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[54] **VOLATILE VAPOR RECOVERY SYSTEM AND METHOD UTILIZING JOULE THOMPSON EXPANSION**


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[51] **Int. Cl.**[2] ..... **F13C 5/04**

[58] **Field of Search** ..... 62/54, 86–88, 62/514, 402, 401; 220/85 VR, 85 VS; 55/88, 89, 90, 93, 94



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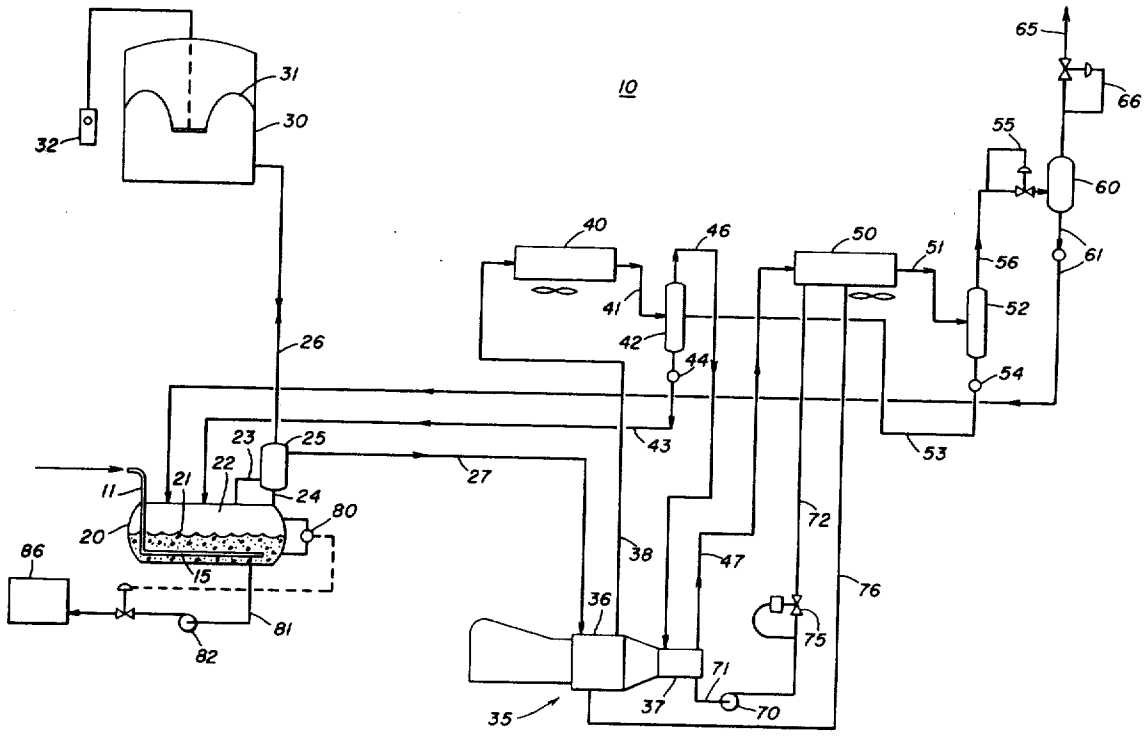
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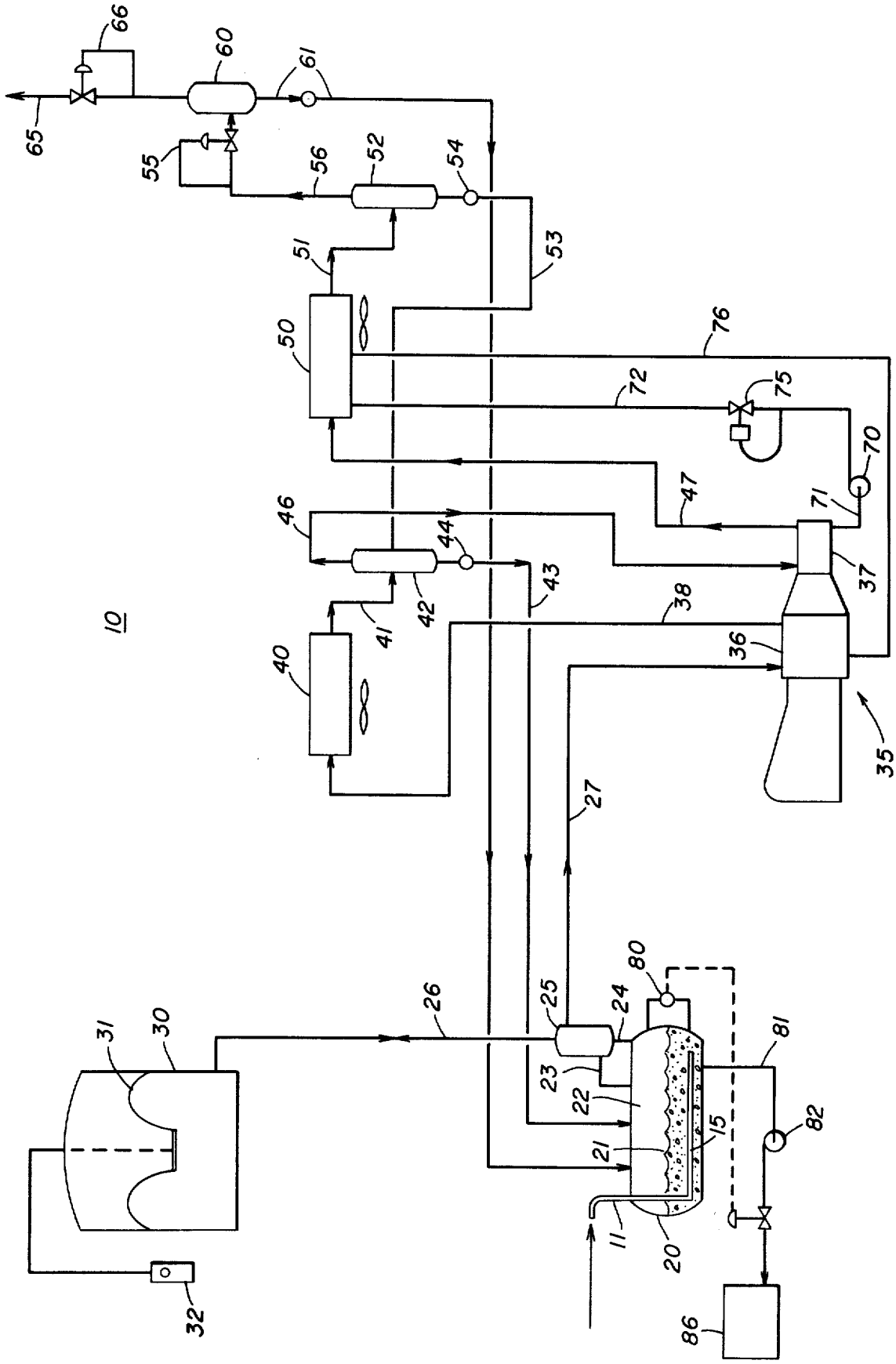


