the final vessel in accordance with the present invention accomplishes this end by heating to a relatively high temperature only the amount of material that is required for displacing the rest at the pressure desired. By heating such amount to high temperature, the total internal energy thereof is at a satisfactory low value.

The transfer of the gas material from the vessel 14 to a receiving device is effected in a manner substantially similar to the transfer from vessel 10 to vessel 14. For example, the transfer to receiver 18 is accomplished by first momentarily opening the valve 25a to provide equalization of pressure between vessel 14 and receiver 18, and then opening valves 24a and 16a and finally opening the valve 17 controlling the discharge to the receiver. If, after valve 25a is initially opened for this purpose, pressure in vessel 14 rises above the critical pressure before valves 16a and 24a are opened, the operation is still the same.

Liquid is discharged past valve 17 into the receiver 18, by reason of the higher pressure in vessel 14 and element 20 than in receiver 18. Vessel 14 and element 20 remain at the same pressure by reason of the connections provided, the discharge continuing as long as the input of thermal energy into element 20 causes material therein to expand and generate pressure sufficient to maintain that in vessel 14 in excess of that in the device 18.

If valve 17' be opened instead of valve 17, the discharge will be into the device 18', which flow is similarly produced by the maintenance of a pressure in vessel 14 in excess of that in receiver 18'. Accordingly, it is seen that pressure is built by means of the element 20 in the vessel 14 above the liquid therein without substantially increasing the sensible heat of the liquid. This input of thermal energy in the element 20 of the thermal leg may continue elevating the pressure in the vessel 14, but it is essential only to elevate the pressure to a point which produces the desired increase in the rate of discharge of liquid from the vessel 14, i. e., to raise the pressure by an amount over the receiver pressure that just effects the discharge at the desired rate. The initial pressure may be below or above the critical pressure depending on the receiver pressure. The pressure rise resulting from the thermal leg action is simply dependent on the resistance to flow in the discharge line from vessel 14 to the receiver. The thermal leg builds up a differential in pressure over that in the receiver and does not necessarily have to produce a wide pressure fluctuation.

If the receiver pressure is well below critical pressure, the thermal leg does not in general create a pressure differential such that the pressure at any point is above the critical pressure. Under these conditions, liquid entering the thermal leg is evaporated and then superheated. If the receiver pressure is above the critical pressure, the gas material entering the thermal leg is rapidly heated and undergoes a rise in temperature simultaneously with a volumetric expansion with the resultant thermosyphonic action. A differential pressure above that in the receiving de-

vice results from this expansion which forces the discharge to occur at a rapid rate.

In the event that the pressure in the vessel 14 should rise to excessive values before valve 17 can be opened fully, the excess of pressure in the vessel 14 above that in the discharge line 19 may be quickly relieved by the opening of valve 25a. The transfer of the liquid from the vessel 14 to the device 18 continues until substantially the whole of the liquid under pressure in the vessel 14 has been discharged. The vessel 14 having discharged its liquid, and all valves being then closed, is ready to receive another charge from the vessel 10 which is effected in the manner above described and the cycle of events repeated.

When discharging liquid to a receiving device of the variety shown at 18', where the material is to be stored in the liquid phase to be later vaporized when desired, it is seen that the present method of effecting the discharge desirably preserves the refrigeration in the liquid discharged by heating substantially only the amount of gas material utilized for building the pressure to a value higher than that of the receiving device which may be located at any elevation relative to the vessel 14.

While the connections, including the heat absorbing element, have been described above as associated with vessels in series cascade relation, whereby there is insured a heat input from an external source to raise the pressure without increasing the sensible heat of the major portion of the liquid, it is contemplated that a single leg may be associated with other arrangements of vessels in cascade relation; for example, a plurality of vessels operating in series-parallel in order to effect a transfer of a large amount of material substantially continuously with a minimum amount of equipment. The series-parallel arrangement admits of this, since one transfer vessel of a parallel pair is adapted to be filled while the other is discharging, and vice versa. An arrangement to this end is shown in Fig. 2.

In Fig. 2, a series parallel arrangement of transfer vessels is shown which employs a thermal leg connected to the final vessels of each series in a manner entirely independent of the liquid discharge connections. In the first series a vessel 40 has an inlet connection 41 for supplying a liquefied gas from a low pressure source, a gas phase outlet 42, and a liquid phase outlet 43 which transfers the liquid to another vessel 44 under the influence of a gravity field, there being also a connection 45 leading from the upper portion of the vessel 44 to the upper portion of vessel 40 to permit gas displacement from the vessel 44 when liquid enters it from the vessel 40. A liquid discharge connection 46 leads from vessel 44 and has union with a connection 47 leading to a receiving and vaporizing device 48 that has a service connection 49 for supplying consuming or storage apparatus.

