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(54) **DEHYDROGENATION SEPARATION UNIT WITH MIXED REFRIGERANT COOLING**

(71) Applicant: **Chart Energy & Chemicals, Inc.**, Ball Ground, GA (US)

(72) Inventors: **Douglas A. Ducote, Jr.**, The Woodlands, TX (US); **Brent A. Heyrman**, The Woodlands, TX (US); **Timothy P. Gushanas**, Pearland, TX (US); **Richard Hopewell**, Medfield, MA (US)

(73) Assignee: **Chart Energy & Chemicals, Inc.**, Ball Ground, GA (US)

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F25J 1/02 (2006.01)
F25J 1/00 (2006.01)

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(Continued)

(58) **Field of Classification Search**
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(Continued)

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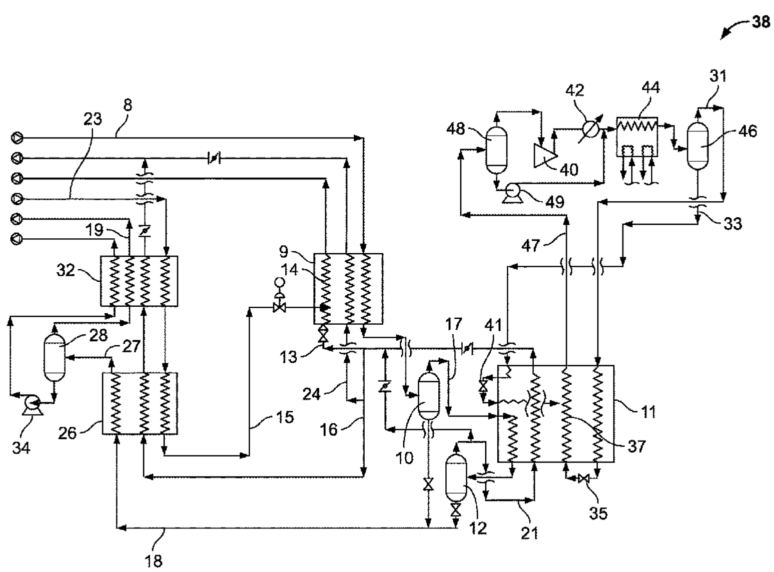
Primary Examiner — Brian M King
(74) *Attorney, Agent, or Firm* — Cook Alex Ltd.

(57) **ABSTRACT**

A main heat exchanger receives and partially condenses an effluent fluid stream so that a mixed phase effluent stream is formed. A primary separation device receives and separates the mixed phase effluent stream into a primary vapor stream including hydrogen and a primary liquid stream including an olefinic hydrocarbon. The main heat exchanger receives and warms at least a portion of the primary vapor stream to provide refrigeration for partially condensing the effluent fluid stream. The main heat exchanger also receives, warms and partially vaporizes the primary liquid stream. A mixed refrigerant compression system also provides refrigeration in the main heat exchanger.

26 Claims, 11 Drawing Sheets



Related U.S. Application Data

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(52) **U.S. Cl.**
CPC *F25J 2220/62* (2013.01); *F25J 2220/64* (2013.01); *F25J 2270/66* (2013.01)

(58) **Field of Classification Search**
CPC F25J 3/0252; F25J 2205/40; F25J 2205/82; F25J 2210/06; F25J 2220/42
See application file for complete search history.

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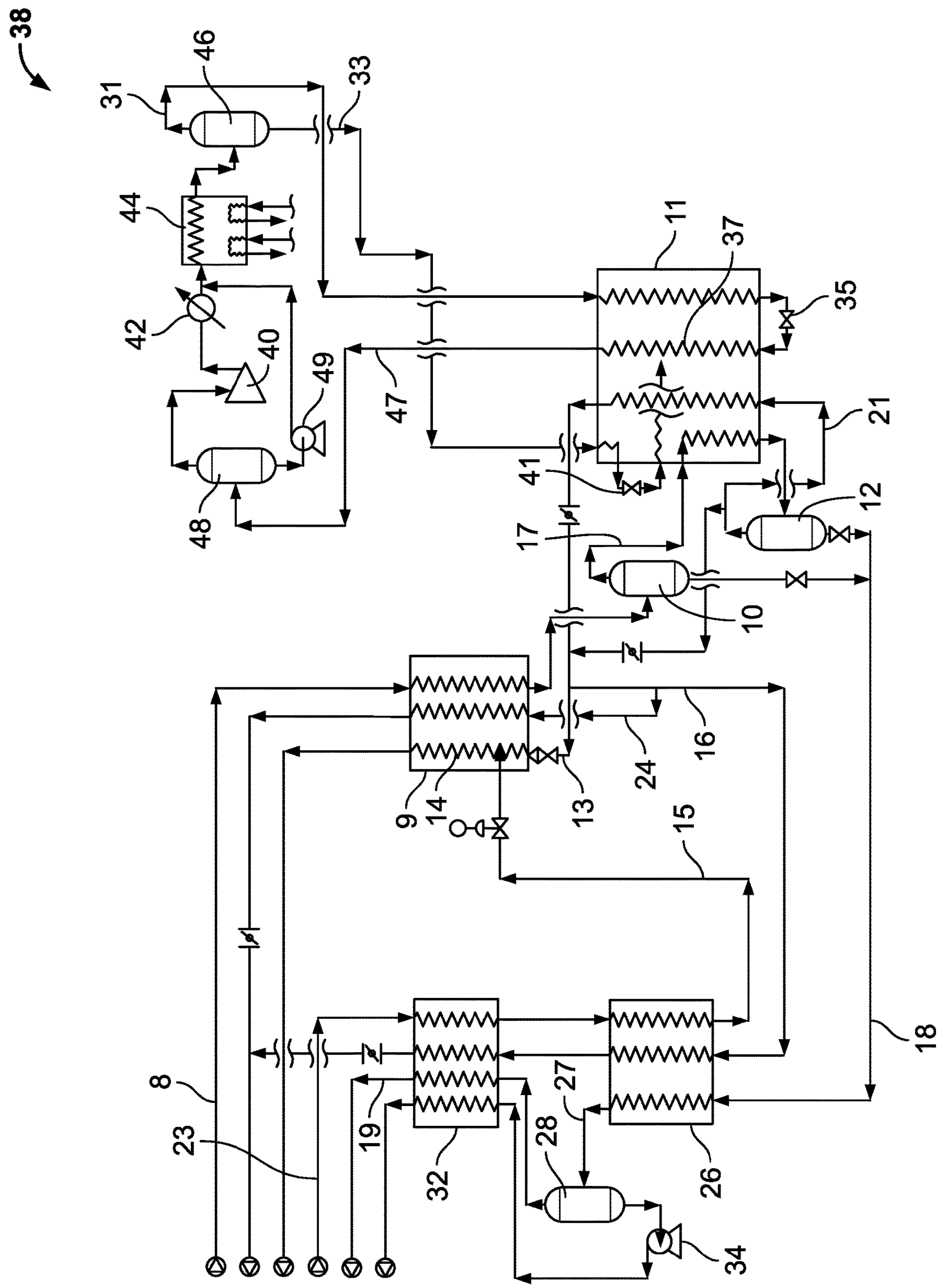
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FIG. 1