[57] **ABSTRACT**

A system for recovering volatile combustible liquids from a vapor stream includes a saturating vessel for rendering the vapor stream non-explosive, a plurality of high-pressure ambient air-cooled condensing stages, each stage compressing the vapor stream and then cooling it to ambient temperature without the use of refrigeration for forming liquid product and residual vapors, an expansion vessel for receiving the vapors from the last condensing stage and further cooling and condensing them by Joule-Thompson expansion, means for returning recovered liquid product from the condensing stages and the expansion vessel to the saturating vessel, and means for venting the residual vapors from the expansion vessel. Means is also provided for cycling compressor coolant through one of the condensing stages.


**9 Claims, 1 Drawing Figure**




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# VOLATILE VAPOR RECOVERY SYSTEM AND METHOD UTILIZING JOULE THOMPSON EXPANSION

The present invention relates to the recovery of volatile liquid product from a vapor stream, and more particularly to the recovery of combustible liquid product such as hydrocarbons. A typical application of the present invention would be in the recovery of vapors produced during the loading of gasoline and the like into the tank trucks at a loading terminal, in the interest of safety and the prevention of air pollution.

The present invention is an improvement of the invention disclosed in my copending application, Ser. No. 127,259, filed Mar. 23, 1971, entitled VOLATILE VAPOR RECOVERY SYSTEM and assigned to the assignee of the present invention, a general object of this present invention being to provide a vapor recovery system which discharges heat directly to the atmosphere without the use of refrigeration and returns the recovered liquid product to storage substantially at ambient temperature, thereby significantly reducing the power requirements of the system.

More particularly, it is an object of this invention to provide a method and apparatus for recovering volatile liquids from a vapor stream by compression and high pressure condensation of the vapors followed by Joule-Thompson expansion of the compressed vapors, all without the use of refrigeration.

It is an important object of the present invention to provide apparatus for recovering volatile liquids from a vapor stream, the apparatus comprising a plurality of stages of condensing apparatus, each of the stages including a compressor having an inlet and an outlet and ambient-air-cooled condensing means having an inlet connected to the outlet of the compressor and a vapor outlet and a liquid product outlet, the inlet of the first stage compressor being adapted for connection to an associated vapor source for receiving therefrom an input vapor stream, the inlet of the compressor of each of the other stages being connected to the vapor outlet of the condensing means of the immediately preceding stage for receiving the cooled vapor stream therefrom, vent means connected to the vapor outlet of the last stage condensing means for discharging to atmosphere the uncondensed vapor stream therefrom, and a liquid product reservoir connected to the liquid product outlets of the condensing means of each of the stages for receiving therefrom the recovered liquid product.

Still another object of the present invention is to provide apparatus of the type set forth, which includes an expansion vessel connected between the vent means and the vapor outlet of the last stage condensing means for further cooling and condensing the compressed vapor stream by Joule-Thompson expansion thereof, and means for returning the recovered liquid product from the expansion vessel to the liquid reservoir.

Still another object of the present invention is to provide a method for recovering volatile liquids from an input vapor stream, the method comprising the steps of compressing the input vapor stream in a plurality of compression stages, condensing the compressed vapor stream by cooling it with ambient air in a plurality of condensing stages alternating with the compression stages, venting to atmosphere the uncondensed vapor stream from the last condensing stage, and collecting the liquid product recovered in each of the condensing stages.



In connection with the foregoing object, still another object of this invention is to provide a method of the type set forth, which includes the step of further cooling and condensing the compressed vapor stream from the last condensing stage by Joule-Thompson expansion and collecting recovered liquid product of this expansion.

Further features of the invention pertain to the particular arrangement of the parts of the vapor recovery apparatus and the steps of the vapor recovery method whereby the above-outlined and additional operating features thereof are attained.

The invention, both as to its organization and method of operation, together with further objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawing, which is a diagrammatic representation of the vapor recovery system of the present invention, indicating the vapor and liquid flow paths therethrough.

With reference to the drawing, there is illustrated a vapor recovery system, generally designated by the numeral **10**, constructed in accordance with and embodying the features of the present invention. The system **10** includes a vapor input conduit **11** adapted to be connected to an associated source of vapor (not shown). In a typical application of the present invention, the source of vapor may be a loading station for loading gasoline into the tank trucks or other vessels by the top-loading method, the air-vapor mixture displaced from the truck tanks by the loading operation being collected by suitable vapor hoods or the like and fed into the vapor input conduit **11**.

The conduit **11** is connected to a concentration correction vessel **20** containing therein a body **21** of liquid product and a vapor space **22** thereabove. Preferably, the vapor input conduit **11** is connected to a manifold pipe **15** disposed along the bottom of the vessel **20** and immersed in the body **21** of liquid product for bubbling the input vapor stream up through the liquid product, thereby saturating the input vapors and insuring that the concentration of hydrocarbons therein shall be above the explosive limit. The concentration correction vessel **20** is connected to an entrainment separator **25** by a vapor conduit **23** and a liquid product conduit **24**, the entrainment separator **25** in turn being connected by a conduit **26** to a surge tank **30** and by a conduit **27** to the first stage **36** of a two-stage compressor **35**. The surge tank **30** is provided with a movable diaphragm **31** therein for forming a variable volume chamber in the surge tank **30**. The diaphragm **31** is connected to a control switch **32**, the switch **32** being responsive to movement of the diaphragm **31** for controlling the operation of the compressor **35** in a manner to be described more fully below.