In another series, which is arranged in parallel with the first, there is a vessel 50 that has a liquid inlet 51, a gas phase outlet 52, and a liquid discharge 53 leading to a vessel 54 that is in parallel with vessel 44. A gas phase displacement connection 55 connects the upper portion of vessel 54 with the upper portion of vessel 50 and a liquid discharge connection 56 leads from the bottom part of vessel 54 to make union with the connection 47 in the same manner as does connection 46.

The series-parallel system of cascaded vessels here shown is preferably provided with a com-

mon thermal leg for accelerating the discharge from the vessels 44 and 54 to the device 48. In this way, the series-parallel arrangement is made relatively economical in construction costs. The thermal leg shown comprises a heat absorbing element 60 disposed in a heating chamber 61 and consists of tubular members disposed between lower and upper headers 62 and 63, the heat bearing medium being admitted to the chamber at any suitable point, for example, through the inlet 58, an exit being provided as shown at 59. The lower header 62 in the element 60 is connected with the lower portion of the vessel 44 by means of a connection 66 that is entirely separate from connection 46, and with the lower portion of vessel 54 by means of a similar connection 66'; this arrangement is facilitated by the provision of a common connection 57 leading to the lower header of the junction of the connections 66 and 66' as shown. A connection 64 leads from the upper header 63 to a junction from which branch connections 65 and 65' lead respectively to the gas phase displacement connections 45 and 55.

The connections 65 and 65' are arranged always to be in relatively free and unobstructed communication with the gas space of the vessels 44 and 54. Accordingly, the valves 45a and 55a which control the connections 45 and 55 are disposed above the junction points where connections 65 and 65' meet the connections 45 and 55 respectively. Valves 43a and 53a are shown respectively in the liquid transfer connections 43 and 53. Similarly, valves are shown at 46a and 56a in the liquid discharge connections 46 and 56. Valves controlling the thermal leg are shown at 66a in the connection 66 and at 66b in the connection 66'. A gas phase connection 68 leading from the junction of conduits 65 and 65' is arranged to communicate with service conduit 49, and may with advantage be provided with a suitable check-valve to permit one-way discharge into the service conduit, for example, with a spring-loaded check valve as shown at 69.

Means for cross-equalization of pressures between vessels in parallel are provided by a connection 70 controlled by valve 70a, which connects discharge conduits 46 and 56 so as to provide communication between the liquid spaces of vessels 44 and 54 and by a connection 71 controlled by valve 71a which connection joins distributors 72 and 72' that are disposed in the lower portions of vessels 40 and 50.

In this arrangement, the operation of the cascaded vessels 40, 44, 50, and 54 which discharge into the receiving device 48 is substantially similar to the series system shown in Fig. 1 except the parallel arrangement provides additional steps of equalization and permits substantially continuous operation, i. e., when the vessel 40 is being filled with liquid, the vessel 44 is transferring its charge to the device at 48 and vessel 50 is being drained into vessel 54. When a charge from vessel 40 is transferred to the vessel 44, the vessel 50 receives a charge through the inlet 51, the vessel at 54, transferring its charge to device 48, is filled with gas at high pressure. Between these filling and discharging events, cross-equalizations are effected by opening the valves 70a and 71a.

If it is desired to discharge liquid into the vaporizer, for example, from vessel 44, when just filled, the connection 70 is opened by opening valve 70a to equalize pressures, gas flowing from vessel 54 through the liquid in vessel 44 after which valve 70a is closed and valve 46a is opened, 75

which brings pressure in vessel 44 up to that in device 48. The thermal leg connection of the element 60 to the vessel 54 having been shut off previous to cross-equalization by closing valves 65b and 66b, the corresponding connections to the vessel 44 are now opened, i. e., valves 66a and 65a are opened. When the liquid in vessel 44 is fully discharged, valves 66a and 65a are closed together with valve 46a and the steps of cross-equalization and discharge by means of the thermal leg are repeated for vessel 54. The heat absorbing element 60 is thus seen to be in substantially continuous operation, building pressure alternately in vessels 44 and 54. In a system of three or more vessels in parallel, the period between successive discharges is still further reduced in duration. In the event that pressure should build to an excessive value in either of the vessels 44 or 54 while connected to thermal leg 60, safe exit is provided through the conduit 68 and the automatic opening of valve 69.

Here it is seen that by properly timing the events of opening and closing the valves of the system as shown, substantially continuous operation may be achieved and the liquefied gas material, such as liquid oxygen, liquid nitrogen, and the like, received from a low pressure source, such as a transport vessel, is passed in predetermined amounts through alternate paths to one or the other of vessels 40 and 50, and from thence alternately to the final vessels 44 and 54 which discharge alternately into the device 48.

