May 9, 1939. G. H. ZENNER 2,157,103

APPARATUS FOR AND METHOD OF OPERATING CASCADE SYSTEMS

Filed June 24, 1936 3 Sheets-Sheet 1

Fig. 1.

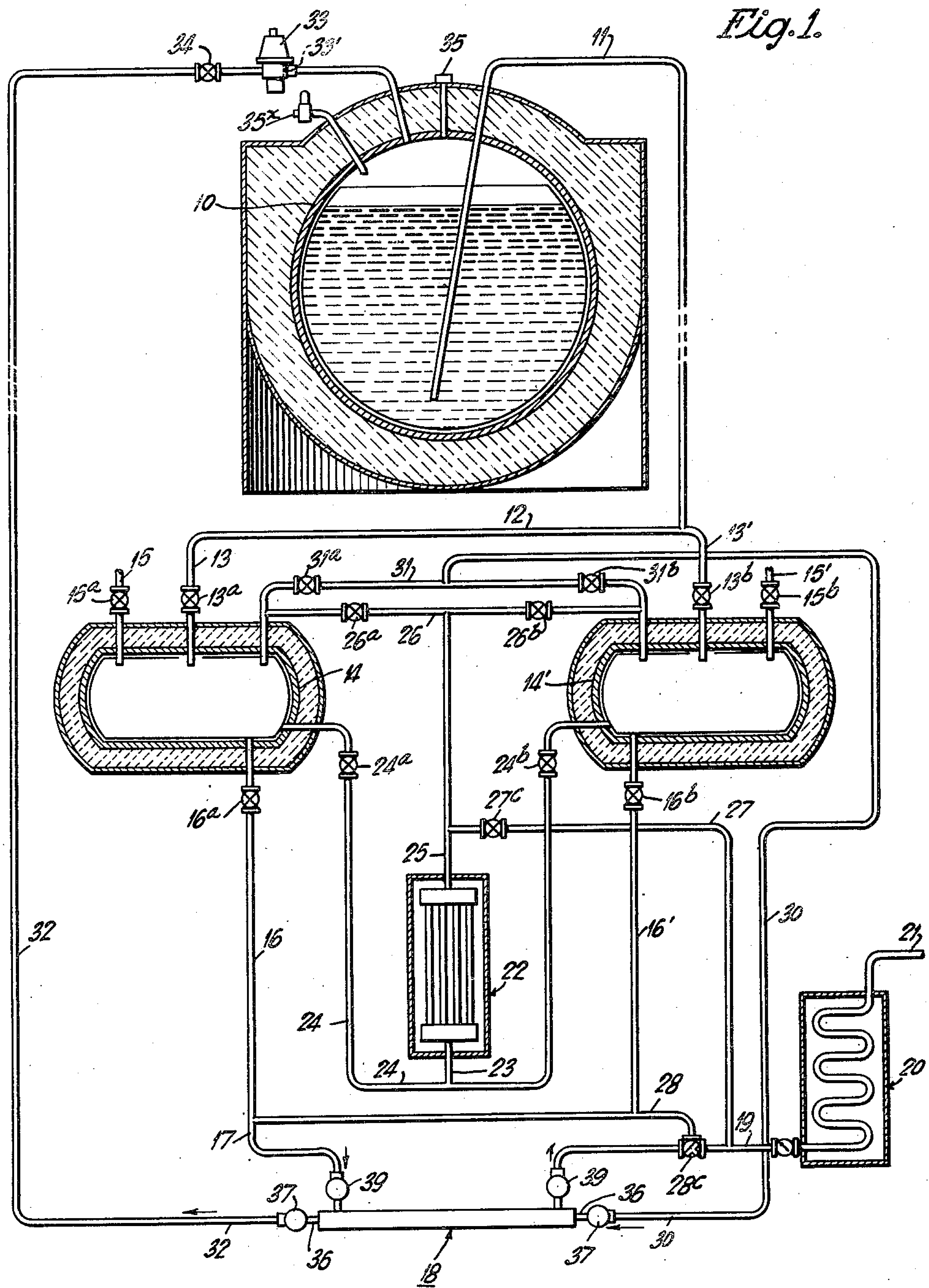

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Fig. 2.

