

[54] VAPOR RECOVERY METHOD AND SYSTEM

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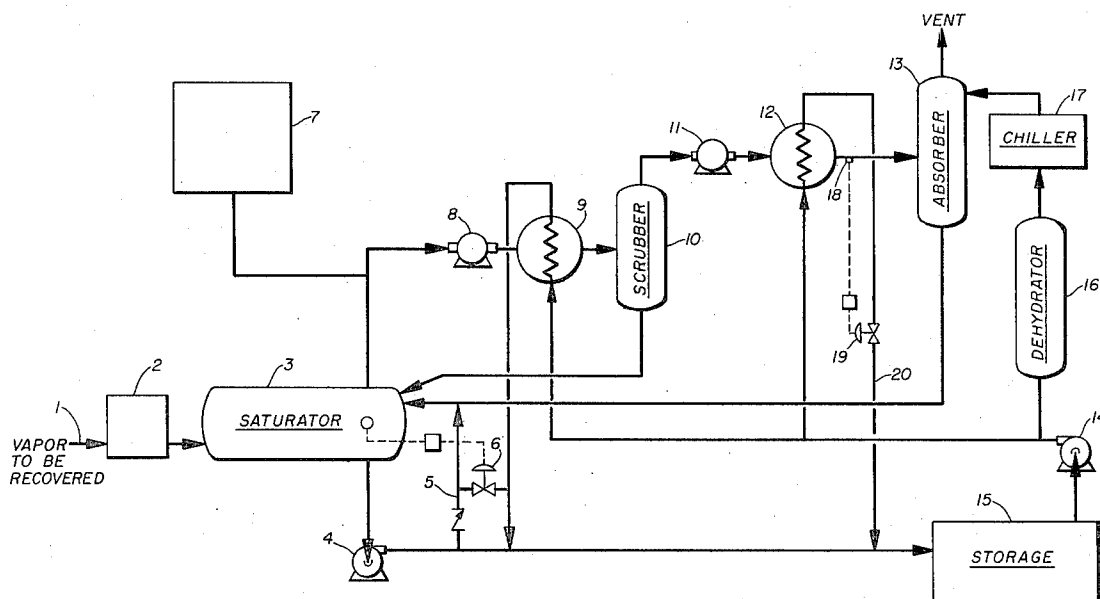
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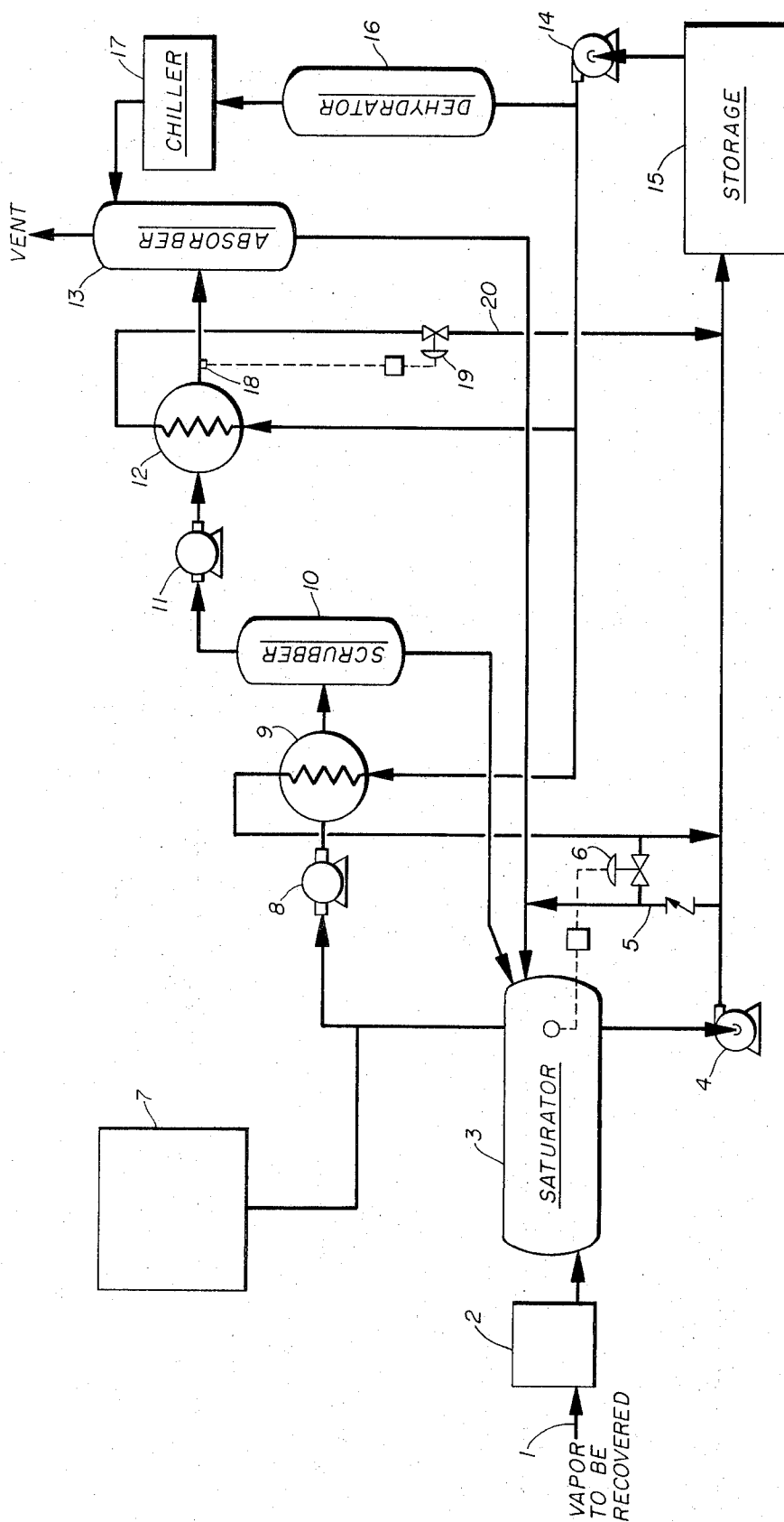
3,815,327 6/1974 Viland 55/89 X
3,830,074 8/1974 Nichols 55/88 X*Primary Examiner*—Charles N. Hart*Assistant Examiner*—Ethel R. Cross*Attorney, Agent, or Firm*—Arthur L. Wade