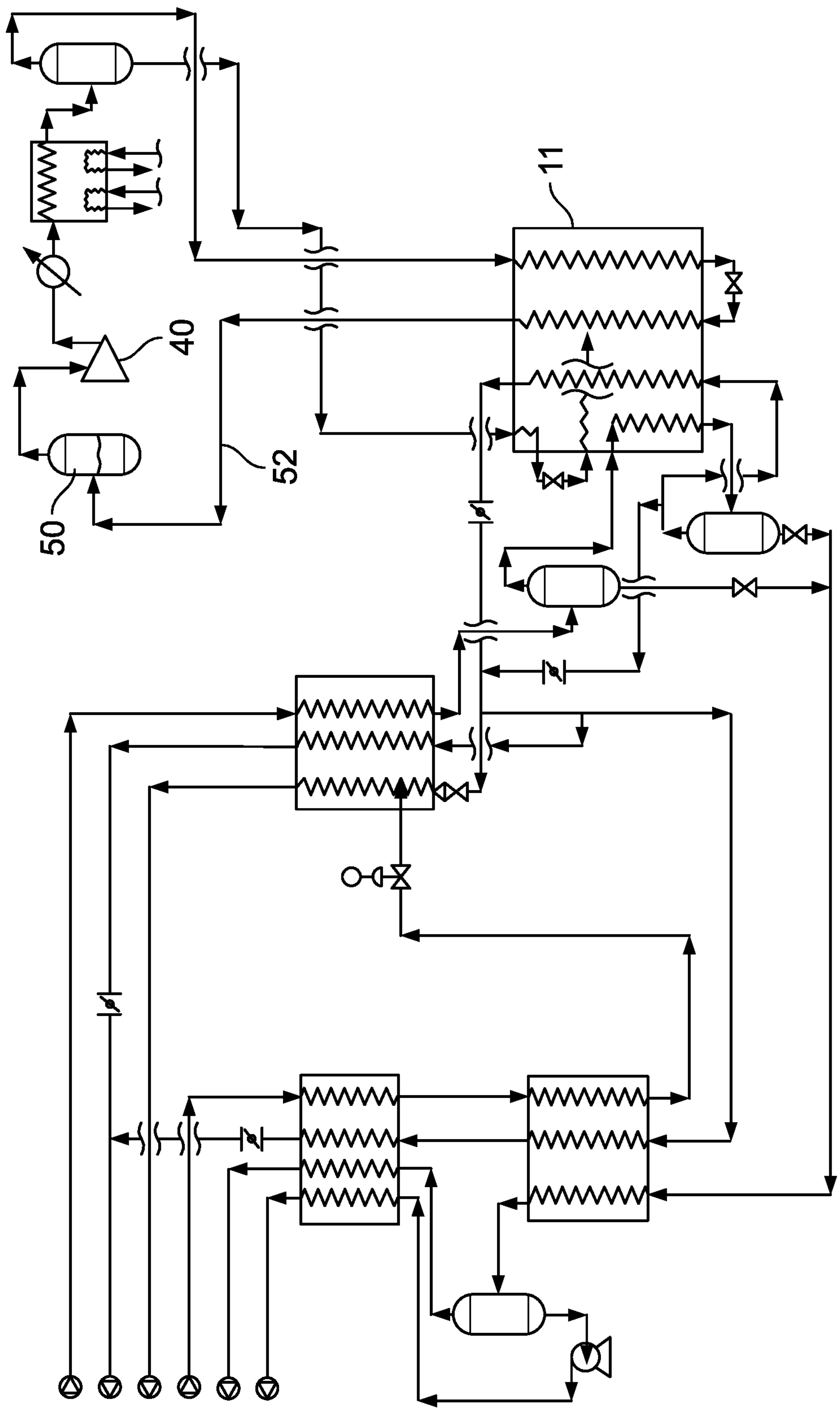

FIG. 2

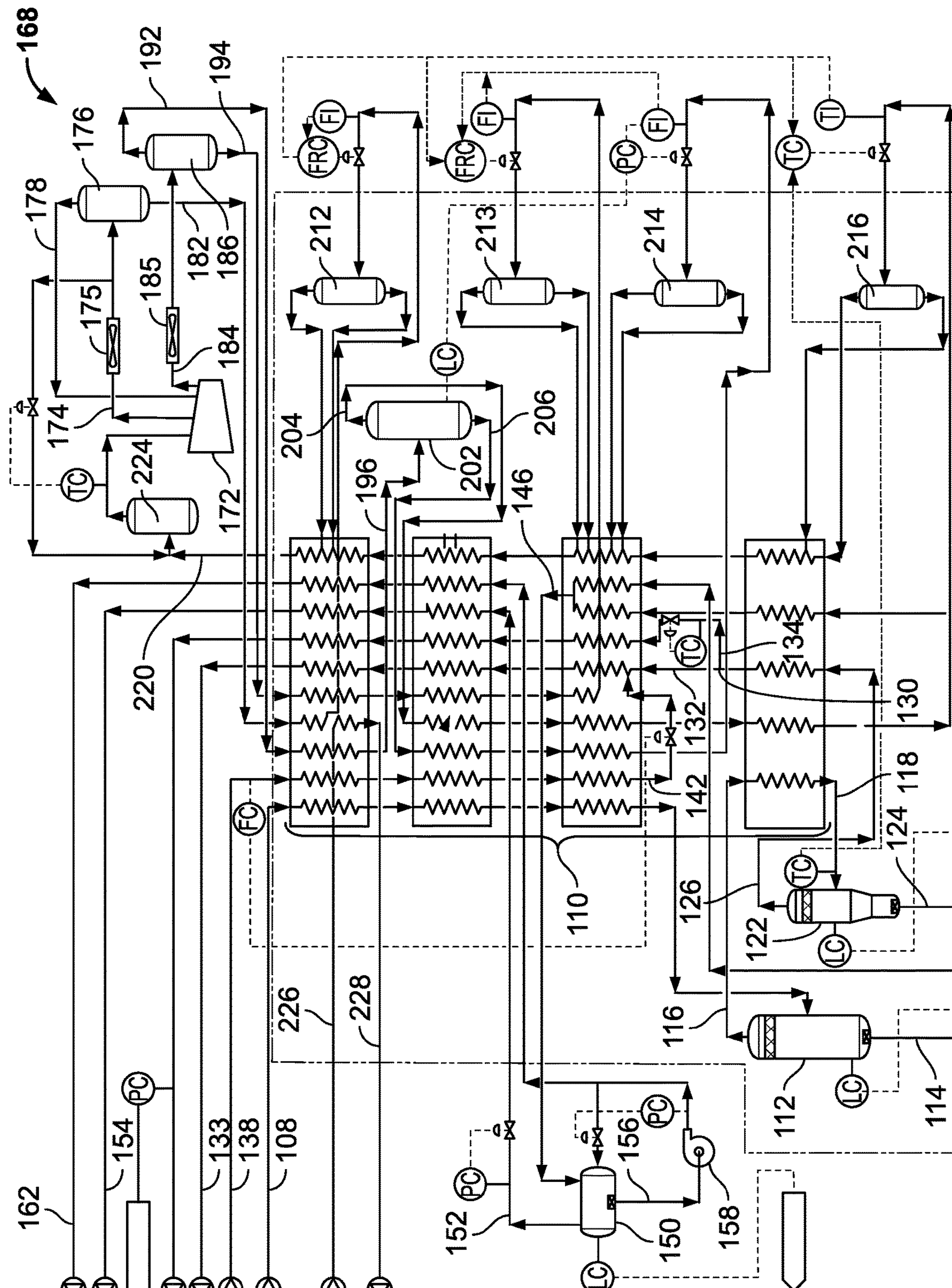
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FIG. 3

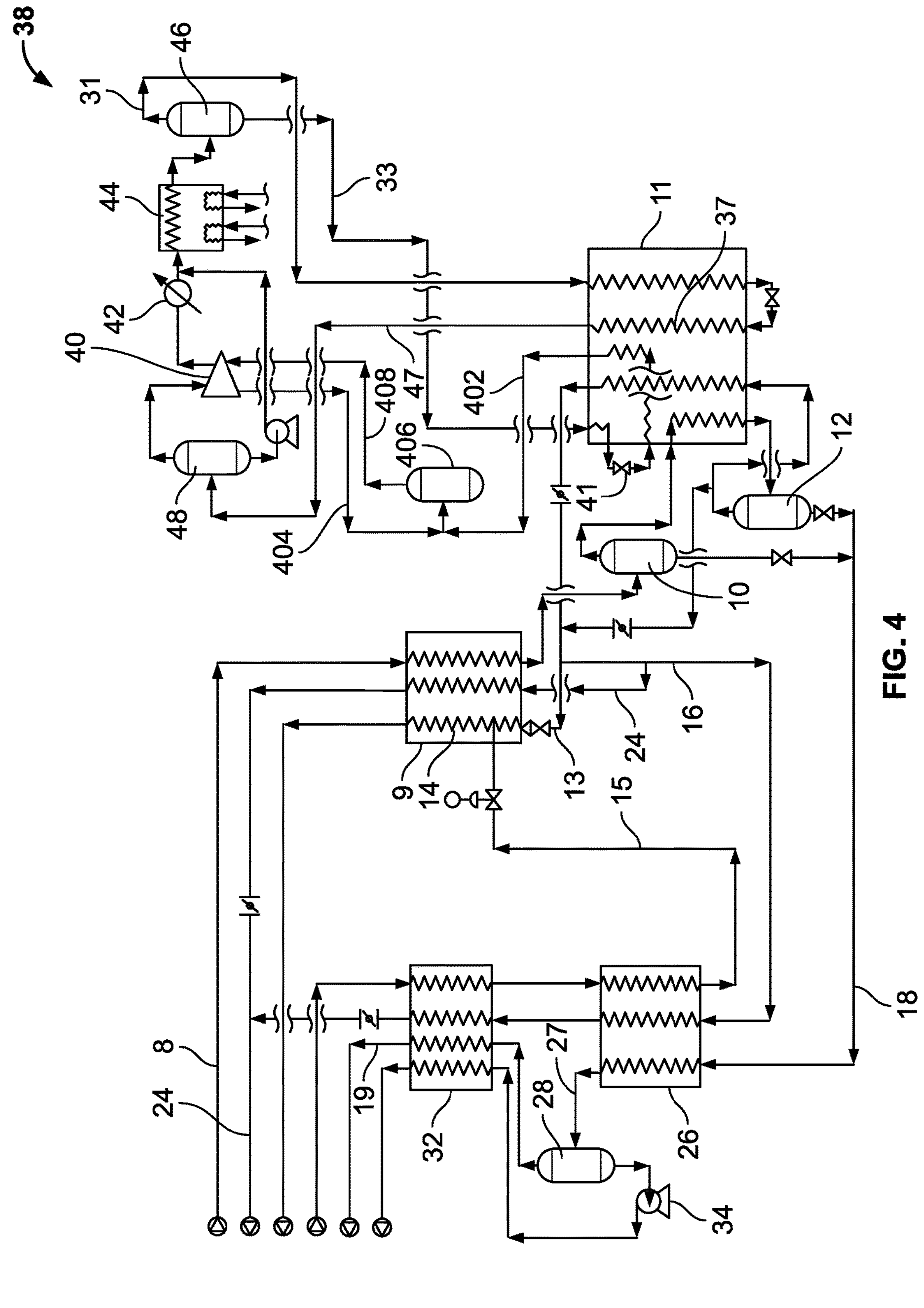
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FIG. 4