An operator, of course, may acquire considerable skill in effecting these events so that this transfer takes place in a minimum of time. It is preferable, however, and in the practice of the invention it is contemplated that the valves shall be automatically operated. It will be understood, therefore, that in the practice of the invention, motor-operated valves of a suitable type will be substituted for the valves shown at 11a, 12a, 13a, 15a, 16a, etc., or those shown at 41a, 42a, 43a, 45a, 46a, etc.; the actuation of the valves being under the control of any suitable master actuator. These features, however, are no part of the present invention and while in practice they may be incorporated in a commercial device and make for the efficiency thereof, the principle by which pressure is built to accelerate discharge by means of a thermal leg is in no wise altered thereby, the acceleration of the discharge contemplated being effected by the rate of energy input into the thermal leg as well as by the rate of flow of fluid into the thermal leg, and not by the periods which elapse between events in the cycle of operations practiced.

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 is new and desire to secure by Letters Patent is:

1. A method of effecting the discharge of liquid oxygen from a final transfer vessel in a cascade system to a receiver at a relatively high pressure, which comprises filling the vessel with a predetermined charge of liquid oxygen, momentarily admitting gaseous oxygen to said vessel, conveying a portion of said charge of liquid oxygen to a heating device while maintaining the same in pressure communication with said charge at points both above and below the liquid level,

supplying thermal energy to said heating device sufficient to cause expansion of said portion and generate pressure in excess of said relatively high pressure whereby the remainder of the body in said vessel is expelled, and maintaining the final temperature of the heated portion remaining in said vessel at a relatively high value while the total internal energy is at a satisfactory low value.

2. A method of effecting the discharge of liquid oxygen from a final transfer vessel in a cascade system to a receiver at a pressure equal to or in excess of the critical pressure, which comprises charging the vessel with a predetermined quantity of liquid oxygen, momentarily admitting gaseous oxygen from a high pressure source, conveying a portion of the charge of liquid oxygen to a heating device, maintaining said portion in pressure communication with the remainder of said charge at points both above and below the liquid level, supplying thermal energy to said heating device to an extent which produces an expansion of said portion and generates a pressure which builds to a value in excess of the critical pressure whereby the remainder of said charge may be expelled from said vessel at a desired rate, and maintaining the final temperature of the heated portion remaining in said vessel at a relatively high value while the total internal energy is at a satisfactory low value.

3. A method of effecting the discharge of a volatile liquid having a boiling point materially below 273° K. from an insulated vessel into a receiver with self-compression of the gas phase evolved, which comprises segregating and controllably heating a portion of each body of liquid being discharged to elevate its pressure while maintaining the temperature of the remainder of said body below that of said heated portion, expelling said remainder to receivers, and subjecting the heated gaseous portion remaining in said vessel to intimate contact with other segregated bodies of liquefied gas whereby a desired portion of the gaseous remainder is condensed.

4. A method of effecting the discharge of a volatile liquid having a boiling point materially below 273° K. from a system to a receiver at a relatively high pressure, which comprises segregating a succession of bodies of said volatile liquid, separating and controllably heating a portion of each of said bodies to an extent sufficient to generate pressures above said bodies to values in excess of that in said receiver, applying said pressures to effect discharge of said bodies into said receiver, and conducting the gaseous remainder of each of said bodies into another body of said volatile liquid whereby a portion of said remainder is condensed and combined with said other body.

5. A method of effecting the discharge of a volatile liquid having a boiling point materially below 273° K. from an insulated vessel in a cascade system and forcing it as gaseous material into a receiver at a pressure and temperature in excess of its critical pressure and temperature solely by the input of thermal energy, which method comprises segregating a succession of bodies of said volatile liquid, subjecting each of said bodies to a plurality of stages of increased pressure, discharging fluid from the final stages of increased pressure into said receiver by controllably introducing thermal energy to isolated portions of each of said bodies whereby said portions are converted to a gas phase, redistributing said portions in the gas phase while bearing the thermal

energy introduced in said final stage among the initial stages in a manner such that said thermal energy is transferred from the gaseous material to the bodies of material in the initial stages, and reconvertng a portion of said gaseous material to the liquid phase for use.

6. A method of transferring a liquefied gas from a supply container at relatively low pressure to a receiver at a relatively high pressure, which comprises withdrawing a succession of metered charges from said container into a transfer vessel, separating and controllably heating a portion of each charge transferred to an extent sufficient to supply energy required to expel the balance of each of said charges into said receiver, and excluding substantially all heat of external origin from the balance of each of said charges so transferred.

7. A method of transferring liquefied gas from a supply container at a relatively low pressure to a receiver at a relatively high pressure, which comprises segregating a succession of metered charges of liquefied gas in a transfer vessel, withdrawing and controllably heating a portion of each of said charges while in pressure communication with the remainder to an extent sufficient to elevate the pressure on each of said charges to a value exceeding that in said receiver, discharging the remainder of each of said charges into said receiver under the influence of said generated pressure, and excluding substantially all heat of external origin from the remainders of said charges.