[57]

ABSTRACT

Liquefiable vapors are compressed and absorbed by cooler liquid. A storage of the liquid supplies inter-stage cooling in the compressor train for the vapors being recovered, saturation of the incoming vapors and dehydrated and refrigerated absorbent for the compressor vapors. The temperature-pressure relation of the compressed vapors is regulated to keep them from their flammable range and the level of liquid in the saturation stage is maintained to prevent explosive vapor mixtures from being drawn into the system.

9 Claims, 1 Drawing Figure



VAPOR RECOVERY METHOD AND SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to the prevention of the escape of vaporized hydrocarbons. More particularly, the invention relates to reliquefying hydrocarbon vapors which are generated when liquid hydrocarbons are transferred between containers.

2. Description of the Prior Art

When hydrocarbon liquid is poured, decanted, drawn from storage and placed into tanks, trucks, ships and the like, a certain amount of vaporization occurs. These vapors have been released to the atmosphere. Not only was a certain amount of the hydrocarbons lost by this vaporization but the atmosphere was thereby polluted.

Hartman et al. U.S. Pat. No. 2,765,872 was filed Jan. 31, 1955 on a system which gathered hydrocarbon vapors to saturate them with stored hydrocarbon liquids. The saturated vapors were compressed and absorbed with additional liquid hydrocarbons.

Tompkins U.S. Pat. No. 2,849,150 was filed Mar. 19, 1956 and disclosed a system which generally paralleled the Hartman et al system. Vapors generated by transfer were saturated, compressed and absorbed. There now appears to be an overlap and conflict between the claims of these two patents, but their disclosures represent the early development of vapor recovery in liquid transfer. Subsequent systems have been developed to use low temperatures for better recovery.

There are a number of vapor recovery systems built on the West Coast which are understood to embody the Hartman et al., or Tompkins, invention. Both disclosures indicate two-stage compression with interstage cooling. However, neither disclosure recognizes the critical requirement for scrubbing liquid condensed by the interstage cooling from the compressed vapor in order to protect the compressor.