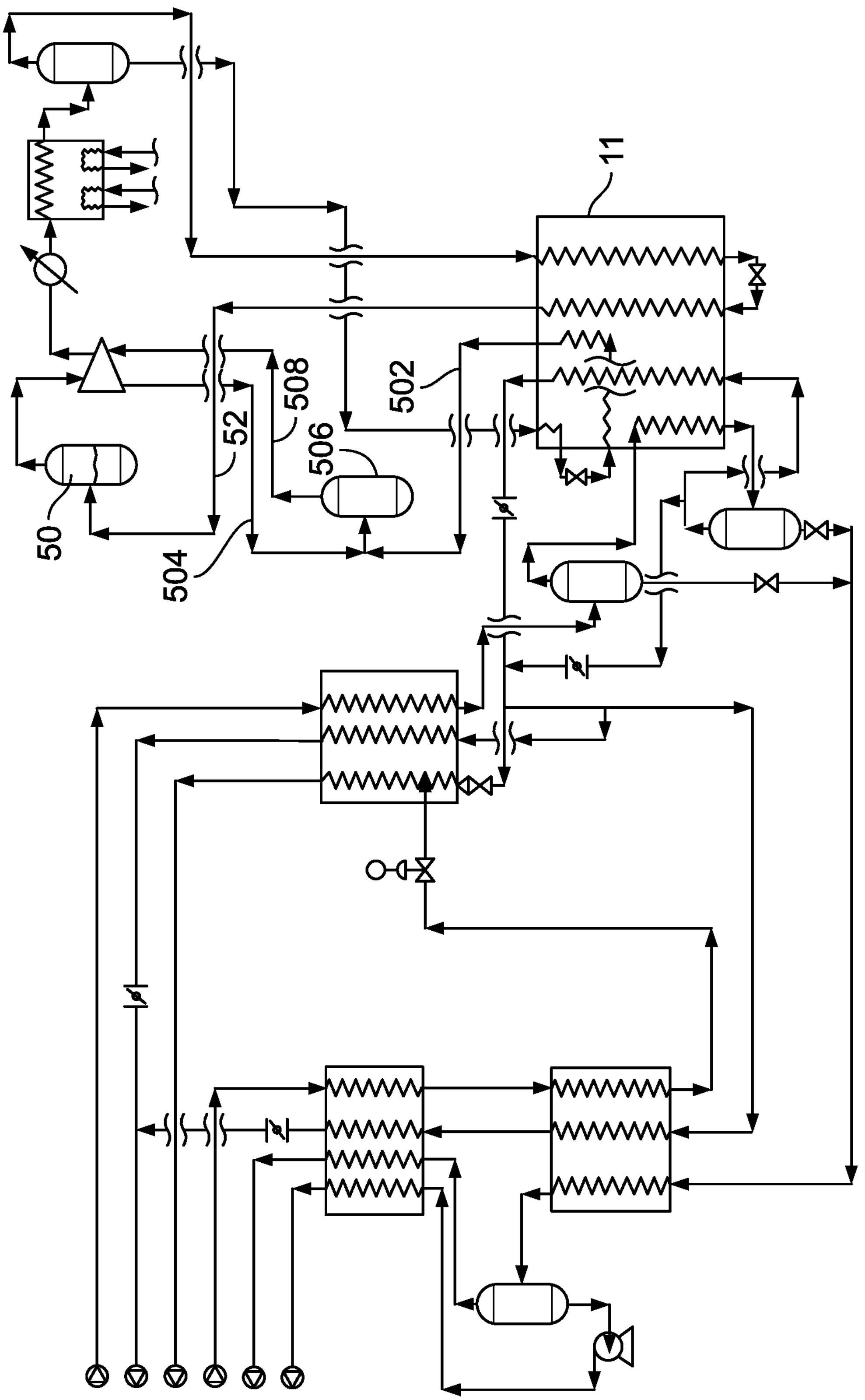

FIG. 5

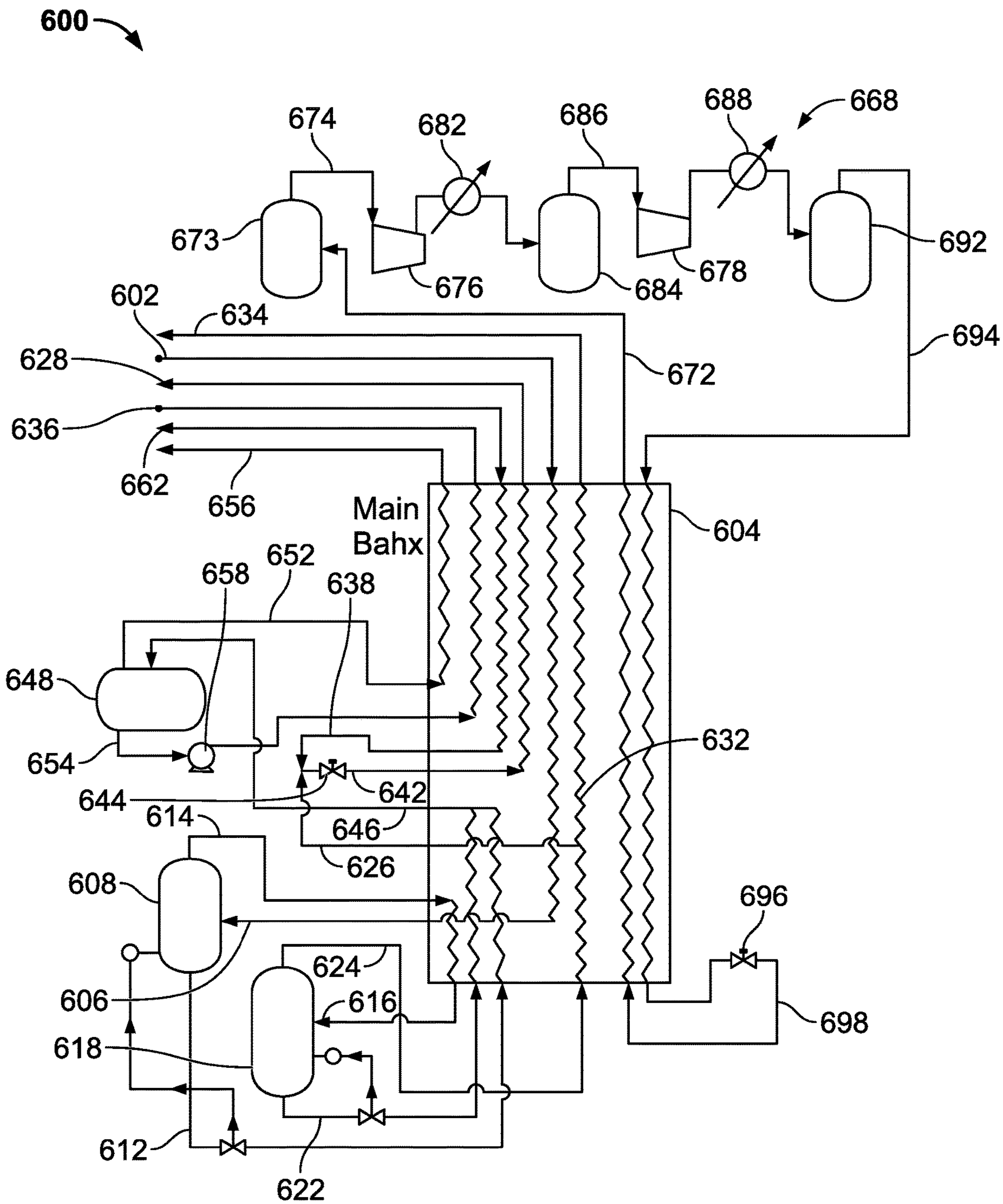
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FIG. 6