8. In a cascade system of the character described, the combination with a plurality of associated vessels arranged to transfer a volatile liquid material, at least one of which is arranged to discharge said material against a relatively high pressure, of a receiver adapted to receive said discharge, means for withdrawing liquid from said high pressure vessel and conveying the same to said receiver, and controllable heating means for withdrawing a portion of liquid connected to communicate with said vessel discharging against high pressure at points both above and below the normal liquid level of said vessel, said last named means including a heat absorbing element having a relatively extended heating surface.

9. In a cascade system of the character described, the combination with a plurality of associated vessels arranged to transfer a volatile liquid material, one of said vessels being arranged finally to hold and discharge said material, of a receiver at a relatively high pressure for receiving said discharge, means for withdrawing liquid from said vessel and conveying the same to said receiver, a connection communicating with said vessel at points both above and below the normal liquid level and including a controllable heat absorbing element having a relatively extended heating surface, and means associated with said element for supplying a heating agent in contact with said heating surface.

10. In a cascade system of the character described, the combination with a plurality of vessels connected in series and arranged to transfer a volatile liquid material, the final vessel of a series being arranged to hold and discharge said material, of a receiver at a relatively high pressure for receiving said discharge, means for withdrawing liquid from said vessel and conveying the same to said receiver, a relatively unobstructed connection leading from a point below the normal liquid level in said final vessel and includ-

ing a heat absorbing element having a relatively extended heating surface and positioned below the normal liquid level, a relatively unobstructed connection leading from said element from a point in the vessel above the normal liquid level therein, means for supplying a heating agent in thermal contact with said surface whereby pressure may be built in the gas space of said vessel in excess of the pressure of said receiver, and means for equalizing gas pressures in the series connected vessels arranged to effect heat exchange between gas and liquid when equalization takes place.

11. In apparatus for transferring a volatile liquid material, the combination with a supply container at a relatively low pressure, of a receiver at a relatively high pressure, an intermediate transfer vessel arranged to receive and hold a metered charge of liquid from said supply container, a thermal leg in fluid communication with said transfer vessel arranged to receive a portion of the charge from said vessel, means for conveying the balance of said charge to said receiver, means associated with said thermal leg for controllably heating the withdrawn portion whereby pressures in excess of that in said receiver may be generated in said vessel, and means associated with said vessel for excluding heat other than that controllably introduced.

12. In apparatus for transferring a volatile liquid material, the combination with a supply container at a relatively low pressure, of a receiver at a relatively high pressure, an intermediate transfer vessel arranged to receive and hold a metered charge of liquid from said supply container, a thermal leg in communication with said vessel at points above and below the normal liquid level therein, a priming connection adapted to admit gas at high pressure from said receiver to said vessel, means for conveying the balance of said charge to said receiver, means associated with said thermal leg for controllably heating the withdrawn portion whereby pressures in excess of that in said receiver may be generated in said vessel, and means associated with said vessel for excluding heat other than that controllably introduced.

13. In apparatus for transferring a volatile liquid material, the combination with a supply container at relatively low pressure, of a receiver at a relatively high pressure, a transfer vessel interposed between said container and receiver and arranged to receive and hold a succession of metered charges of the liquid supplied from said container, a thermal leg in fluid communication with said transfer vessel at points above and below the normal liquid level therein whereby a portion of a charge in said vessel may be withdrawn, means for conveying the balance of a charge in said vessel to said receiver, means associated with said thermal leg for controllably heating said withdrawn portion, said thermal leg and heating means being proportioned to supply the energy required to force said remainder into said receiver in a desired period of time, and means for excluding heat from the portion transferred other than that controllably introduced in said thermal leg.

14. A method of effecting discharge of a volatile liquid having a boiling point materially below 273° K. from a selected vessel in a cascade system discharging to a receiver at a relatively high pressure, which comprises, filling said vessel successively with bodies of predetermined vol-

ume of the liquid to be transferred, withdrawing and controllably heating a portion of each of said bodies to an extent which causes expansion and produces a pressure for expelling the remainder of the body in a desired period of time, and causing the gaseous remainder to pass in thermal contact with another body of the liquid being transferred.

15. A method of effecting the discharge of liquid oxygen from a selected vessel in a cascade system discharging to a vaporizer, which comprises filling said vessel successively with bodies

of liquid oxygen intended to be transferred, withdrawing and controllably heating a portion of each of said bodies to an extent such that pressure is generated in excess of that in the vaporizer to which the remainder of said body is supplied, the gaseous remainder being heated to a relatively high value while the total internal energy associated with said charge is at a satisfactory low value, and subjecting the gaseous remainder to heat exchange treatment with an incoming body of liquid oxygen.

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