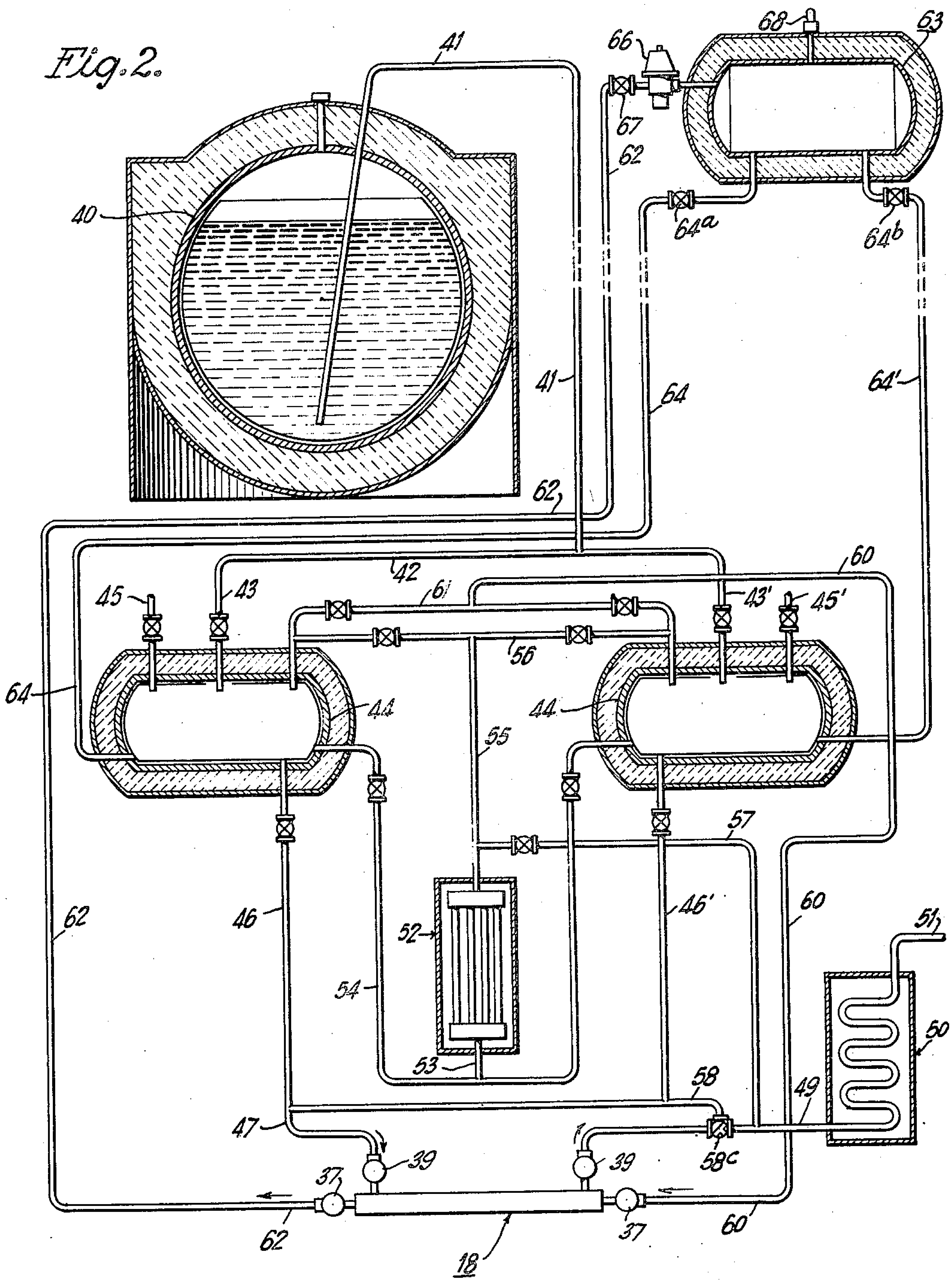

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Fig. 3.

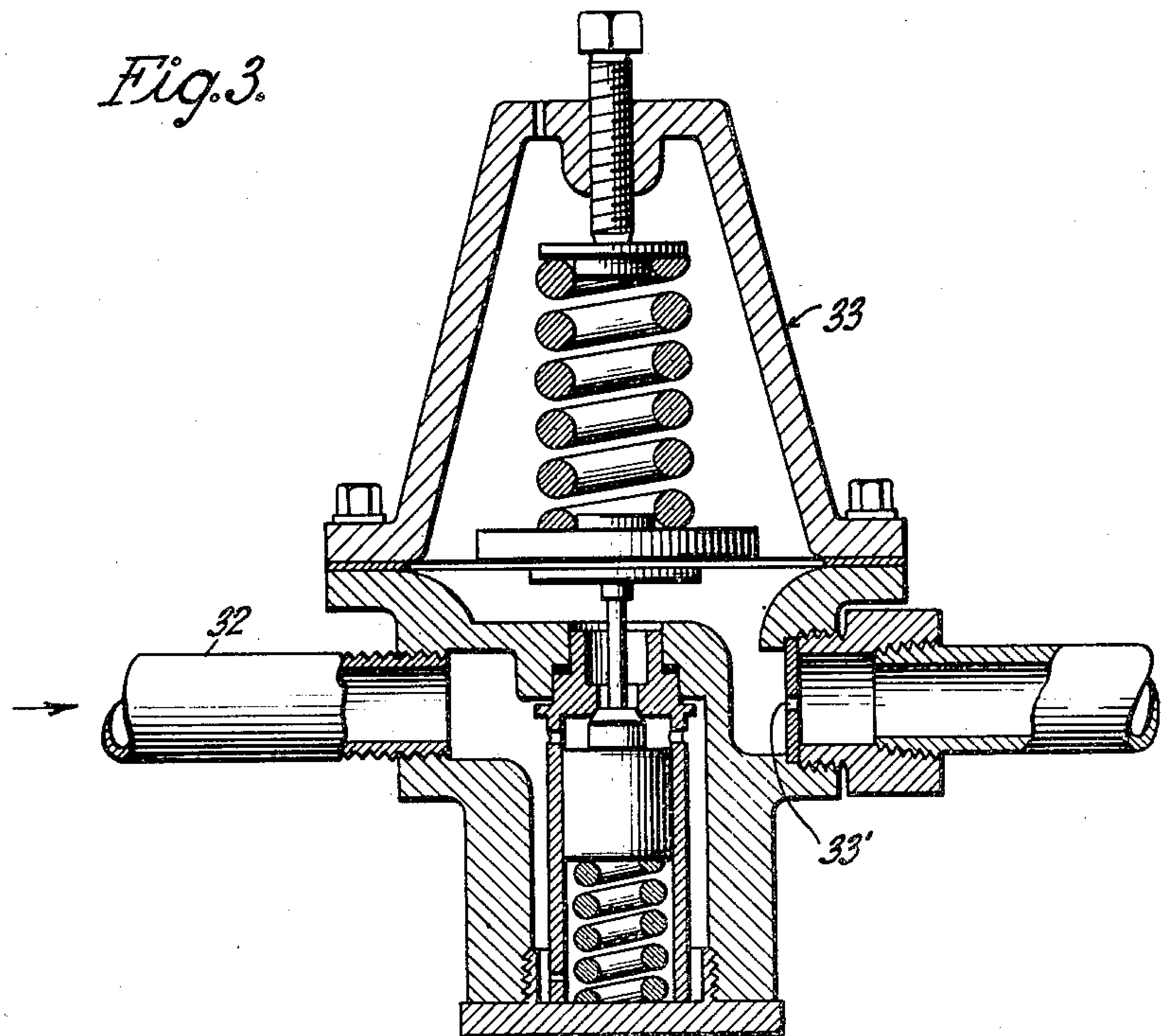


Fig. 4.