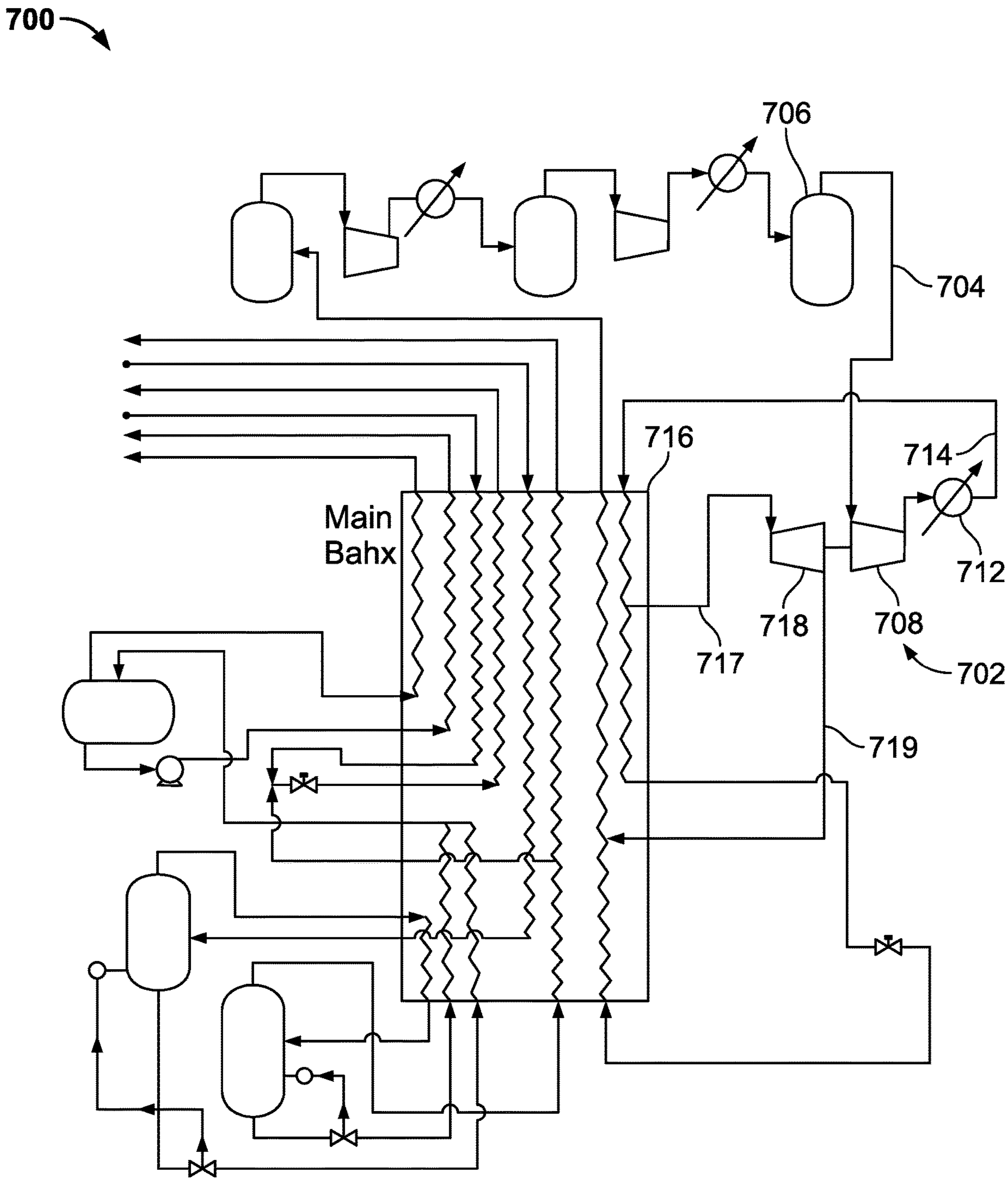

FIG. 7

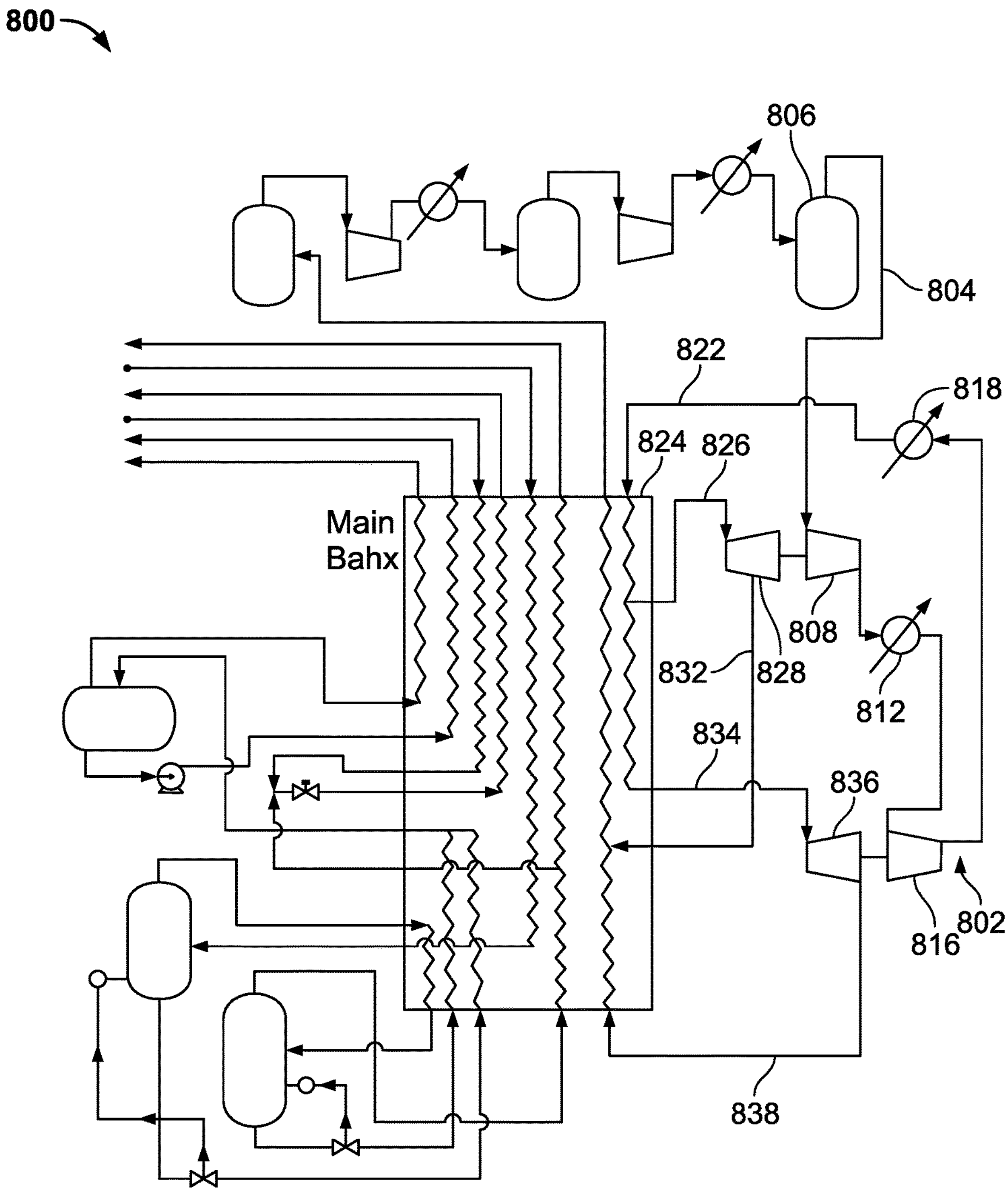
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FIG. 8