Perhaps it is not the best representation of the steps following the art of Hartman et al. and Tompkins, but Battey U.S. Pat. No. 3,714,790 which issued Feb. 6, 1973 purported to add refrigeration to the systems of Hartman et al and Tompkins. Battey stated he specifically wished to eliminate the large gas-holding tank of the former systems. In eliminating the gas-holding tank, Battey refrigerated the liquid hydrocarbons used in both the first "saturating" step and after the compression of the vapors. It is somewhat surprising, in this relatively recent disclosure of Battey, to see that he ignores some practical problems. As an example, Battey suggests that the refrigerated liquid be injected ahead of the compressor to saturate the collected vapors as they flow to the compressor. It would appear, by this arrangement, that Battey is insensitive to the danger liquid presents to the compressor.

Also, Battey gives short shift to the operation of his so-called condensation column in which additional refrigerated gasoline is enriched by the saturated and compressed vapors. The water content of the refrigerated gasoline is not controlled to keep the formation of ice on the trays of the column to a minimum, and the true relationship between the fluids in countercurrent flow within the column is not realistically disclosed.

Refrigeration does improve recovery by the saturation-compression-absorption systems. Battey claims to reduce discharge of vapors to about 7% by weight. The

Hartman et al., Tompkins, system claims a 10% discharge but is probably well above that, as a practical matter.

Recently, several different vapor recovery systems have appeared to compete for a share of the market. The one on which the most published information is available is that marketed by Parker-Hannifin Corporation out of Irvine, California. U.S. Pat. No. 3,771,317 issued Nov. 13, 1973 to R. A. Nichols apparently discloses the system. This system may have several unique features which would recommend it over the Battey system. However, its compression system is not well developed. Further the absorber is not a trayed column to give a multi-stage absorption operation with icing problems isolated to the upper trays. Also, the dehydration of the refrigerated absorption liquid is not controlled to lengthen uninterrupted operation of the absorber.

In summation, the art of these particular vapor recovery systems has not completely developed the compressor train with liquid scrubbing after interstage cooling and dehydration of the refrigerated liquid prior to its use as the absorbing agent in contact with the compressed vapors. Also, the system for interstage cooling has not been designed to prevent the compressed vapors being conditioned into their explosive range.

SUMMARY OF THE INVENTION

A principal object of the invention is to compress the saturated vapor of hydrocarbons to be recovered in multiple stages with interstage cooling. The condensate, and air mixed with the condensate, is flashed back to the head of the compressor train to reduce the hydrocarbons vented from the system.

Another object is to dehydrate liquid hydrocarbons to be refrigerated before the liquid is used to absorb saturated and compressed hydrocarbon vapors to be recovered.

Another object is to control the interstage cooling of the compressed vapor to keep the compressed vapor out of its explosive range.

The invention contemplates gathering vaporized hydrocarbons and air and saturating the mixture with liquid hydrocarbons. The saturated mixture is then compressed and subsequently cooled by heat exchange with liquid hydrocarbons. The compressed and cooled mixture is stripped of any condensed liquids. The liquids are flashed back to the point of collection. The vapors are again compressed and cooled with liquid hydrocarbons from storage. Stored liquid hydrocarbons are then dehydrated and chilled by refrigeration to the order of 10°F. The compressed and cooled vapor, at a temperature in the order of 50°F, is passed in countercurrent flow with the dehydrated and refrigerated liquid hydrocarbons, the enriched liquid thereafter being used to saturate the gathered and vaporized hydrocarbons before the liquid is pumped to storage.

Other objects, advantages and features of this invention will become apparent to one skilled in the art upon consideration of the written specification, appended claims, and attached drawings, wherein;

The single drawing FIGURE is a somewhat diagrammatic representation of a complete system for recovering vaporized hydrocarbons to a liquid form embodying the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring specifically to the drawing, it is a simple flow sheet of the system embodying the invention. The same degree of simplicity as used in the disclosure of Battey U.S. Pat. No. 3,714,790 and Hartman et al. U.S. Pat. No. 2,765,872 is used. The story is completely unfolded by use of this single sheet of drawing.