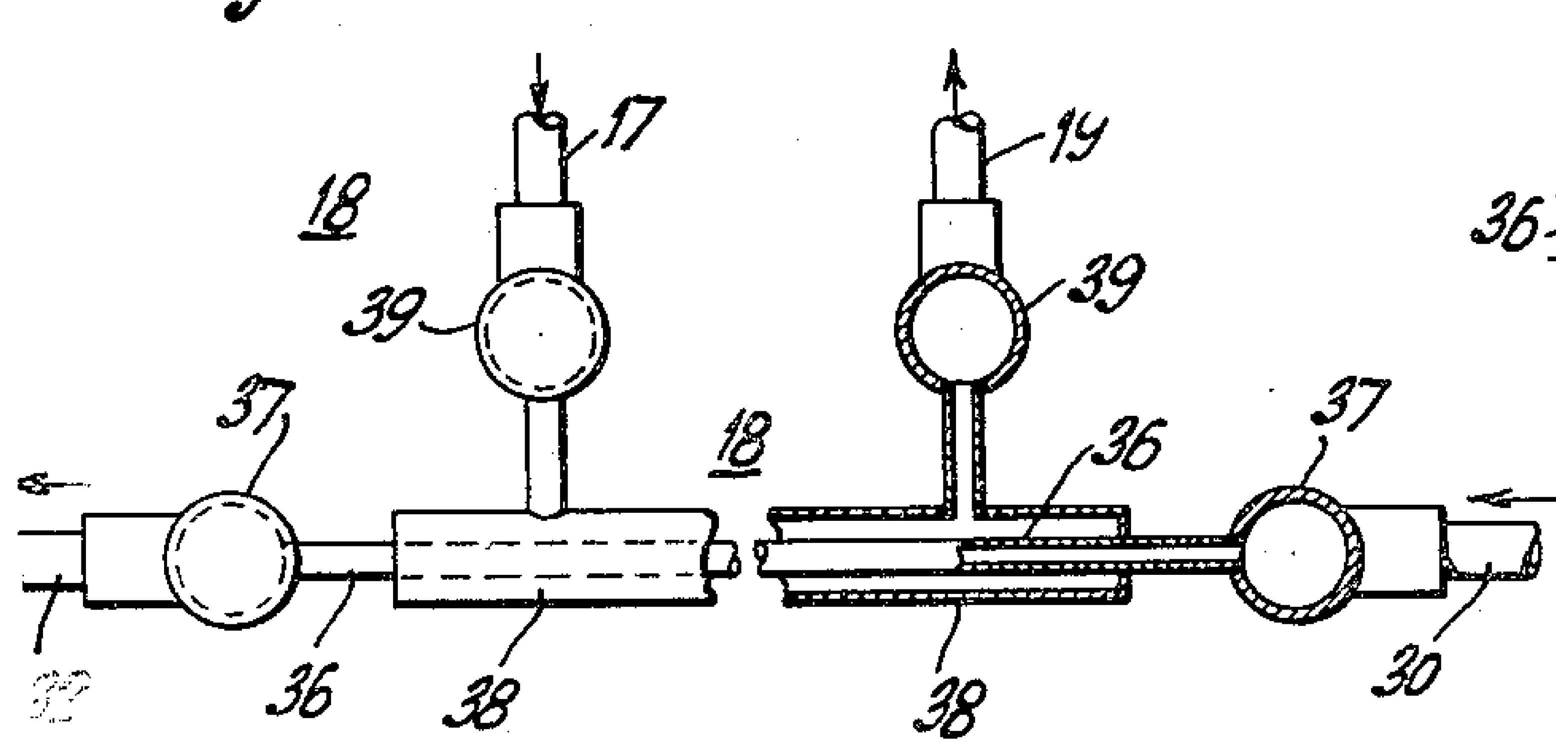


Fig. 5.

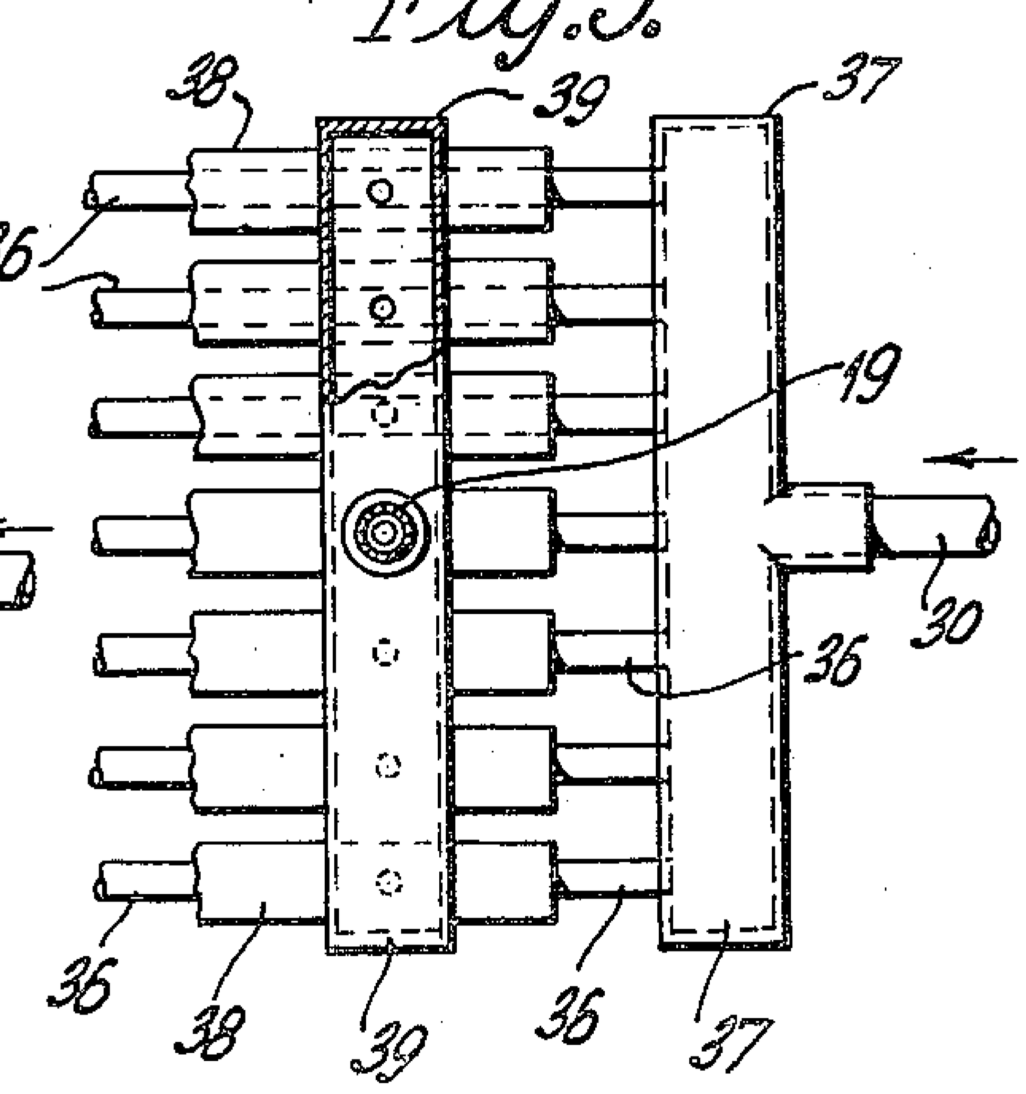
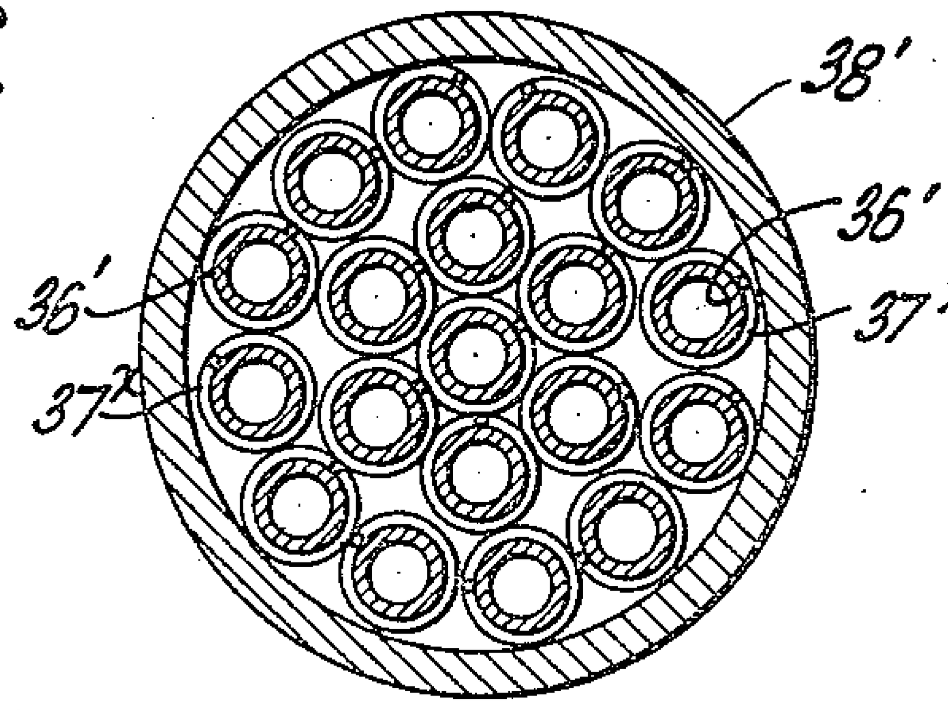