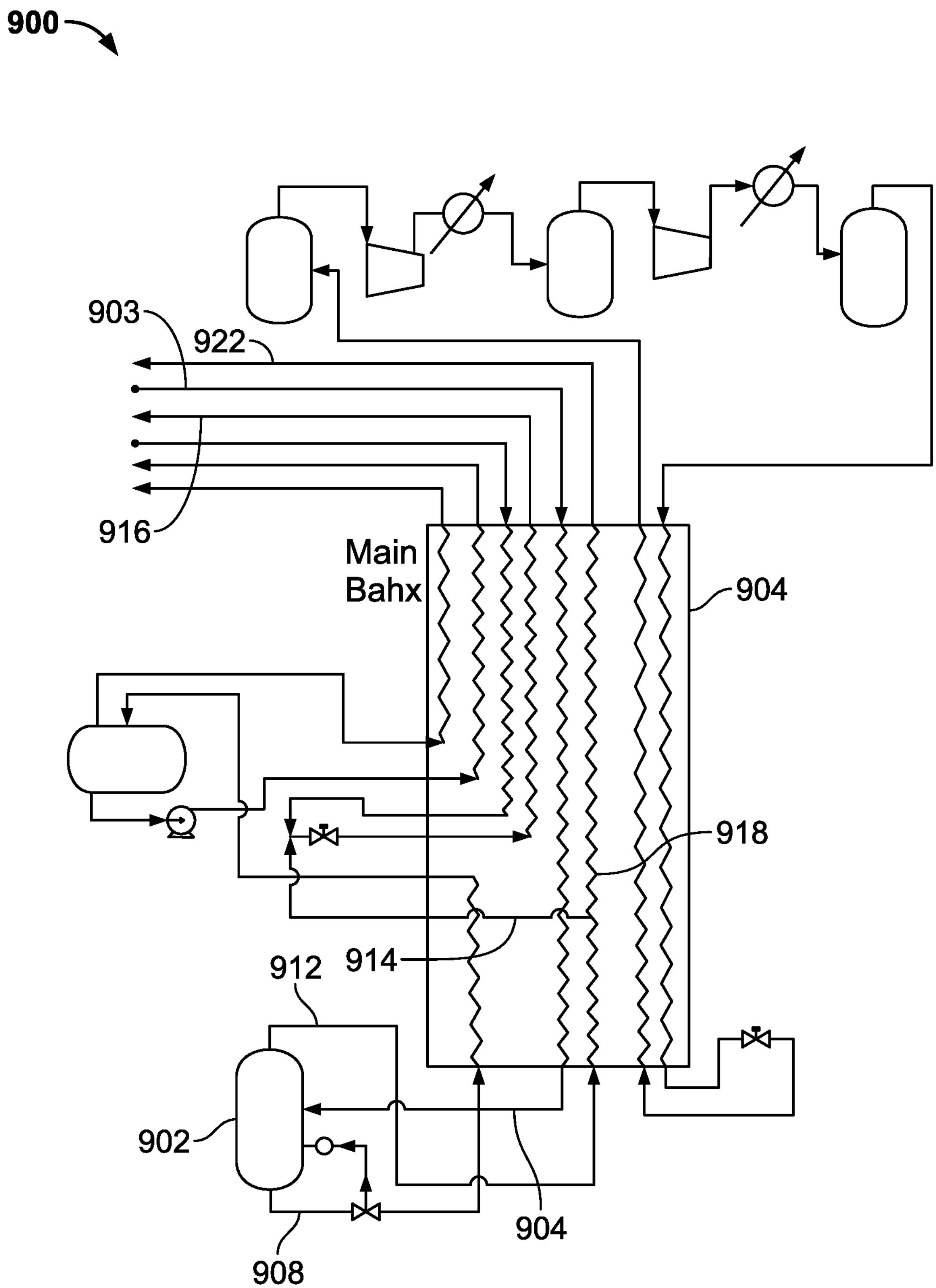

FIG. 9

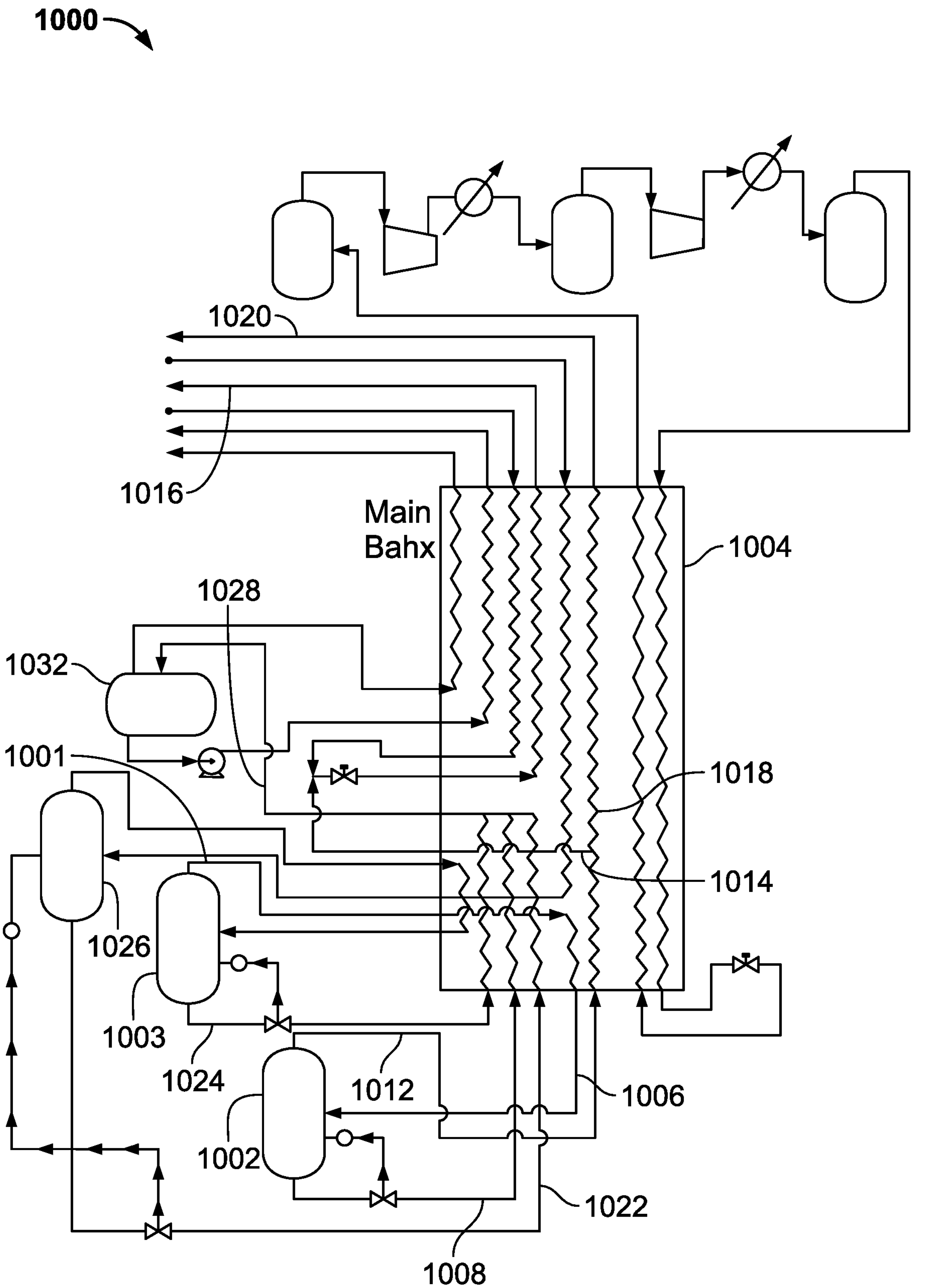
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FIG. 10

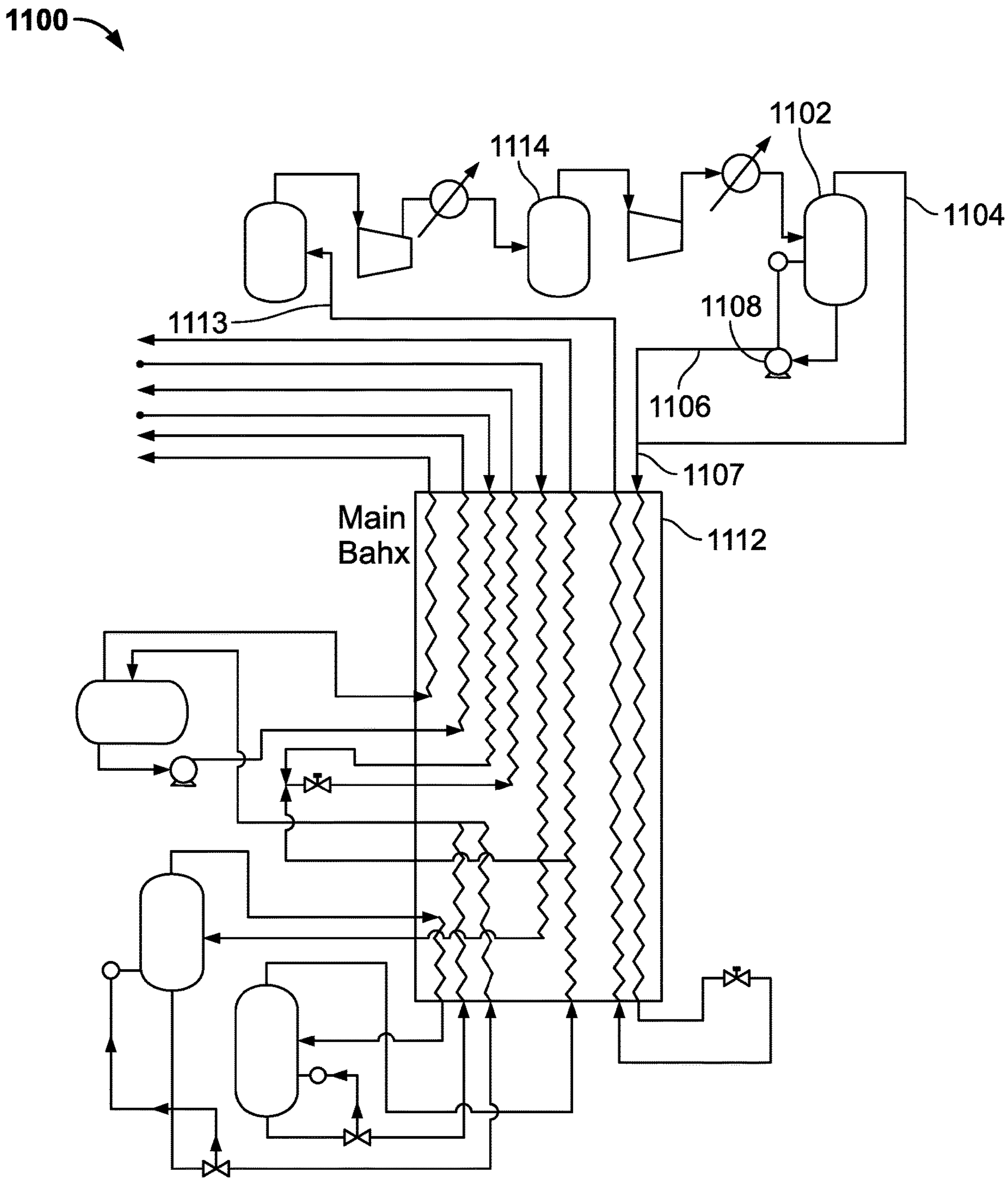

FIG. 11

DEHYDROGENATION SEPARATION UNIT WITH MIXED REFRIGERANT COOLING

CLAIM OF PRIORITY

This application is a Continuation-in-Part of U.S. patent application Ser. No. 16/595,866, filed Oct. 8, 2019, which claims the benefit of U.S. Provisional Application No. 62/743,263, filed Oct. 9, 2018, the contents of both of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Propane Dehydrogenation (PDH) Separation Systems are known in the art. An example of such a system is described in commonly owned U.S. Pat. No. 6,333,445, the contents of which are incorporated herein by reference.

The current designs for PDH separation systems requires that the Reactor Effluent vapor stream be compressed to high pressure (~12 Barg) using the Reactor Effluent Compressor and then de-pressurized using two, generator-loaded or compressor-loaded, cryogenic turbo-expanders to provide the refrigeration required for the separation and recovery of the liquid olefin product.

Disadvantages of such prior art systems include power consumption of the overall process, the added cost and maintenance requirements of the turbo-expander/generator (or compressor) sets, the high required Reactor Effluent Compressor discharge pressure (which increases capital and operating costs) and lack of flexibility to significantly adjust the olefin and hydrogen separation temperatures.

SUMMARY

There are several aspects of the present subject matter which may be embodied separately or together in the devices and systems described and claimed below. These aspects may be employed alone or in combination with other aspects of the subject matter described herein, and the description of these aspects together is not intended to preclude the use of these aspects separately or the claiming of such aspects separately or in different combinations as set forth in the claims appended hereto.

In one aspect, a system for separating olefinic hydrocarbon and hydrogen in an effluent fluid stream from a dehydrogenation reactor includes a main heat exchanger configured to receive and partially condense the effluent fluid stream so that a mixed phase effluent stream is formed. A primary separation device receives and separates the mixed phase effluent stream into a primary vapor stream including hydrogen and a primary liquid stream including an olefinic hydrocarbon. The main heat exchanger receives and warms at least a portion of the primary vapor stream to provide refrigeration for partially condensing the effluent fluid stream. The main heat exchanger also receives, warms and partially vaporizes the primary liquid stream. A mixed or single component refrigerant compression system provides refrigeration in the main heat exchanger.