The output of the first compressor stage **36** is connected by conduit **38** to the inlet of an ambient-air-cooled condenser **40**, which preferably includes cooling coils through which the vapor stream is passed and over which a stream of ambient air is forced by a suitable fan or blower. The outlet of the condenser **40** is connected by a conduit **41** to an inlet of a separator **42** which separates the condensed liquid from the uncondensed vapor stream. The separator **42** has a liquid product outlet which is connected by a conduit **43** to an inlet of the concentration correction vessel **20**, the conduit **43** being provided with an automatic trap **44**

therein for accommodating passage of liquid product from the separator **42** to the vessel **20** while maintaining the pressure differential therebetween. The separator **42** is also provided with a vapor outlet connected by a conduit **46** to the inlet of the second stage **37** of the compressor **35**, the outlet of the compressor stage **37** being connected by a conduit **47** to the inlet of a second ambient-air-cooled condenser **50** which is substantially the same in construction and operation as the condenser **40**. The outlet of the condenser **50** is connected by a conduit **51** to an inlet of a second separator **52**, identical in construction and function to the separator **42**. The separator **52** has a liquid product outlet connected by conduit **53** to another inlet of the separator **42**, the conduit **53** being provided with an automatic trap **54** therein for accommodating passage of liquid product from the separator **52** to the separator **42** while maintaining the pressure differential therebetween.

The separator **52** is also provided with a vapor outlet connected by a conduit **56** to the inlet of a Joule-Thompson expansion vessel **60**, the conduit **56** being provided with a back pressure valve **55** for maintaining the system pressure established by the second compressor stage **37**. The expansion vessel **60** has a liquid product outlet connected by a conduit **61** to another inlet of the concentration correction vessel **20**, the conduit **61** preferably being provided with an automatic trap **62** for accommodating passage of liquid product from the expansion vessel **60** to the concentration correction vessel **20** while maintaining the pressure differential therebetween. The expansion vessel **60** has a vapor outlet connected by conduit **65** to the atmosphere for venting the uncondensed vapors, the conduit **65** preferably being provided with a back pressure valve **66** therein set at a relatively low pressure of approximately 5 p.s.i.g. for maintaining a slight pressure differential between the expansion vessel **60** and the concentration vessel **20**, thereby preventing backflow of liquid product from the vessel **20** to the vessel **60**.

The compressor **35** is preferably provided with a coolant such as glycol and water, and it is a feature of the present invention to utilize the condenser **50** for effecting cooling of this compressor coolant. More particularly, the coolant is fed from the second compressor stage **37** by a conduit **71** to a pump **70** which pumps the coolant through a conduit **72** to a separate section of the condenser **50** in which heat is rejected to atmosphere, the cooled liquid then being returned by a conduit **75** to the first stage **36** of the compressor **35**. The conduit **72** is provided with a temperature controlled valve **75** therein adjusted to maintain optimum operating temperature in the compressor **35**. Preferably, the pump **70** is connected so as to operate only when the compressor **35** is running.

The concentration correction vessel **20** is provided with a liquid product outlet connected by a conduit **81** and a pump **82** to a storage tank **86** for removing recovered liquid product from the vessel **20** and returning it to the storage tank **86**. The vessel **20** is provided with a level control device **80** which is connected to a control valve **85** in the conduit **81**, the control device **80** being responsive to the level of liquid product in the vessel **20** for opening the valve **85** when the liquid product level exceeds a first predetermined level and for closing the valve **25** when the liquid product level falls below a second predetermined level.

The operation of the vapor recovery system **10** will now be described in detail. For purposes of illustration, it is assumed that the input vapor stream flowing to the conduit **11** is a mixture of air and hydrocarbons at about 14.7 p.s.i.a. at 80° F., it also being assumed that the ambient air temperature is approximately 90° F. The input vapor stream is fed via the conduit **11** in the manifold **15** to the interior of the concentration correction vessel **20**, wherein it is bubbled up through the body of liquid product **21** for saturating the hydrocarbon vapors and insuring that the concentration thereof shall be above the explosive limit for gasoline vapors.