Fig. 6.



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Patented May 9, 1939

2,157,103

UNITED STATES PATENT OFFICE

2,157,103

APPARATUS FOR AND METHOD OF OPERATING CASCADE SYSTEMS

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Application June 24, 1936, Serial No. 86,954

15 Claims. (Cl. 62—1)

This invention relates to apparatus for and method of operating a cascade system having but one set of transfer vessels arranged in parallel for transferring material, volatile at normal atmospheric pressure, from a region of relatively low pressure to a region of relatively high pressure, and more particularly to an arrangement and method of operation using a single pair of transfer vessels for transferring a precious volatile liquid, such as liquid oxygen, liquid nitrogen, certain liquefied hydrocarbons, and the like, from a storage vessel to a receiving device at a desired high pressure.

The invention has for its object generally an improved construction of and mode of operation for cascade systems of the character indicated, whereby a simplification of necessary parts is effected and the number of operating steps reduced, in order to obtain lightness in weight and celerity of operation.

More specifically, it is an object of the invention to provide a cascade system with duplicate transfer vessels operating in parallel but simplified to avoid series and cross-equalization connections between transfer vessels and the steps incident to the effecting of condensations of material from the gas phase into the liquid phase through such connections.

Another object is to provide a cascade system of the character indicated with an improved cycle of operating events whereby a relatively large volume of a volatile liquid may be passed from a supply vessel to a receiver or vaporizer in a relatively short period of time with desired correlation of the flow of material in the gas and liquid phases without the provision of elaborate control apparatus.

Still another object is to provide an improved arrangement for systems of the character indicated whereby the blowdowns incident to the beginning of any cycle of charging and discharging a selected transfer vessel may be completed before final discharge of liquid from another such vessel when discharging liquid, thereby reducing the time required for operation of the system and increasing the capacity thereof.

Still another object is to provide a system of the character described with an improved heat exchanging device disposed in the liquid phase withdrawal connection and constructed to have a gas pass and heat storage arrangement whereby the refrigeration of the liquid may be more efficiently utilized and retained in the system in order to reduce the amount of losses incident to the blowdown.

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 cascade system having duplicate transfer vessels adapted for the transfer of liquid oxygen provided in accordance with the invention.

Fig. 2 is a view similar to Fig. 1, but showing a modified arrangement of apparatus;

Fig. 3 is a view, mainly in vertical section, showing a regulator for accomplishing throttling in accordance with the invention;

Fig. 4 is a view partly in section and partly in elevation showing details of a heat exchanging or regenerative device of the character shown in Figs. 1 and 2;

Fig. 5 is a fragmentary view showing as a top plan the features of an end of the device shown in Fig. 4; and

Fig. 6 is a vertical cross section through a modified form of heat exchanging device adapted for use in accordance with the invention.

A cascade system which is adapted to transfer a precious volatile liquid, such as certain liquefied hydrocarbons, liquid oxygen, liquid nitrogen, and the like, is described generically in United States Patent No. 2,035,399, issued March 24, 1936 in the name of J. J. Murphy, as a system of communicable vessels which receive and effect the countercurrent passage of such material in the gas and liquid phases by stages in such a manner that the liquid phase is advanced from a region of low pressure to a region of high pressure. Advantage of the countercurrent passage of material in the gas and liquid phases is taken to effect condensations of the material from the gas phase into the liquid phase so that losses incident to blowdown at the inception of a cycle of operation may be reduced to substantially any desired extent. Time is, of course, required for the gaseous material to be passed in heat exchanging relation with the liquid, the liquid being retained at some stage in a relatively stationary position while the condensation takes place, connections for the vessels being provided to accommodate the liquid and the gas passage in such stage.

In the practice of the present invention, the apparatus is simplified by avoiding the use of a series of transfer vessels with the incident equalizing connections whereby a relatively light and inexpensive device is provided capable of operation at relatively high rates of speed.

The operation cycle of a transfer vessel as herein provided comprises two main steps or events, namely, filling with a desired charge and then discharging. During the discharge the gas material, which is at a relatively high pressure in the parallel vessel, is passed in heat exchanging relation with the discharged liquid and conveyed to a storage space associated with the supply, this passage being made to take place with appropriate throttling, whereby a portion of the gas phase may be conserved and returned in the liquid phase to augment the material being transferred. When a transfer vessel filled with gas at high pressure is thus blown down, it is ready again for the inception of a cycle of operation.

Simple apparatus for carrying out the present invention comprises duplicate transfer vessels arranged to be operated in parallel to receive charges alternately from a common supply of liquefied gas, such as an insulated storage container. The duplicate transfer vessels are arranged to discharge alternately into a common receiving device such as a vaporizer where the material is converted into gas at a desired high pressure. For example, liquid oxygen may be vaporized in such a device and converted into gas supplied at 2000 psi gauge.