In another aspect, a method for separating olefinic hydrocarbon and hydrogen in an effluent fluid stream from a dehydrogenation reactor comprising the steps of partially condensing the effluent fluid stream so that a mixed phase effluent stream is formed, separating the mixed phase effluent stream into a primary vapor stream and a primary liquid product stream, warming at least a portion of the primary vapor stream to provide refrigeration for partially condensing the effluent fluid stream and partially vaporizing the primary liquid product stream.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic of a first embodiment of the system of the disclosure;

FIG. **2** is a schematic of a second embodiment of the system of the disclosure;

FIG. **3** is a schematic of a third embodiment of the system of the disclosure;

FIG. **4** is a schematic of a fourth embodiment of the system of the disclosure;

FIG. **5** is a schematic of a fifth embodiment of the system of the disclosure;

FIG. **6** is a schematic of a sixth embodiment of the system of the disclosure;

FIG. **7** is a schematic of a seventh embodiment of the system of the disclosure;

FIG. **8** is a schematic of an eighth embodiment of the system of the disclosure;

FIG. **9** is a schematic of a ninth embodiment of the system of the disclosure;

FIG. **10** is a schematic of a tenth embodiment of the system of the disclosure;

FIG. **11** is a schematic of an eleventh embodiment of the system of the disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

The present disclosure is directed to a dehydrogenation separation unit that here uses a Mixed Refrigerant (MR) system, consisting of a MR compressor with heat exchangers and drums (or other separation devices), to provide the refrigeration required for the separation and recovery of the liquid olefin product. As examples only, the MR system can either use a single mixed refrigerant system or be a single mixed refrigerant system that is pre-cooled using a second refrigerant. As examples only, the MR mixture may be made up substantially of methane, ethylene and/or ethane. While embodiments of the disclosure are described below as using a MR system, a single component refrigerant (such as nitrogen) may alternatively be used.

While achieving the same product recovery as prior art systems, some of the benefits may include: 1) the power consumption of the overall process is lower, 2) both turbo-expander/generator (or compressor) sets are eliminated, 3) the required Reactor Effluent Compressor discharge pressure is significantly reduced, which saves capital and operating costs, 4) the operation, maintenance and reliability of the Separation System is improved with the MR process compared to the turbo-expander process, 5) the MR process allows for a more robust and forgiving design of the main Feed Heat Exchanger, 6) the MR process provides an independent means to adjust the refrigeration level for the Separation System without impacting the Recycle Effluent Compressor.

Since propylene refrigeration is used in many PDH facilities, the MR process described herein uses propylene refrigeration to pre-cool the MR refrigerant and reduce the MR compressor power consumption. Pre-cooling also allows the MR component mix to be simplified, requiring only methane, ethylene (or ethane) and propylene (or propane), with ethylene and propylene being preferred. Without C_4 or C_5 in the MR mix, the possibility of reactor catalyst contamination is reduced.

While the explanation of the invention presented below is specific to a Propane Dehydrogenation Unit, the same process may be employed for Butane Dehydrogenation. In addition, when the term "drum" is used below, it is to be understood that any alternative separation device known in the art may be used instead.

With reference to FIG. **1**, Reactor Effluent Gas is compressed in the REC compressor to ~7.2 Barg and the heat of compression is removed prior to entering the cryogenic Separation System as the Cold Box Vapor Feed 8. The gas is sent to the Cold Box Feed Heat Exchanger **9**, where it is partially condensed and then flows to an outlet Primary Separator **10**. Vapor and liquid are separated, with the liquid stream containing a portion of the C_3 olefin product and a vapor stream **17** containing hydrogen and the remaining olefin product.

This vapor stream **17** flows to the Mixed Refrigerant Heat Exchanger **11** (MR exchanger), where it is further cooled to the required temperature and partially condensed to achieve the desired product recovery. The partially condensed stream flows to the Secondary Separator **12** and is separated into a liquid olefin product and a hydrogen rich vapor stream **21**. The hydrogen rich stream is reheated in the MR exchanger and is then divided into two streams—Recycle Gas **13** (which is the hydrogen required for the Combined Reactor Feed) and Net Vapor, which is further divided into streams **16** and **24**, which is the balance of the hydrogen stream and which will be exported from the Separation System.

Portion **16** of the Net Vapor stream is reheated and refrigeration recovered in a Fresh Feed Heat Exchanger (having cold end **26** and warm end **32**). The liquid product streams (from the Primary and Secondary Separators **10** and **12**) are combined to form combined liquid product stream **18** and flow to the Fresh Feed Heat Exchanger **26**, **32**.

The Cold Box Vapor Feed **8** ("Reactor Effluent") is cooled firstly in the Cold Box Feed Exchanger **9**. It is cooled primarily by the Combined Reactor Feed **14** and secondarily by a portion **24** of the export Net Vapor Product. The Combined Reactor Feed **14** provides the bulk of the refrigeration, by combining the Recycle Gas stream **13** with a cold Fresh Feed liquid stream **15** (such as propane or n-butane) and vaporizing the combined stream in the Cold Box Feed Heat Exchanger **9**. The cold Fresh Feed liquid stream **15** is formed from a Fresh Feed inlet stream **23** that is sub-cooled in the Fresh Feed Heat Exchanger at **26** and **32**, before entering the Cold Box Feed Heat Exchanger **9**. Refrigeration for the Fresh Feed is provided by recovering the cold from the C3 olefin product **18** and from a portion of the Net Vapor Product **16**.

Flash Gas (recycle) **19** is produced by partially warming the separator liquids in the cold-end section **26** of the Fresh Feed Exchanger. The resulting vapor-liquid mix **27** is separated in the Liquid Product Tank **28**. The vapor from tank **28** is warmed in the warm-end section **32** of the Fresh Feed Exchanger and the Flash Gas **19** is recycled to the suction of the upstream Reactor Effluent Compressor (see FIG. 1 of U.S. Pat. No. 6,333,445). The Liquid Product from tank **28** is pumped via pump **34** and additional cold is recovered in the warm-end section **32** of the Fresh Feed Exchanger.

The overall refrigeration balance for the Separation System is provided by the Mixed Refrigerant (MR) compression system, indicated in general at **38** in FIG. **1**, via the final cooling in the MR Exchanger (MRHX) **11**. A C_3 pre-cooled MR system is described here; however, a single MR system may also be used. FIG. **1** shows a single-stage MR Compressor **40**, followed by an air or water cooler **42**, and then followed by a C_3 (propylene) pre-cooler **44**. The pre-cooler can utilize as many stages of refrigeration as required to obtain the desired temperature, two stages are shown for simplicity. The MR refrigerant is separated via separator **46** into vapor and liquid phase streams **31** and **33**, respectively, and sent to the MRHX **11**. The MR vapor stream **31** is cooled and condensed in the MRHX **11** and is flashed at **35** to create the coldest refrigerant for the process and the low pressure refrigerant stream **37**. The MR liquid stream **33** is also cooled in the MRHX, flashed at **41** and sent to the low pressure refrigerant stream **37**, where it joins and is mixed with the low pressure refrigerant stream **37** at a warmer temperature. The common refrigerant return stream **47** exits the MRHX **11** as a mixed phase vapor/liquid stream. Before being compressed, the vapor and liquid are separated via separator **48**. The liquid is pumped via pump **49** to higher pressure and the vapor is compressed at compressor **40** to the required discharge pressure. The system uses an MR composition suitable for the specific design conditions.

The heat exchangers illustrated in FIG. **1** and described above may be incorporated or integrated into a single main heat exchanger.

With reference to FIG. **2**, in a second embodiment of the system, the suction drum to the MR Compressor can also be designed to act as a heavy component refrigerant accumulator. The MR system may be operated with excess heavy components (such as C_3, C_4 or C_5) in the refrigerant and with the resulting MR being, at least temporarily, a 2-phase stream **52** exiting the exchanger **11**. These excess heavy components are separated in the compressor suction drum **50** and remain in the drum. The refrigerant vapor, which flows to the MR Compressor **40**, is now at its dew point and the system operates automatically at the dew point condition. As "make up" refrigerant is added to the system, the accumulated heavy components will then equilibrate with light components to the dew point at suction pressure and temperature. If needed, the heavy components can be preferentially removed from the refrigeration system at the suction accumulator or preferentially added and retained in the suction drum.

In a third embodiment of the system, illustrated in FIG. **3**, Reactor Effluent Gas is compressed in the REC compressor to ~7.2 Barg and the heat of compression is removed via ambient exchanger (air or water) cooling prior to entering the Cryogenic Separation System as the Cold Box Vapor Feed **108**. The gas is sent to the Main Heat Exchanger **110**, where it is cooled and partially condensed and then flows to the Primary Separator **112**. Vapor and liquid are separated, with the liquid stream **114** containing a portion of the C3 olefin product and the vapor stream **116** containing hydrogen and the remaining olefin product. This vapor stream flows back to the Main Heat Exchanger **110**, where it is further cooled and partially condensed to achieve the desired product recovery. The partially condensed stream **118** flows to the Secondary Separator **122** and is separated into a liquid olefin product **124** and a hydrogen rich stream **126**. The hydrogen rich vapor stream is reheated in the Main Heat Exchanger and is then divided at **130** into two streams—Recycle Gas **132** (which is the hydrogen required for the Combined Reactor Feed **133**) and Net Vapor **134** (which is the remaining balance of the hydrogen stream and will be exported from the Separation System). The Net Vapor stream is reheated and the refrigeration is recovered in the Main Heat Exchanger.

Warm fresh propane feed **138** is sent to the Main Heat Exchanger **110**, and cooled to approximately the same temperature as the Primary Separator **112**. The cooled fresh propane feed **142** is then mixed with the Recycle Gas **132** to form the Combined Reactor Feed **133**. This stream is reheated, and the refrigeration is recovered in the Main Heat Exchanger. This provides the majority of the refrigeration for the cryogenic separation system.

The liquid product streams **114** and **124** (from the Primary and Secondary Separators **112** and **122**) are fed to the Main Heat Exchanger **110** at an appropriate location relative to their respective temperature. The liquid product streams are heated, and partially vaporized. The liquid product streams exit the Main Heat Exchanger thru a common header to form liquid product stream **146**. This orientation of the liquid product streams improves efficiency, reduces piping complexity, and lowers the risk of freezing.

The partially vaporized mixed C3 liquid product stream **146** is sent to the Liquid Product Tank **150**. The vapor **152** from the Liquid Product Tank (Flash Gas) is heated in the Main Heat Exchanger and then recycled to the suction of the upstream Reactor Effluent Compressor as Flash Gas Stream **154**. The liquid **156** from the Liquid Product Tank (Liquid Product) is pumped via pump **158**, and then heated in the Main Heat Exchanger for additional energy recovery. The warmed Liquid Product exits the Main Heat Exchanger as C3 Product stream **162**.