The air-vapor mixture then leaves the correction vessel **20** by way of the vapor conduit **23** and passes through the entrainment separator **25**, entering tangentially to remove any entrained liquid from the vapor stream, liquid product removed in the entrainment separator being returned to the correction vessel **20** by the conduit **24**. The vapor stream may then leave the separator **25** by either or both of the conduits **26** and **27**, the vapor passing through the conduit **26** entering the variable volume surge tank **30**. Preferably, the compressor **35** is controlled by the switch **32** which is responsive to the volume of gas in the surge tank **30**. More particularly, as the volume and pressure of the gas stored in the surge tank **30** decreases below a predetermined minimum level, the diaphragm **31** moves downwardly for actuating the control switch **32** and de-energizing the compressor **35**. Normally, when the compressor **35** is in operation, it draws the vapor stream through the conduit **27** from either or both of the correction vessel **20** or the surge tank **30**. The input vapor stream will flow directly through the separator **25** to the compressor **35**, with any excess vapor flow being temporarily stored in the surge tank **30**. Then, when the input vapor stream through the conduit **11** reduces below the level required to properly feed the compressor **35**, the vapors stored in the surge tank **30** are drawn off to the compressor **35**, thereby permitting longer uninterrupted compressor operation and minimizing stoppage of the compressor.

The input vapor stream enters the first compressor stage **36** at approximately atmospheric pressure, the pressure of the vapor stream being raised by the compressor to about 65 p.s.i.a. and its temperature being raised to about 232° F. This hot compressed vapor mixture is passed through the conduit **38** to the inlet of the condenser **40**, where it passes through cooling coils over which a stream of ambient air is blown by the blower. In the condenser **40**, the temperature of the compressed vapor stream is reduced to near ambient temperature, i.e., to about 90°–95° F., and, as the heat of compression is removed, the heavier hydrocarbons will condense until they reach their saturation point at the 65 p.s.i.a. pressure.

Then the mixture of cooled vapor and condensed liquid will pass through the conduit **41** to the separator **42**. The condensed liquid will be discharged from the separator **42** by the automatic trap **44** through the conduit **43** and back to the concentration correction vessel **20**, while the uncondensed vapor stream passes from the separator **42** through the conduit **46** to the suction of the second compressor stage **37**. The input vapor stream which is at 65 p.s.i.a. and approximately 90°–95° F. is compressed in the second compressor stage **37** to approximately 275 p.s.i.a., which raises its temperature to about 230° F. This further compressed

vapor stream is then passed through the conduit **47** to the inlet of the second ambient-air-cooled condenser **50** in which the temperature of the vapor stream is again reduced by ambient-air-cooling to approximately ambient temperature, or 90°–95° F. As the heat of compression is discharged to the atmosphere in the condenser **50**, more hydrocarbons, including the balance of the heavier hydrocarbons and most of the lighter ones are condensed, and the liquid and vapor mixture passes from the condenser **50** through the conduit **51** to the inlet of the separator **52**. The condensed liquid hydrocarbons are discharged from the separator **52** through the trap **54** and the conduit **53** to the separator **42**. This liquid product, its pressure being reduced to 65 p.s.i.a. after it passes the trap **54**, joins the liquid product in the separator **42** and passes therewith through the conduit **43** to the concentration correction vessel **20**.

The uncondensed vapor stream leaves the separator **52** through the conduit **56** and the back pressure valve **55** to the expansion vessel **60**, the back pressure valve **55** being set so as to maintain the system pressure of 275 p.s.i.a. established by the second compressor stage **37**. As the vapor stream enters the expansion vessel **60**, it is at 275 p.s.i.a. and approximately ambient temperature, the heat of compression having been removed by the condenser **50**. In the vessel **60**, the vapor stream undergoes Joule-Thompson expansion, whereby the vapor stream is further cooled by the Joule-Thompson effect and more of the lighter hydrocarbons are condensed. The condensed liquid product is discharged from the vessel **60** through the automatic trap **62** and the conduit **61** to the concentration correction vessel **20**. The uncondensed residual vapors are vented to atmosphere from the vessel **60** through the conduit **65** and the back pressure valve **66**, the valve **66** preferably being set at a relatively low pressure of approximately 5 p.s.i.g. so as to provide maximum expansion of the gas in the vessel **60**, while maintaining a slight pressure differential between the vessel **60** and the concentration correction vessel **20**.