Transfer vessels employed in cascade systems in accordance with the principles set forth in the above referred to patent to Murphy provide for the exclusion of heat of external origin from the material being transferred prior to a predetermined point, such as the vaporizer, in order to reduce the amount of material in the gas phase that must be blown down at the inception of a cycle. Heat exclusion is practiced in conjunction with the transfer vessels provided in accordance with the present invention, such vessels being provided either with interior baskets or with exterior insulating jackets or with both. It is desirable, however, to practice the heating of isolated portions of the liquid taken from a transfer vessel while being transferred in order to build pressure to accelerate the discharge. Convenient means for effecting this heating step in conjunction with a cascade system is disclosed in United States Letters Patent to Zenner, No. 2,037,673, dated April 14, 1936, such means being briefly described as a "thermal leg".

The conservation in the system of the refrigeration of the liquid being discharged from a transfer vessel is conveniently effected by means of a heat exchanging or regenerative device, such as shown in United States Letters Patent to Dana, No. 2,037,679, dated April 14, 1936. Such device in general comprises countercurrent passes provided with intervening heat storage elements, the passages being associated with the gas and liquid withdrawal means of the transfer vessels, i. e., one pass is arranged to convey the gas phase supplied from a transfer vessel which has discharged its liquid and is filled with gas at relatively high pressure, the heat of this gas being abstracted and transferred to the liquid passing in the other pass. In consequence, the input of heat incident to the ultimate conversion of the material into the gas phase is reduced. Here, the use of a regenerator with a relatively large storage effect is desirable because it avoids the necessity for relatively close control of the gas and liquid discharge rates from the respective transfer vessels.

In order to conserve the material in the gas phase thus being withdrawn, without the practice of equalizations, the gaseous material is led through the regenerator into a storage space associated with the supply, the material being deprived of heat so as to effect substantially complete condensation of the gas phase into the liquid. This last step of heat removal is effected by heat exchange with liquid being discharged and the pressure reduced to that of the storage space. The pressure reduction may be accomplished in any convenient manner, for example, by throttling. A convenient device for accomplishing this comprises a pressure reducing valve so placed as to discharge the cooled gas material that has passed through the regenerator, into the storage space of the storage vessel. The vessel in such case is formed to have dimensions adapted to this purpose. Any pressure added in consequence of such introduction into the storage vessel is seen to assist in building a pressure for expelling the liquid; excess pressure, of course, being blown down to the atmosphere. A suitable chamber, however, may be provided instead, to receive the cooled gas material, and when so provided takes the place of the space in the storage vessel.

Referring now to the drawings, and particularly to Fig. 1, **10** denotes an insulated storage container for the volatile material which, in the case of liquid oxygen and the like, is relatively highly insulated. A withdrawal connection **11** leads to a manifold **12** which has inlet connections **13** and **13'** leading respectively to transfer vessels **14** and **14'**, the inlets being controlled by suitable valves as indicated at **13***a* and **13***b*, respectively. The transfer vessels are also provided with blowdown connections **15** and **15'** that are controlled respectively by valves **15***a* and **15***b*.

The transfer vessels here provided are constructed to withstand considerable pressure, and, consequently, have relatively heavy outer walls. In order to exclude heat to the desired extent, these vessels, when oxygen is being transferred, have both inner baskets and exterior insulating jackets. Liquid withdrawal connections for the vessels are shown at **16** and **16'** which are controlled respectively by valves shown at **16***a* and **16***b*. These connections have a common outlet **17** which communicates with the inlet end of the liquid pass of the regenerative device shown generally at **18**. From the outlet of the liquid pass a connection **19** leads to the heating coil of a receiving or vaporizing device shown generally at **20**; the vaporizing device having a service connection or pipe line **21** which leads the vaporized material away to a suitable storage receiver or to a place of consumption at high pressure.

In order to practice the heating of isolated portions of material withdrawn from the transfer vessels, a common thermal leg is provided comprising a heating element shown generally at **22**, which has an inlet **23** at its lower end that communicates with an auxiliary withdrawal connection **24** that communicates with both transfer vessels, the communication being controlled respectively by valves as shown at 24a and 24b. At the upper end of the heating element, a connection 25 communicates with the gas space of the transfer vessels through a common connection 26, the communication with the two vessels being controlled respectively by valves 26a and 26b. To afford relief in the event undesirable high pressures obtain in the thermal leg a by-pass 27 is provided leading from the upper end of the thermal leg directly to the connection 19, such by-pass being normally closed by a valve 27c. Another by-pass 28 is provided leading from the withdrawal connections 16 and 16' which also communicates with the connection 19, this second by-pass being normally closed by a three-way valve 28c located at the junction and arranged to shut off the branch of conduit 19 leading to the regenerator 18 when opening communication between conduits 28 and 19.

In order to provide for the blowdown of gas from a transfer vessel through a regenerator to the storage space, as proposed herein, a connection 30 is provided leading to the inlet of the gas pass of the regenerator 18, this inlet being adjacent the liquid outlet. The connection 30 is made to have selective communication with the transfer vessels through a manifold 31 whose communication is controlled respectively by valves 31a and 31b. From the outlet of the gas pass of the regenerator 18 a connection 32 is arranged to discharge into the space above the liquid level in the storage container 10, the discharge into this space being at a temperature and pressure materially below that of the transfer vessel supplying the gaseous material, the pressure reduction being effected by throttling produced by a suitable means, such as the pressure regulator shown at 33 having an orifice 33' (Fig. 3) introduced at a point just beyond the point where regulation is accomplished. A suitable auxiliary control valve may be introduced in connection 32 as shown at 34, the container being also shown as provided with a filling connection 35 and a relief discharge device 35x.

The mode of operation to be here practiced with the arrangement above described is as follows: A charge of predetermined volume of the material in the liquid phase is drawn from the container 10 and run into a vented transfer vessel, say vessel 14, by the opening of valve 13a; the venting having been effected by the opening of valve 15a just prior to the filling event. Vessel 14' is, of course, filled with material in gas phase remaining from a previous operation. Valve 15a and valve 13a are closed at the conclusion of filling, after which discharging to the vaporizer 20 may be begun. This is effected by opening valve 16a. This discharge is accelerated, of course, by putting the thermal leg into operation, which is effected by opening valves 24a and 26a, the corresponding valves leading to vessel 14' being maintained closed.

As soon as the discharge is commenced, material in the gas phase at high pressure is led from vessel 14' through the gas pass of regenerator 18. This is effected by opening valve 31b. The gas thus released passes into the gas space of container 10 through reducing valve 33, the valve shown at 34 being normally open. This passage is continued until pressures in vessel 14' and 10 are equalized, or until it is necessary to begin filling vessel 14', when it is vented by opening valve 15b, valve 31b having been closed. With vessel 14' vented, the operating cycle is repeated by filling and discharging this vessel; relatively continuous operation of the system being thus possible.