The overall refrigeration balance for the Separation System is provided by a Mixed Refrigerant (MR) system, indicated in general at **168**. The embodiment of FIG. **3** uses a two-stage MR Compressor **172**, with air or water intercooling and discharge cooling. The discharge **174** of the first MR Compressor Stage is partially condensed at **175**, and sent to the MR Interstage Drum **176**. The vapor **178** is sent to the Second MR Compressor Stage, and the liquid **182** is sent to the Main Heat Exchanger **110**. The second MR Compressor Stage Discharge **184** is partially condensed at **185**, and separated in the MR Accumulator **186**. The MR Accumulator Vapor **192** and Liquid **194** are sent to the Main Heat Exchanger **110**. The MR Accumulator Vapor is partially condensed in the Main Heat Exchanger, and the resulting stream **196** is sent to a Cold Vapor Separator Drum **202** in order to improve the process efficiency. The Cold Vapor Separator Vapor **204**, Cold Vapor Separator Liquid **206**, MR Accumulator Liquid **194**, and MR Interstage Liquid **182** are all condensed and subcooled in the Main Heat Exchanger **110**. All of these streams exit the exchanger, are flashed across JT Valves (as an example only), and the resulting mixed phase streams separated and sent back to the Main Heat Exchanger via standpipes **212**, **213**, **214** and **216** at the appropriate temperatures to provide the refrigeration balance required for the separation system. Additional details regarding operation of the MR system **168** are available in commonly owned U.S. Pat. No. 10,480,851 to Ducote, Jr. et al., the entire contents of both of which are hereby incorporated by reference.

The flashed low pressure MR streams are mixed within the Main Heat Exchanger and exit as a single superheated vapor stream **220** which is sent to the MR Compressor Suction Drum **224**. The system uses an MR composition suitable for the specific design conditions.

The MR system allows for the integration of additional heat transfer services that are at ambient temperature or cooler into the Main Heat Exchanger. As an example, FIG. **3** shows the integration of the Deethanizer Rectifier Condenser (deethanizer overhead inlet stream **226** and deethanizer overhead outlet stream **228**) into the Main Heat Exchanger. This increases the size of the MR system due to the additional refrigeration duty that is required, but removes the need for a separate C3 refrigeration system for the Deethanizer Rectifier Condenser service which reduces overall equipment count for the dehydrogenation plant.

In a fourth embodiment of the system of the disclosure, illustrated in FIG. **4**, an interstage separation device **406** is added to the system of FIG. **1**. A mixed phase MR stream **402**, from a secondary refrigeration passage of the MR heat exchanger **11** (which receives a stream that originated as the liquid outlet of separator **46** prior to entering the MR heat exchanger), is combined with a mixed phase MR stream **404** from the outlet of the first stage of compressor **40**. The combined stream is directed to the inlet of separation device **406** and the resulting vapor stream **408** is directed into the inlet of the second stage of compressor **40**. The outlet of the second stage of compressor **40** is directed to cooling devices **42** and **44**, and processing of the MR stream then continues as described above with respect to FIG. **1**, with the exception that stream **33**, after cooling in mixed refrigerant heat exchanger **11** and flashing via valve **41**, does not join with the low pressure refrigerant stream **37**. In alternative embodiments, however, a portion of the stream **33**, after cooling in mixed refrigerant heat exchanger **11** and flashing via valve **41**, may join the low pressure refrigerant stream **37**.

In a fifth embodiment of the system of the disclosure, illustrated in FIG. **5**, an interstage separation device **506** is added to the system of FIG. **2**. A mixed phase MR stream **502**, from MR heat exchanger **11**, is combined with a mixed phase MR stream **504** from the outlet of the first stage of a MR compressor. The combined stream is directed to the inlet of separation device **506** and the resulting vapor stream **508** is directed into the inlet of the second stage of the MR compressor. The outlet of the second stage of the MR compressor is directed to one or more cooling devices, and processing of the MR stream then continues as described above with respect to FIG. **4**.

The referenced heat exchangers in the description may be combined, with the use of multi-stream heat exchangers, such as Brazed Aluminum Plate Fin heat exchangers, to simplify the piping design, plant layout or performance. Examples of combinations may be the Fresh Feed-1 Exchanger with the Fresh Feed-2 Exchangers or both Fresh Feed Exchangers with the Cold Box Feed Exchanger. Other combinations may also be desirable.

In a sixth embodiment of the system of the disclosure, indicated in general at **600** in FIG. **6**, a reactor effluent gas stream **602** is directed to a main heat exchanger **604**, where it is cooled and partially condensed. As examples only (for the embodiment of FIG. **6** and other embodiments), the reactor effluent gas stream **602** may be a mixture of propylene, propane and hydrogen, a mixture of isobutylene, isobutane and hydrogen or a mixture of propylene, isobutylene, propane, isobutane and hydrogen. The resulting mixed-phase stream **606** flows to a primary separator **608** wherein vapor and liquid are separated, with a resulting liquid stream **612** containing a portion of a C3 olefin product and a resulting vapor stream **614** containing hydrogen and the remaining olefin product. Vapor stream **614** flows back to the main heat exchanger **604**, where it is further cooled and partially condensed. The resulting partially condensed stream **616** flows to the secondary separator **618** and is separated into a liquid olefin product **622** and a hydrogen rich vapor stream **624**. The hydrogen rich vapor stream **624** is reheated in the main heat exchanger and is then divided into two streams—recycle gas stream **626** (which is the hydrogen required for the combined reactor feed stream **628**) and net vapor stream **632** (which is the remaining balance of the hydrogen stream). The net vapor stream is reheated in the main heat exchanger **604**, so that the refrigeration is recovered, and directed out of the main heat exchanger and system as stream **634**.

Warm fresh propane feed **636** is sent to the main heat exchanger **604**, and cooled to approximately the same temperature as the primary separator **608**. The cooled fresh propane feed **638** is then combined or mixed with the recycle gas **626** and the combined stream is expanded via expansion device **644** to form stream **642**. Stream **642** is reheated so that the refrigeration is recovered in the main heat exchanger. This provides the majority of the refrigeration for the cryogenic separation system. The resulting reheated stream exits the main heat exchanger and separation system as combined reactor feed stream **628**.

The liquid product streams **612** and **622** (from the primary and secondary separators **608** and **618**) are fed to the main heat exchanger **60** wherein they are heated, partially vaporized and combined. The resulting mixed phase product stream **646** exits the main heat exchanger and is directed to a product tank **648** so that product vapor stream **652** and product liquid stream **654** are produced.

The vapor **652** from the product tank **648** (flash gas) is heated in the main heat exchanger and then exits the separation system as flash gas stream **656**. The liquid stream **654** from the product tank is pumped via pump **658** and then heated in the main heat exchanger for additional refrigeration recovery. The warmed liquid exits the main heat exchanger as a product stream **662**.

The overall refrigeration balance for the separation system **600** of FIG. **6** is provided by a mixed refrigerant system, indicated in general at **668**. Mixed refrigerant (MR) exits the main heat exchanger **604** as stream **672** after providing cooling therein. This stream is received by a separation device such as suction drum **673** so that any liquid remaining in stream **672** is removed before vapor MR stream **674** is provided to a first MR compressor stage **676**. The suction drum **673** may optionally be provided with a liquid outlet leading to a pump so that liquid from the suction drum **673** may be pumped down stream to the discharge pressure of compressor stage **676**, as illustrated in the embodiment of FIG. **1** (where the pump is illustrated at **49**).

While the embodiment of FIG. **6** uses a single two-stage MR compressor to provide first (**676**) and second (**678**) compressor stages, two separate compressors may instead be used to form the first and second stages. In addition, the mixed refrigerant system **668** may use an alternative number of compression and cooling stages with intercooling and discharge cooling.

The discharge of the first MR compressor stage **676** is cooled and partially condensed by after-cooler **682** (which, as an example only, may provide cooling via air or water), and sent to a separation device such as an MR interstage drum **684**. A vapor stream **686** exits the interstage drum **684** and is sent to a second MR compressor stage **678**. The discharge of second MR compressor stage **678** is cooled by after-cooler **688** with the resulting cooled vapor stream directed to a separation device such as discharge drum **692**.

The vapor stream **694** from the discharge drum **692** is sent to the main heat exchanger **604** where it is condensed and subcooled and then flashed across an expansion device **696** (such as a Joule-Thomson/JT valve or other type of expansion valve or device known in the art). The resulting mixed-phase stream **698** is directed to the main heat exchanger where it serves as the primary MR refrigeration stream in the main heat exchanger at the appropriate temperature to provide the refrigeration balance required for the separation system.

Precooling of the mixed refrigerant may be done within the core of the main heat exchanger **604** to eliminate the need for a separate propane or mechanical refrigeration system to cool the mixed refrigerant after the final stage of compression.

In the embodiment of FIG. **6**, preferably no liquids are produced at the suction drum **673**, the interstage drum **684** or the discharge drum **692**. This is due maintaining the mixed refrigerant below the dew point of the mixture during the compression cycle. By not producing liquids, liquids do not have to be pumped or handled in the process simplifying the process and decreasing the costs.

It is to be understood that, in the system of FIG. **6**, and the systems described below, that alternative types of separation devices known in the art may be substituted for each of the suction drum **673**, the interstage drum **684** and/or the discharge drum **692**.

In some applications, the mixed refrigerant composition of the system of FIG. **6** is primarily made up of methane, ethylene, and propylene. Ethane can be substituted for the ethylene and propane can be substituted for propylene. Refrigerants are generally readily available as part of the propylene dehydrogenation process as a by-product of the process, making them easy to source.