Let's state the use of the disclosed system. There may still be virtue in restating what is obvious. The system receives a mixture of air and/or gasoline vapors from location of vaporization. This location may be a loading facility. By an optimum combination of compression, refrigeration, and absorption processes, the removal and recovery of the majority of the gasoline contained in the air is effected by the system. The system is included in equipment which is completely skid-mounted, designed for automatic, unattended, continuous operation, with special emphasis being put on holding operating and maintenance costs to a minimum while assuring a maximum amount of safety necessary to handle the potentially explosive vapors.

The vapors to be processed are conducted through 1 to the unit from the collection system. An inline flame arrestor 2 is located in the conduit 1 to avoid the propagation of the flames that might occur in unsaturated vapors within the line.

The vapors flow from the flame arrestor 2 to the inlet saturator vessel 3 where the vapor mixture, which can possibly support combustion, is bubbled through and sprayed with gasoline. This intimate contact with the gasoline enriches the vapor mixture with gasoline above the explosive concentration range of the vapor. This saturator vessel 2 also functions as a suction scrubber for the first stage compressor and as a near-atmospheric flash tank for absorbent gasoline being returned from the absorption process and on its way to product storage. Flashing of this stream of the gasoline minimizes light ends or dissolved air content of the gasoline in storage.

Excess liquids from the saturator vessel 3 are returned to storage by a recirculation pump 4. A sidestream 5 from pump 4 is used to assure continuous flow of gasoline to the spray system of the saturator vessel 3. If the sidestream is inadequate and the level in vessel 3 continues to drop, a liquid level control valve 6 flows additional gasoline from the coolant circulation system. This double safety system minimizes the possibility of losing the gasoline level in vessel 3, thus insuring against explosive vapors getting into the system.

If a vapor holder is provided as at 7, the holder is normally located downstream of the saturator vessel 3. This arrangement is to minimize the time for the vapors in tank 7 to be in the explosive range. Vapors leaving the vessel 3 are stored in holder 7 until a sufficient volume exists to warrant starting the recovery unit. If the unit is not supplied a vapor holder, an existing storage tank is usually utilized as a vapor holder, and this storage would be located ahead of the saturator tank 3. In either case, controls must be furnished on the vapor holder to signal for the recovery unit to start when the vapors have accumulated to a predetermined volume.

Whatever the vapor holder arrangement, when the signal is generated, vapors flow to the first stage compressor 8. Here the vapors are compressed to about 21 psig. After intercooling in exchanger 9 and scrubbing

of liquids in 10, the vapors the further compressed to about 65 psig in second stage compressor 11 and after-cooled in exchanger 12.

After the two-stage compression, the vapors are directed to the lower end of the absorber vessel 13. This vessel has a series of valve trays to provide a contacting surface for the ascending vapor stream with a descending stream of cold gasoline. The cold gasoline stream is fed into the top of the absorber vessel 13 and flows downward, cascading across the trays to give intimate contact with the vapor flowing upward through the variable opening valves in the trays.

The cold gasoline functions in two ways to remove hydrocarbons from the vapor stream. First, the vapor is cooled to condense out hydrocarbons. Second, the hydrocarbons are absorbed into the stream of gasoline. The resultant air-rich vapor, containing less than 10% by weight hydrocarbons, is vented to atmosphere from the top of the absorber through a back pressure valve and an inline flame arrestor. Alternatively, this vapor could be used as a pneumatic supply for the control instruments used throughout the system.

The vapors entering the bottom of the absorber vessel 13 are relatively warm (70°F - 100°F). The gasoline entering the top of the vessel is relatively cold (10°F - 20°F). Thus, the absorber has a relatively warm temperature at its base and a relatively cold temperature at its top. As the vapor stream rises, it is cooled and any water in the stream will condense and fall back to the bottom. The small amount of water vapor remaining when the stream reaches 32°F is an insignificant amount to prevent any freezing problems in the top of the absorber. Further, as the unit operates intermittently, down periods would allow the overall absorber temperature to equalize at some temperature above 32°F, thus allowing any ice buildups to thaw automatically.

The gasoline used as the absorbent is pumped, along with the gasoline used as coolant in the heat exchangers 9 and 12, by pump 14 from the storage tank 15. Tank 15 must be of an adequate volume such that it will not be significantly affected by the heat absorbed in the exchangers or the lighter hydrocarbons recovered in the absorber 13. Alternatively, the return gasoline could be taken to a separate tank so a fresh gasoline supply is constantly being used in the vapor recovery unit. The absorbent gasoline, pumped by 14, is first routed through the guard dehydrator 16 in which the gasoline is contacted with a bed of calcium chloride. Periodic inadvertent traces of water are removed by the bed to prevent freezepup in the refrigeration system chiller 17.