As the recovered liquid product from the separators **24, 42,** and **52** and the expansion vessel **60** accumulates in the concentration correction vessel **20** and exceeds the first predetermined level, the liquid level controller **80** opens the control valve **85** and permits the liquid product to be pumped through the conduit **81** by the pump **82** to the storage tank **86** until the level of liquid product in the vessel **20** has been reduced below a second predetermined level.

When the compressor **35** is running, the pump **70** pumps the compressor coolant from the cylinder jacket of the second compressor stage **37** through the conduits **71** and **72** to the separate section of the condenser **60** for discharging the heat to atmosphere, the cooled coolant then being returned through the conduit **76** to the cylinder jacket of the first compressor stage **36**. Preferably, the pump **70** is connected to the compressor **35** and to the heat control valve **75** so that the pump is operable only when the compressor **35** is running and the control valve **75** is open. Thus, a predetermined optimum operating temperature may be contained in the compressor **35**.

In a typical application of the vapor recovery system **10**, the input vapor stream to the input conduit **11** may be as follows:

| | Wt. Fraction | Partial Press. | Wt. Flow LB/HR |
|---|---|---|---|
| $C_3$ | .006 | .09 | 6.4 |
| $C_4$ | .303 | 3.40 | 298.3 |
| $C_5$ | .235 | 2.12 | 231.5 |
| $C_6$ | .080 | .61 | 79.6 |
| AIR | .376 | 8.48 | 371.5 |
| | 1.000 | 14.70 | 987.4 |

Total HC to compressor = 615.8 LB/HR

When the flow volume and composition of the input vapor stream is as indicated above, the vapor stream preferably enters the first compressor stage **36** at approximately 138 cubic feet per minute, the total hydrocarbon being fed to the compressor being equal to approximately 615.8 lb. per hour. With the system pressures as indicated above and with the ambient temperature assumed to be approximately 90° F., the vapor recovery system **10** is effective for recovering in excess of 90% of the hydrocarbons in the input vapor stream. More particularly, it is estimated that the total recovery of condensed hydrocarbons from the two condensers **40** and **50** will be as follows:

| | LB/HR | Vented: LB/HR | |
|---|---|---|---|
| $C_3$ | 3.02 | 3.38 | |
| $C_4$ | 258.70 | 39.60 | |
| $C_5$ | 225.48 | 6.02 | |
| $C_6$ | 77.51 | 2.09 | (HC=51.09 LB/HR) |
| AIR | — | 371.50 | |
| | 564.71 | 422.59 | |

Recovery = 564.71/615.8 × 100 = 91.70%

In addition, some additional hydrocarbons will be condensed in the expansion vessel **60**, thereby insuring that well in excess of 90% of the hydrocarbons will be recovered by the vapor recovery system **10**.

It is a significant feature of the present invention that this efficient recovery of the hydrocarbons from the input vapor stream is accomplished without the use of an external refrigeration system, thereby significantly decreasing the total power required to operate the system. In addition, it will be appreciated that the vapor recovery system **10** of the present invention does away with the considerable cost of operation and maintenance of an external refrigeration system.

From the foregoing, it will be seen that there has been provided a novel and improved volatile vapor recovery system including a method and apparatus particularly adaptable for recovering combustible hydrocarbon vapors without the use of an external refrigeration system.

In addition, there has been provided a vapor recovery system which effects multi-stage compression and condensation of the vapor stream, with the condensation being effected through cooling of the compressed vapor stream by ambient air.