In the arrangement here shown, no special means for determining the charge admitted to a transfer vessel is shown since any convenient means may be employed; many suitable metering means being known in the prior art, for example, a venting connection may be used which depends into the transfer vessel a predetermined distance and seals off the escape of gas through the vent upon the attainment of a predetermined liquid level. Such means is shown in the patent to Murphy above referred to.

The metering means, whether it comprises the depth tube arrangement or an independent metering device, is adjusted differently for the present system from that in the system of the aforesaid patent to Murphy since here it is not necessary to provide as much space for expansion of liquid caused by heating and for additions of liquid added during condensations prior to final discharge. The duplicate vessels, in consequence, may be more fully filled than heretofore, that is, the charge of liquid material introduced may be made to occupy substantially the full liquid holding space. In this way, the filling efficiencies for cascade systems are increased by the present invention.

While substantially any countercurrent regenerator having separate passes and the requisite heat capacity may be employed, it is found that regenerators which divide the passing gas stream into a plurality of little streams surrounded by the body of liquid passing in the other direction accelerate the heat transfer and are highly desirable. A convenient arrangement of this character is illustrated in Figs. 4 and 5 and symbolically indicated as embodied in the systems of Figs. 1 and 2. Here a plurality of small tubes 36 are disposed between headers 37 and arranged to pass gas. About each tube 36 is a tube 38, the group of the latter being connected between headers 39 that are arranged parallel to headers 37 and pass liquid.

Another form of regenerator which may be employed is shown in Fig. 6 and comprises an outer shell of metal 38' for the liquid pass which encloses a plurality of small tubes 36' beginning and ending in headers disposed respectively at the ends of the shell, the tubes being preferably maintained in a desired spaced relation by wrappings of wire as indicated at 37x. The greater the number of tubes of this character which are used the greater will be the amount of heat transferred since it multiplies the heat conducting surface which intervenes between the gas and liquid phases.

The regenerator of the present invention is designed to exchange a relatively large part of the heat in the gas at high pressure remaining in a transfer vessel at the conclusion of a liquid discharge period with the refrigeration in the liquid discharged from the other vessel, regardless of whether the temperature and pressure conditions for heat exchange remain an optimum in the gas and liquid passed in the exchanger throughout the period and regardless of whether the two are always in simultaneous passage. Accordingly, the mass of metal that comprises the tubing of the gas pass is an important factor since it is desired to have enough metal in the tubing to store the heat absorbed from the gas from the instant liquid ceases to flow from one vessel until resumed from another, or to store refrigeration of the liquid from the instant gas ceases to flow from one vessel until resumed from the other. While enough metal to provide the regenerator with the desired storage capacity to take care of these overlapping periods is desirable, it is also important that an excess of metal be avoided in order to preserve a desired degree of lightness.

Among the factors which determine the amount of material required in the regenerator are the magnitude of the blowdown loss permissible, the heat unbalance in the masses of the liquid and gas which are passed, and the magnitude in the temperature fluctuation from initial to final conditions. While it is desirable to achieve lightness and reduce the mass of the regenerator to a relatively low value, each reduction in the amount of metal employed results in an increase in the losses resulting from uncondensed gas material. It is seen, in consequence, that economical operation determines a lower limit in the amount of metal employed in connection with the regenerator. In connection with the heat unbalance between the mass of the gas and liquid passed, no adjustment is readily available for maintaining optimum heat transfer conditions. The excess of heat to be supplied by the blowdown gas or the excess refrigeration to be taken out from the liquid passed must be compensated for under these conditions. The metal in the regenerator consequently should have sufficient heat capacity to take up this excess and act like a thermal flywheel taking over excess heat during one portion of the cycle and delivering it at another time. The amount of unbalance in the heat transfer therefore largely determines the upper limit of the mass required for the regenerator.

With reference to the magnitude of the temperature fluctuation it is seen that under the best countercurrent conditions the discharged fluid should issue from the regenerator at successively lower temperatures, the discharge at the end of the cycle being substantially as cold as the liquid which enters. When the mass of the regenerator is sufficient, the outlet temperature of the discharged fluid will remain nearly constant. This in short makes greater use of the lower temperatures available for refrigeration.

The diameter of the tubing while preferably small is not so small that the resulting frictional resistance offsets the effect of rapid heat transfer or the advantage had by the increased coefficient of heat exchange resulting from the arrangement of the tubing here employed. Since length is the factor which determines the pressure drop, it substantially determines the limit of the smallness of the tubing that can be utilized. A balance of these factors within the range of reasonable economy is a matter that may be attained by skill in design.

The regulator provided between the regenerator and the gas receiving space is shown in detail in Fig. 3 and is of a character adapted to keep a constant pressure on the material passed to the blowdown orifice. The pressure drop through the regenerator is preferably as small as can be feasibly employed while that through the orifice and regulator is substantially the whole drop so that only liquid reaches the orifice, substantially all gas having been condensed. The constant head of pressure maintained by the regulator should cause a constant amount by weight of material to pass the orifice. Such an arrangement is found to facilitate the transfer of heat in the regenerator. The actual pressure drop thus produced varies from time to time in the operation of the system. For example, at the beginning of a blowdown period when the pressure is high, there is a relatively small pressure drop through the regenerator. Later during the period of this blowdown, as the velocity of the gas in the regenerator increases, the pressure drop in the regenerator increases, and that due to throttling decreases since only a small drop is now required of the regulator. There comes a time, however, when the regulator is wide open and ceases to maintain the passage of a constant amount of gas material by weight. After this, the rate of flow and pressure drop in the regenerator decrease. The maximum pressure drop occurs when the regulator has just reached the wide open position and before the weight-rate of flow has begun to drop off.

While the supply vessel or container shown in Fig. 1 is indicated as constructed to provide not only the space desired to hold the quantity of material in the liquid phase but also to receive the condensed material blown down from a transfer vessel whereby there is provided a single source to supply the transfer vessels, it is contemplated employing containers adapted to accommodate only the liquid supply material, the storage space being externally provided in the form of a separate chamber and associated to receive the condensate resulting in a manner such that it may be supplied to the transfer vessels in parallel with the liquid from the supply vessel the same as if it had been delivered originally from the supply vessel. Such separately provided chamber may be any suitable vessel that is insulated and connected to the transfer vessels to receive blowdown gas material and supply condensate through connections arranged in parallel with the supply vessel. An arrangement of this character is shown in Fig. 2.