After contacting the vapor stream in the absorber 13, the absorbent gasoline, plus any recovered product, is taken back to the saturator 3 where it is sprayed through the incoming vapors as previously described. This stream is flashed from about 60 psig down to near atmospheric pressure. This flashing minimizes the light ends and dissolved air content of the gasoline before it is returned to storage 15.

FLAMMABILITY GUARD

Going back over the general pattern of pressures and temperatures of the vapors as they are compressed and cooled, a sensitive zone is pointed out. At the exit from the second cooler, there is danger that the vapor mixture compressed will be brought into its flammability range.

Assuming a winter blend of gasoline, the vapor mixture compressed would be in its flammability range at the following pressures:

14.6 psia	8.7 vol. % Hydrocarbon
31.0 do.	14.8 do.
65.0 do.	22.0 do.
75.0 do.	23.3 do.

Next, the volume % of hydrocarbons in the vapor mixture passed through the recovery system is charted:

	SATURA- TOR 3	SCRUB- BER 10	AB- SORBER 13	INLET
TEMP. F	14.6 psia	31 psia	65 psi	75 psi
70	68.07	64.11	41.73	36.99
60	65.43	59.57	36.48	32.25
50	61.74	53.66	31.48	27.79
40	56.77	46.93	26.76	23.61
30	50.59	40.03	22.43	19.78

It is apparent that operation of the second stage of compression becomes critical when 65 – 75 psia vapor pressure is reached and the temperature of the vapors is allowed to drop 40° – 30°F. The vapor mixture becomes flammable. Therefore, to avoid this dangerous condition, the operation of at least heat exchanger 12 must be controlled.

The drawing shows one way of exerting control over exchanger 12. The temperature of the compressed vapors can be sensed at 18 and a valve 19 regulated in conduit 20. The controller can be any one of several well-known types and is thus arranged to control the temperature of the output of the second stage of compression to avoid the dangerous range of temperature at which the vapor becomes flammable at the pressures attained.

COMPRESSORS 8 AND 11

In the actual reduction to practice of the invention, rotary compressors were selected for this service. These compressors are the single stage multivane type and operate on the positive displacement principle. Free liquid is passed at the rate of one gallon for every 35 cubic feet of vapor entering the compressor at normal efficiency.

It is expected that the efficiency of this type of compressor will be sustained for years by the automatic, self-adjustment of the sliding vanes. The vanes are expected to be of a tough, hard, non-metallic, non-corrodible material that is impervious to oil, moisture, and hydrocarbons. Ductile iron is acceptable for the compressor case. The mechanical shaft seals will be oil-lubricated. The lubrication system is driven by the rotary compressor with a static-resistant positive drive to insure positive oil lubrication at three injection points. Safety shutdown devices are provided for unattended oil lubrication monitoring. Manual adjustment is provided for lube oil flow rate.

HEAT EXCHANGERS 9 AND 12

These are finned double pipe type heat exchangers. As has been described before, gasoline from the storage 15 is utilized as the coolant source. The tempera-

ture of the vapors from the heat exchangers is controlled automatically by adjusting the flow of gasoline for cooling.

In general, it is desirable to keep the vapors above approximately 40°F. The explosive range of the vapors increases as the pressure increases. The actual gasoline concentration decreases as the temperature decreases. Thus, at about the 65 psig level, the mixture would probably be in the explosive range at temperatures below 40°F.

The more sensitive location in the system is at the exit from exchanger 12 and entrance to absorber 13. These conditions have been analyzed and charted in connection with the operation of valve 19 in conduit 20 by temperature element 18.

It has been calculated and concluded that aerial coolers could be substituted for the double pipe heat exchangers 9 and 12. When otherwise practical, the use of aerial coolers would eliminate the need for the coolant gasoline source. In such arrangement, the only external gasoline supply needed would be the small volume required for the absorber vessel 13.