In addition, there has been provided a vapor recovery system of the character described, which further includes Joule-Thompson expansion of the cooled compressed vapor stream for effecting further cooling and condensation thereof.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made therein, and it is intended to cover

in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. Apparatus for recovering volatile liquids from a vapor stream, said apparatus comprising a plurality of stages of condensing apparatus, each of said stages including a compressor having an inlet and an outlet and ambient-air-cooled condensing means having an inlet connected to the outlet of said compressor and a vapor outlet and a liquid product outlet, the inlet of the first stage compressor being adapted for connection to an associated vapor source for receiving therefrom an input vapor stream, the inlet of said compressor of each of the other stages being connected to the vapor outlet of said condensing means of the immediately preceding stage for receiving the cooled vapor stream therefrom, vent means connected to the vapor outlet of the last stage condensing means for discharging to atmosphere the uncondensed vapor stream therefrom, compressor cooling means for circulating a coolant other than said liquid product through said compressor in each of said stages and through said condensing means in one of said stages, and a liquid product reservoir connected to the liquid product outlets of said condensing means of each of said stages for receiving therefrom the recovered liquid product.

2. The apparatus set forth in claim 1, wherein the input vapor stream includes combustible hydrocarbons, said condensing apparatus included two stages, said first stage compressor compressing the vapor stream to approximately 65 p.s.i.a. at approximately 232° F., said second stage compressor further compressing the vapor stream to approximately 275 p.s.i.a. at approximately 230° F.

3. Apparatus for recovering volatile liquids from a vapor stream, said apparatus comprising a compressor having an inlet and an outlet, said inlet being adapted for connection to an associated vapor source for receiving therefrom an input vapor stream, ambient-air-cooled condensing means having an inlet connected to the outlet of said compressor and a vapor outlet and a liquid product outlet, an expansion vessel having an inlet connected to the vapor outlet of said condensing means and a vapor outlet and a liquid product outlet, said expansion vessel effecting further cooling and condensing of the cooled compressed vapor stream from said condensing means by Joule-Thompson expansion thereof, vent means connected to the vapor outlet of said expansion vessel for discharging to the atmosphere the uncondensed vapor stream therefrom, and a liquid product reservior connected to the liquid product outlets of said condensing means and said expansion vessel for receiving therefrom the recovered liquid product.

4. The apparatus set forth in claim 3, wherein said expansion vessel reduces the pressure of the compressed vapor stream to approximately 5 p.s.i.g.

5. Apparatus for recovering volatile liquids from a vapor stream, said apparatus comprising a plurality of stages of condensing apparatus, each of said stages including a compressor having an inlet and an outlet and condensing means having an inlet connected to the outlet of said compressor and a vapor outlet and a liquid product outlet, the inlet of the first stage compressor being adapted for connection to an associated vapor source for receiving therefrom an input vapor stream, the inlet of said compressor of each of the other stages being connected to the vapor outlet of said condensing means of the immediately preceding stage for receiving the cooled vapor stream therefrom, an expansion vessel having an inlet connected to the vapor outlet of the last stage condensing means and a vapor outlet and a liquid product outlet, said expansion vessel effecting further cooling and condensing of the cooled compressed vapor stream from the last stage condensing means by Joule-Thompson expansion thereof, vent means connected to the vapor outlet of said expansion vessel for discharging to atmosphere the uncondensed vapor stream therefrom, and a liquid product reservoir connected to the liquid product outlets of said condensing means of each of said stages and said expansion vessel for receiving therefrom the recovered liquid product.

6. The apparatus set forth in claim 5, wherein the last stage compressor effects compression of the vapor stream to approximately 275 p.s.i.a. at approximately 230° F., said expansion vessel effecting expansion of the compressed vapor stream to approximately 5 p.s.i.g.

7. A method for recovering volatile liquids from an input vapor stream, said method comprising steps of compressing the input vapor stream in a plurality of compression stages, condensing the compressed vapor stream by cooling it in a plurality of condensing stages alternating with said compression stages, expanding the vapor stream from the last condensing stage by Joule-Thompson expansion for further cooling and condensing thereof, venting to atmosphere the uncondensed expanded vapors, and collecting the liquid product recovered in each of the condensing stages and the expansion step.

8. The method of claim 7, wherein the Joule-Thompson expansion of the cooled compressed vapor stream effects reduction of the pressure thereof to approximately 5 p.s.i.g.

9. The method set forth in claim 7, wherein the input vapor stream includes a mixture of combustible hydrocarbons, and further including the step of correcting the concentration of the hydrocarbons of the input vapor stream to a non-explosive level.

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