In Fig. 2, a supply vessel for liquid material is shown at **40** which has a liquid withdrawal connection **41** leading to a manifold **42** having inlet connections **43** and **43'** for introducing liquid to the transfer vessels **44** and **44'** selectively. Venting connections for the vessels **44** and **44'** are shown at **45** and **45'** respectively. Likewise, these vessels have liquid withdrawal connections **46** and **46'** leading to the common connection **47** that communicates with the inlet end of the liquid pass of a heat exchanger **18**, a connection **49** leading from the other end of the liquid pass to any suitable receiving means such as a vaporizer **50** that has a connection **51** leading to gas storage or consuming devices.

This modified form is also shown as provided with a thermal leg comprising a heating element **52** connected with the liquid space of the vessels **44** and **44'** through connections **53** and **54** and with the gas space through connections **55** and **56**. A by-pass **57** leads from the thermal leg directly to the connection **49**. A second by-pass **58** is also shown leading from the liquid withdrawal connections **46** and **46'** directly to the connection **49**. By means of this second by-pass and three-way valve **58c** the heat exchanger is cut out when desired. All of these connections are provided with control valves, the same as in Fig. 1.

In the arrangement shown in Fig. 2, a connection **60** is provided, which has selective communication through the manifold **61** with the gas space of the transfer vessels **44** and **44'**, to withdraw gaseous material at high pressure from the transfer vessels to blow down the same. The connection **60** leads to the inlet end of the gas pass of the exchanger 18. From the outlet end of the gas pass a connection 62 leads to an insulated vessel 63 which receives the gas at a point external to the supply vessel 40. The vessel 63 has connections 64 and 64′ adapted to lead condensate from the lower portion of the vessel 63 and introduce the same in the liquid space of the transfer vessels, these connections being individually controlled by valves shown at 64a and 64b respectively, whereby the condensate from the vessel 63 may be introduced into a selected transfer vessel. The vessel 63 is here arranged to receive the condensate resulting from the temperature and pressure drop produced by a reducing valve 66 in the connection 62 similar in character and position to that shown in Fig. 3. A normally open auxiliary valve 67 is also preferably inserted in the connection adjacent valve 66; the insulated vessel being also provided with a suitable pressure relief device 68.

The mode of operation of the modification shown in Fig. 2 is similar to that described in connection with Fig. 1, since the parts described are similarly shown and situated with the exception of the arrangement of the means for receiving and storing condensate. A detailed description of the steps of filling and discharging the vessels 44 and 44′ is therefore omitted. In this connection, it will be observed, however, that during the filling step when liquid is introduced in a transfer vessel from the supply vessel 40 and preferably after the step is completed, the liquid connection leading from the liquid space of the storage chamber to the transfer vessel is opened in order that liquid condensate from the vessel 63 may supplement that from the vessel 40.

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. The method of operating a cascade system having but one set of transfer vessels that are in parallel, which comprises charging said vessels in turn with desired charges of liquid from a common source of supply, discharging the liquid from said charged vessel to a receiver through a heat exchanging device, and reliquefying gas from another of said vessels by passage in heat exchanging relation through said device to a storage space associated with said supply, which supply is at a pressure materially below the operating pressure of the discharging vessel.

2. The method of operating a cascade system having but one pair of transfer vessels that are duplicates and arranged in parallel, which method comprises charging said vessels alternately with desired charges of liquid from a common source of supply when vented to a pressure below the supply pressure, discharging the liquid from said charged vessel when filled to a receiving device through a heat exchanging device, discharging the gas from the other vessel which is at high pressure during said liquid discharge, passing said discharged gas in heat exchanging relation through said heat exchanging device, and reliquefying at least a portion of said gas while passing it from said heat exchanger into a storage space associated with said supply.

3. The method of operating a cascade system having but one set of transfer vessels that are in parallel, which comprises charging said vessels in turn with predetermined charges of liquid from a common source of supply when vented below the supply pressure, discharging the liquid from said charged vessel to a receiver through a heat exchanging device, passing gas from another of said vessels through said device in heat exchanging relation into a storage space associated with said supply, causing a sufficient drop in the temperature of the gas material traversing said device to liquefy at least a portion of the gas, and thereafter delivering said reliquefied gas material to said storage space in throttled condition.

4. The method of operating a cascade system having but one pair of transfer vessels that are duplicates and arranged in parallel, which method comprises charging said vessels alternately with metered charges of liquid from a common source of supply when vented to a pressure below the supply pressure, discharging the liquid from said charged vessel when filled to a receiving device through a heat exchanging device, discharging the gas from the other vessel which is at high pressure during said liquid discharge, passing said discharged gas in heat exchanging relation with a cooled element of said device, causing a drop in the temperature of the gas discharged from said other vessel while passing through said heat exchanging device, and delivering said gas from said heat exchanger to a storage space associated with said supply sufficiently throttled to reduce at least a portion of the same to liquid.

5. The method of operating a cascade system having but one set of transfer vessels that are in parallel, which comprises charging said vessels in turn with metered charges of liquid from a common source of supply when vented below the supply pressure, discharging the liquid from said charged vessel to a receiver through a heat exchanging device, accelerating the liquid discharge by withdrawing and heating a portion of the charge from said charged vessel, passing gas from another of said vessels through said device in heat exchanging relation with a cooled element of said device into a storage space associated with said supply, causing a drop in the temperature of the gas material traversing said device, and further reducing the pressure and temperature of the gas by throttling when entering said storage space.

6. The method of operating a cascade system having but one pair of transfer vessels that are duplicates and arranged in parallel, which method comprises charging said vessels alternately with metered charges of liquid from a common source of supply when vented to a pressure below the supply pressure, discharging the liquid from said charged vessel when filled to a receiving device through a heat exchanging device, discharging the gas from the other vessel which is at high pressure during said liquid discharge, passing said discharged gas in heat exchanging relation with the refrigeration of the liquid passed through said heat device, accelerating the liquid discharge by withdrawing and heating a portion of the charge from said charged vessel, causing a drop in both the temperature and pressure of the gas discharged from said other vessel while passing through said heat exchanging device, and delivering said gas from said heat exchanger to a storage space associated with said supply throttled to reduce its pressure to that of the storage space.

7. The method of operating a cascade system having but one pair of transfer vessels that are

duplicates and arranged in parallel, which method comprises charging said vessels alternately with metered charges of liquid from a common source of supply when vented to the atmosphere, discharging the liquid from said charged vessel when filled to a receiving device through a heat exchanging device, discharging the gas from the other vessel which is at high pressure during said liquid discharge, passing said discharged gas in heat exchanging relation with the refrigeration of the liquid passed through said device, causing a drop in both the temperature and pressure of the gas passing through said heat exchanging device, delivering said gas from said heat exchanger to a storage space above the liquid in said supply, and throttling the gas delivered to said storage space sufficiently to reduce at least a portion of the same to liquid.