CHILLER 17

This refrigeration unit in the actual reduction to practice is a Vilter Mfg. Co. Model 340 VMC reciprocating compressor. The compressors are sized to operate at 1,250 rpm. This is a relatively low speed which minimizes operating problems of the higher speeds. A flooded type chiller is provided, of all steel construction. The initial Freon charge is included, as is a receiver sized to hold 125% of the pump down charge.

SAFETY SHUTDOWN SYSTEM

As it is planned for the unit to operate unattended the majority of the time, the possible locations of trouble are monitored. Level, temperature, pressure and flow are the variables monitored for malfunction as follows:

1. High liquid level in saturator 3.
2. High liquid level in scrubber 10.
3. High liquid level in absorber 13.
4. Low oil level — compressor oil storage.
5. High temperature of absorption gasoline out of 17.
6. High bearing temperature of compressor 8.
7. High discharge temperature of vapor from compressor 8.
8. High bearing temperature of compressor 11.
9. High bearing temperature of vapor from compressor 11.
10. Low suction pressure of compressor 8.
11. High discharge pressure of vapor of compressor 8.
12. Low discharge pressure of vapor of compressor 8.
13. High discharge pressure of vapor of compressor 11.
14. Low discharge pressure of vapor of compressor 11.
15. Low flow of coolant gasoline to exchangers 9 and 12.
16. Low flow of absorption gasoline from chiller 17.
17. Low flow of recovered gasoline to saturator 3.
18. High discharge pressure of refrigerant compressor.
19. Low suction pressure of refrigerant compressor.
20. Low oil pressure of refrigerant compressor.

If any of the first seventeen of these variables can shut the unit down. Variables 18, 19 and 20 can shut down only the refrigeration unit. Of course, shutdown of the refrigeration unit will eventually cause a high temperature of the absorption gasoline which will result in shutdown of the entire unit.

There are variables which do not shut down the entire unit. The level in saturator 3 is arranged to shut down recirculation pump 4 until the saturator 3 level builds back up. This protects the pump 4. The low suction pressure out of scrubber 10, and to compressor 11, is arranged to shut down compressor 11 until the pressure builds back up.

There is a low-pressure value which indicates substantially no hydrocarbon vapors remain, but have been condensed. If the hydrocarbon content of the vapors to the unit are so high as to cause this condensation and therefore low-pressure out of scrubber 10, the compressor 11 simply shuts down until recoverable vapors appear.

CONCLUSION

When the prior art is considered, invention is embodied in the process and structure disclosed. Here is a method by which the vapors of volatile liquids are reliquefied. The vapors often contain air and the vapor mixture could support combustion. Therefore, the vapors are first saturated.

The saturated vapors are then compressed in two stages and cooled after each compression with stored liquid. The next step is dehydrating a stream of the stored volatile liquid before chilling, or refrigerating, the liquid. Then this cooled liquid is brought into contact with the compressed, saturated vapors to absorb almost all of the vapors. The cycle is completed by using the absorbent liquids to saturate the incoming, collected vapors.

In the process and structure, where hydrocarbon vapors are processed, the invention contemplates compression of the vapors to a range in the order to 25 to 85 psig. The temperature contemplated for these compressed vapors is about 90°F. Therefore, it is contemplated that the dehydrated stream of stored volatile liquid is to be chilled to a range in the order of 5°F to 25°F before contact with the compressed, saturated vapors for their absorption.

Any liquefaction of vapors that takes place in the compression train provides liquid which is re-cycled to the saturation step of the process. The vapors which are discharged to atmosphere, from the absorption step, contain well below 10 percent hydrocarbon.

The cooling-after-compression of the saturated vapors is regulated to prevent the temperature-pressure relationship of the vapors reaching their flammability range. Of course there are many specific arrangements for control of the degree of cooling provided the compressed vapors. The disclosure illustrates one way with regulation of the flow of stored liquid through the last heat exchanger in accordance with the temperature of the compressed vapors flowing from the heat exchanger. This is a most important safety system.

A second safety system is provided in direct connection with saturator vessel 3. The liquid level in this vessel must be guarded. It must not be lost with the resulting risk of bringing explosive vapors into the system. This level is guarded carefully and multiple sources of

liquid supplies regulated to keep the level within safe limits.

From the foregoing, it will be seen that this invention is one well adapted to attain all of the ends and objects hereinabove set forth, together with other advantages which are obvious and inherent to the method and apparatus.

It will be understood that certain features and sub-combinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the invention.