8. The method of operating a cascade system having but one pair of transfer vessels that are duplicates and arranged in parallel, which method comprises charging said vessels alternately with metered charges of liquid from a common source of supply when vented to the atmosphere, discharging the liquid from said charged vessel when filled to a receiving device through a heat exchanging device, discharging the gas from the other vessel which is at high pressure during said liquid discharge, passing said discharged gas in heat exchanging relation with the refrigeration of the liquid passed through said heat exchanging device, causing a drop in the temperature of the gas material passing through said heat exchanging device, liquefying said gas material in said heat exchanger and passing the same to the receiving space of a vessel operating in parallel with said supply, and throttling the admitted gas material.

9. The method of operating a cascade system having but one pair of transfer vessels that are duplicates and arranged in parallel, which method comprises charging said vessels alternately with metered charges of liquid from a common source of supply when vented to the atmosphere, discharging the liquid from said charged vessel when filled to a receiving device through a heat exchanging device, discharging the gas from the other vessel which is at high pressure preparatory to refilling, passing said discharged gas in heat exchanging relation with the refrigeration of the liquid passed through said heat exchanging device, causing a drop in the temperature of the gas passing through said heat exchanging device sufficient to convert the gas into liquid, delivering said reconverted gas material to the receiving space of a vessel operating in parallel with said supply, and re-introducing the liquid from said parallel vessel into the liquid of the newly charged transfer vessel.

10. The method of operating a cascade system having but one pair of transfer vessels that are duplicates and arranged in parallel, which method comprises charging said vessels alternately with metered charges of liquid from a common source of supply when vented to the atmosphere, discharging the liquid from said charged vessel when filled to a receiving device through a heat exchanging device, discharging the gas from the other vessel which is at high pressure during said liquid discharge, passing said discharged gas in heat exchanging relation with the refrigeration of the liquid passed through said heat exchanging device, accelerating the discharge from said liquid charged vessel by independently withdrawing and heating a portion of the liquid charge, and causing the gas delivered from said heat exchanging device to enter a storage space over the liquid in said supply reduced in both temperature and pressure sufficiently to reduce at least a portion of the gas to liquid.

11. The method of operating a cascade system having but one pair of transfer vessels that are duplicates and arranged in parallel, which method comprises charging said vessels alternately with metered charges of liquid from a common source of supply when vented to the atmosphere, discharging the liquid from said charged vessel when filled to a receiving device through a heat exchanging device, discharging the gas from the other vessel which is at high pressure during said liquid discharge, passing said discharged gas in heat exchanging relation with the refrigeration of the liquid passed through said heat exchanging device, accelerating the discharge from said liquid charged vessel by independently withdrawing and heating a portion of the liquid charge, and causing the gas issuing from said heat exchanging device to enter the space of a vessel operated in parallel with said supply having both its temperature and pressure sufficiently reduced to reduce at least a portion of the gas to liquid.

12. In a cascade system for transferring material that is volatile at normal atmospheric pressure, the combination with a plurality of transfer vessels arranged in parallel, of a storage vessel for holding liquefied gas at relatively low pressure arranged to supply material in the liquid phase to any of said transfer vessels and having associated therewith a space for the storage of reliquefied gas material, one of said transfer vessels normally containing material in the gas phase at relatively high pressure, means for selectively withdrawing liquid from said transfer vessels and conveying the same to a receiver, heat exchanging means associated with said withdrawing means having separate passes for the passage of material in the gas and liquid phases respectively, means in communication with the gas pass of said heat exchanging means for conveying gas from said gas filled vessel to said storage space, and throttling means in said conveying means for reducing the temperature and pressure of the gas material introduced in said storage space.

13. In a cascade system for transferring material that is volatile at normal atmospheric pressure, the combination with duplicate transfer vessels arranged to be operated in parallel, of a storage vessel maintained at a relatively low pressure and containing a supply of material in the liquid phase and having associated therewith a space for the storage of material in the gas phase, means for supplying liquid charges from said storage vessel alternately to said transfer vessels, the uncharged transfer vessel normally containing material in the gas phase at a relatively high pressure, means for selectively withdrawing liquid from said transfer vessels and conveying the same to a receiver, heat exchanging means associated with said withdrawing means having separate passes for the passage of material in the gas and liquid phases respectively, means in communication with the gas pass of said heat exchanging means for selectively withdrawing gas from said transfer vessels and conveying the same to said storage space, and automatic pressure regulating means in said conveying means at the entrance to said storage

space arranged for reducing at least a portion of the gaseous material thus introduced substantially to liquid.

14. In a cascade system for transferring material that is volatile at normal atmospheric pressure, the combination with duplicate transfer vessels arranged in parallel, of a storage vessel at relatively low pressure arranged to supply material in the liquid phase to any of said transfer vessels and having associated therewith a space for the storage of condensed gas material, one of said transfer vessels normally containing material in the gas phase at relatively high pressure, means for selectively withdrawing liquid from said transfer vessels and conveying the same to a receiver, additional means for selectively withdrawing portions of liquid from said transfer vessels arranged to communicate therewith at points both above and below the normal liquid level and provided with means for heating the liquid withdrawn, heat exchanging means associated with said first named withdrawing means having separate passes for the countercurrent passage of material in the gas and liquid phases respectively, means in communication with the gas pass of said heat exchanging means for conveying gas from said gas filled vessel to said storage space, and throttling means in said conveying means for reducing the temperature and pressure of the gas material introduced in said storage space.

15. In a cascade system for transferring material that is volatile at normal atmospheric pressure, the combination with duplicate transfer vessels arranged to be operated in parallel, of a storage vessel maintained at a relatively low pressure and containing a supply of material in the liquid phase and having associated therewith a space for the storage of material in the gas phase, means for supplying liquid charges from said storage vessel alternately to said transfer vessels, the uncharged transfer vessel normally containing material in the gas phase at a relatively high pressure, means for selectively withdrawing liquid from said transfer vessels and conveying the same to a receiver, additional means for selectively withdrawing portions of liquid from said transfer vessels arranged to communicate therewith at points both above and below the normal liquid level and provided with means for heating the liquid withdrawn, heat exchanging means associated with said first named withdrawing means having separate passes for the countercurrent passage of material in the gas and liquid phases respectively, means in communication with the gas pass of said heat exchanging means for selectively withdrawing gas from said transfer vessels and conveying the same to said storage space, and automatic pressure regulating means in said conveying means at the entrance to said storage means arranged for reducing at least a portion of the gaseous material thus introduced substantially to liquid.

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