As many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted in an illustrative and not in a limiting sense.

The invention, having been described, what is claimed is:

1. A method of liquefying vapors released when volatile liquid is transferred between containers, including, collecting a mixture of the released vapors and air, saturating the collected vapor mixture with the volatile liquid, compressing the saturated vapor mixture a first time, cooling the compressed vapor mixture with volatile liquid from a stored quantity of the liquid, removing liquids condensed by the cooling of the compressed vapor mixture, compressing the saturated vapor mixture a second time, cooling the compressed vapor mixture with volatile liquid from a stored quantity of the liquid, dehydrating a stream of volatile liquid from the stored quantity, refrigerating the dehydrated stream, contacting the compressed, saturated vapor mixture with the refrigerated and dehydrated stream of volatile liquid whereby vapors released by transfer are absorbed by the liquid, and collecting the volatile liquid which absorbed the released vapors and using the liquid to saturate the collected vapor mixture.
2. The method of claim 1, wherein the volatile liquid transferred is hydrocarbons and the saturated vapor mixture is compressed to the range of 25 to 85 psig in the order of 90°F and the dehydrated stream is refrigerated to the range of 5°F to 25°F.
3. The method of claim 2 wherein the liquids condensed by the cooling of the first compression of the vapor mixture are conducted to the step of saturation of the collected vapor mixture for recycle of any air mixed with the condensate.
4. Apparatus for liquefying vapors released when volatile liquid is transferred between containers, including, means for collecting a mixture of the released vapors and air from the receiving container, a vessel connected to the collecting means to receive the mixture and in which the mixture is saturated with the vapors from a collection of the volatile liquid, a first compressor connected to receive the saturated vapor mixture and elevate its pressure, a first heat exchanger connected to receive the compressed vapor mixture and reduce its temperature

with volatile liquid from a stored quantity of the liquid,
 a scrubber vessel connected to receive the compressed and cooled vapor mixture and separate condensed liquids from the mixture,
 a second compressor connected to receive the saturated vapor mixture from the scrubber vessel and elevate its pressure,
 a second heat exchanger connected to receive the compressed vapor mixture and reduce its temperature with volatile liquid from the stored quantity of the liquid,
 a dehydrator connected to receive a stream of volatile liquid from the stored quantity of the liquid and reduce its water content,
 a refrigeration unit connected to receive the stream of dehydrated volatile liquid and reduce its temperature,
 an absorption tower connected to receive the compressed and cooled vapor mixture from the second heat exchanger in its lower end and to receive the refrigerated stream of dehydrated volatile liquid in its upper end, whereby the fluids are passed on countercurrent flow to absorb the vapors released by transfer into the dehydrated volatile liquid,
 and a conduit connected from the lower portion of the tower to the vessel receiving the mixture from the collecting means for saturation of the collected vapors with the dehydrated volatile liquid which has absorbed the vapors released by transfer.

5. The apparatus of claim 4 wherein the volatile liquid transferred is hydrocarbons and the second compressor elevates the pressure of the saturated hydrocar-

bons to the range of 25 to 85 psig and the second heat exchanger reduces the temperature of the compressed vapor mixture to the order of 90°F and the refrigeration unit reduces the temperature of the dehydrated liquid hydrocarbons to the range of 5°F to 25°F.

6. The apparatus of claim 5 wherein the liquids condensed in the scrubber vessel are conducted to the vessel in which the collected mixture is saturated for recycle of any air mixed with the condensate.

7. The apparatus of claim 5 wherein,
 a second conduit is provided between the scrubber vessel and the vessel receiving the mixture from the collecting means for saturation of the collected vapors with the condensed liquids from the mixture,
 a second conduit is provided from the liquid in the bottom of the receiving vessel to storage for the liquids, and
 a third conduit is provided from the second conduit to the first conduit to insure maintenance of the liquid level in the receiving vessel.

8. The apparatus of claim 7 wherein,
 a fourth conduit is provided from liquid used in the interstage cooling of the compressed vapor mixture to the third conduit, and
 a control system for the fourth conduit from the liquid level in the receiving vessel.

9. The apparatus of claim 5 wherein a control system is provided for the liquid used is temperature reduction in the heat exchangers to regulate the temperature of the vapor mixture compressed for reception by the absorption tower.

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