While the embodiment of FIG. **6** features a single main heat exchanger **604**, multiple heat exchangers may be used instead. Using a single heat exchanger, however, reduces equipment count and two-phase distribution concerns. In addition, having the ability to perform this process in a single heat exchanger provides for improved heat transfer between all streams in the process thereby improving efficiency.

Using a mixed refrigerant (instead of mechanical refrigeration) in the system of FIG. **6** may provide improved overall process efficiency, allow for colder separator temperatures, and independent temperature control. In addition, using a mixed refrigerant (instead of cascade refrigeration) may provide improved efficiency and allow for colder separator temperatures with significantly lower equipment counts.

In alternative embodiments compression in the system of FIG. **6** can be performed using a single stage process without intercooling.

In a seventh embodiment of the system of the disclosure, indicated in general at **700** in FIG. **7**, a first or "warm" turbo-expander, indicated in general at **702**, has been added to the system of FIG. **6**. More specifically, the vapor stream **704** exiting the discharge drum **706** enters a compressor **708**, where it is compressed. The compressed vapor stream exiting the compressor **708** is directed to after-cooler **712** (which, as examples only, may be air or water cooled) for cooling, and the resulting stream **714** is directed to the main heat exchanger **716** for further cooling. A compressed and cooled stream **717** branches off of stream **714** and exits the main heat exchanger **716**. Stream **717** enters turbine **718** and is expanded with the resulting cooled stream **719** directed to the primary MR refrigeration passage of the main heat exchanger.

As illustrated in FIG. **7**, the turbine **718** is mechanically linked to the compressor **708** so that the expansion energy recovered by the turbine **718** may be used to drive the compressor **708**. As a result, the turbo-expander recovers energy from the expansion process used to reduce the temperature of the refrigerant to provide an additional compression stage. In an alternative embodiment, the recovered expansion energy may instead be used to generate electricity or for another process.

The remaining components of the system of FIG. **7** operate in the same manner as those illustrated in, and described with respect to, FIG. **6**.

In an eighth embodiment of the system of the disclosure, indicated in general at **800** in FIG. **8**, a second or "cold" turbo-expander, indicated in general at **802**, has been added to the system of FIG. **7**. In this system, the vapor stream **804** exiting the discharge drum **806** enters a compressor **808** of a warm turbo-expander, where it is compressed. The compressed vapor stream exiting the compressor **808** is directed to after-cooler **812** (which, as examples only, may be air or water cooled) for cooling, and the resulting stream **814** is directed to the compressor **816** of the cold turbo-expander. The stream exiting compressor **816** is directed to after-cooler **818** (which, as examples only, may be air or water cooled) for cooling, and the resulting stream **822** is directed to the main heat exchanger **824** for further cooling. A first compressed and cooled stream **826** branches off of stream **822** and exits the main heat exchanger **824**. Stream **826** enters the turbine **828** of the warm turbo-expander and is expanded with the resulting cooled stream **832** directed to the primary MR refrigeration passage of the main heat exchanger. A second compressed and cooled stream **834** branches off of stream **822** and exits the main heat exchanger **824**. Stream **834** enters the turbine **836** of the cold turbo-expander and is expanded with the resulting cooled stream **838** directed to the primary MR refrigeration passage of the main heat exchanger.

In view of the above, the warm and cold turbo-expanders recover energy from expansion processes used to reduce the temperature of the refrigerant to provide additional compression stages. In alternative embodiment the recovered energy from either expansion or both expansions may be used to generate electricity or for other processes.

In the system of FIG. **8**, the refrigerant can be a mixed refrigerant or a single refrigerant, such as nitrogen. Nitrogen can also be part of a refrigerant mixture primary made up of nitrogen and hydrocarbons.

The cold turbo-expander **802** may be eliminated or bypassed using one or more bypass valves and/or bypass lines.

The remaining components of the system of FIG. **8** operate in the same manner as those illustrated in, and described with respect to, FIG. **6**.

In a ninth embodiment of the system of the disclosure, indicated in general at **900** in FIG. **9**, a single separation device or separator **902** may be used instead of the primary and secondary separators **608** and **618** of FIG. **6**.

In the system of FIG. **9**, as in the system of FIG. **6**, a reactor effluent gas stream **903** is directed to a main heat exchanger **904**, where it is cooled and partially condensed. The resulting mixed-phase stream **906** flows to a separator **902** wherein vapor and liquid are separated, with a resulting liquid stream **908** containing an olefin product and a resulting vapor stream **912** containing hydrogen. Vapor stream **912** flows back to the main heat exchanger **904**, where it is reheated and divided into two streams—recycle gas stream **914** (which is the hydrogen required for the combined reactor feed stream **916**) and net vapor stream **918** (which is the remaining balance of the hydrogen stream). The net vapor stream **918** is reheated in the main heat exchanger **904**, so that the refrigeration is recovered, and directed out of the main heat exchanger and system as stream **922**.

While using a single separator **902** reduces the pieces of equipment and lowers the capital costs, efficiency of the process may suffer.

The remaining components of the system of FIG. **9** operate in the same manner as those illustrated in, and described with respect to, FIG. **6**.

In a tenth embodiment of the system of the disclosure, indicated in general at **1000** in FIG. **10**, a tertiary separation device or separator **1002** has been added to the system of FIG. **6**. More specifically, in the embodiment of FIG. **10**, a vapor stream **1001** flows from the secondary separator **1003** into the main heat exchanger **1004**. The resulting mixed-phase stream **1006** flows to the tertiary separator **1002** wherein vapor and liquid are separated into a liquid olefin product **1008** and a hydrogen rich vapor stream **1012**. The hydrogen rich vapor stream **1012** is reheated in the main heat exchanger and is then divided into two streams—recycle gas stream **1014** (which is the hydrogen required for the combined reactor feed stream **1016**) and net vapor stream **1018** (which is the remaining balance of the hydrogen stream). The net vapor stream is reheated in the main heat exchanger **1014**, so that the refrigeration is recovered, and directed out of the main heat exchanger and system as stream **1020**.

The liquid product stream **1008** is combined with liquid product streams **1022** and **1024** (from the primary and secondary separators **1026** and **1003**) are fed to the main heat exchanger **1004** wherein they are heated, partially vaporized and combined. The resulting mixed phase product stream **1028** exits the main heat exchanger and is directed to a product tank **1032**.

The remaining components of the system of FIG. **10** operate in the same manner as those illustrated in, and described with respect to, FIG. **6**.

The separation process of FIG. **6** therefore can be carried out using three separation vessels, as illustrated in FIG. **10**, instead of one or two separation vessels. This process improves the separation efficiency of the process though increases the total equipment pieces.

In an eleventh embodiment of the system of the disclosure, indicated in general at **1100** in FIG. **11**, it is recognized that modifications to the mixed refrigerant, discharge pressure of the second compressor stage, and/or cooling temperature may cause liquids to be formed in the discharge drum **1102** of the compressor. This liquid can be combined with the vapor stream **1104** via line **1106** at junction **1107**. Line **1106** may be provided with a pump **1108** or a valve to control the flow of liquid from the discharge drum **1102** to the junction **1107** and thus to vapor stream **1104**.

Forming liquids in the discharge drum **1102** can create advantages when additional loads are desired to be included into the main heat exchanger **1112**. These additional loads would likely come from different processes of the larger dehydrogenation process. An example would be the integration of a deethanizer rectifier condenser. The liquid stream (in line **1106** of FIG. **11**) may be combined with the vapor stream **1104**, as shown in FIG. **11**, or it may also be sent to its own heat transfer path within the main heat exchanger **1112**. When sent to its own heat transfer path, the liquid stream (from line **1106**) could be combined with the low pressure vapor return stream **1113** after flashing the liquid stream to the lower pressure of the return stream.

Liquids may also be formed in the interstage drum **1114**, which may be dealt with in a similar manner as described above for discharge drum **1102** and for the same reasons as liquids that form in the discharge drum

The remaining components of the system of FIG. **11** operate in the same manner as those illustrated in, and described with respect to, FIG. **6**.

In an alternative embodiment, the system of FIG. **11** may instead be configured so that the vapor and liquid streams

1104 and 1106 exiting discharge drum 1102 are individually cooled in dedicated passages of the heat exchanger 1112, individually expanded across dedicated expansion devices (such as Joule-Thomson/JT valves or other type of expansion valves or devices known in the art) and then directed to the primary refrigeration passage of the heat exchanger 1112 (as shown in the embodiment of FIG. 1) or dedicated refrigeration passages of the heat exchanger 1112 (as shown in the embodiment of FIG. 4). In addition, in the latter embodiment (dedicated heat exchanger refrigeration passages as shown in FIG. 4), the outlet of the dedicated refrigeration passage corresponding to the liquid stream 1106 of the discharge drum 1102 may be directed to interstage drum 114 (as illustrated at 406 in FIG. 4).

While the preferred embodiments of the invention have been shown and described, it will be apparent to those skilled in the art that changes and modifications may be made therein without departing from the scope of the invention.

What is claimed is:

1. A system for separating olefinic hydrocarbon and hydrogen in an effluent fluid stream from a dehydrogenation reactor comprising:
- a. a main heat exchanger configured to receive and partially condense the effluent fluid stream so that a mixed phase effluent stream is formed;
- b. a primary separation device configured to receive and separate the mixed phase effluent stream into a primary vapor stream including hydrogen and a primary liquid stream including an olefinic hydrocarbon;
- c. said main heat exchanger configured to:
  - i) receive and warm at least a portion of the primary vapor stream to provide refrigeration for partially condensing the effluent fluid stream; and
  - ii) receive, warm and partially vaporize the primary liquid stream;
- d. a mixed refrigerant compression system configured to provide refrigeration in the main heat exchanger,
- e. a product tank configured to receive and separate at least the partially vaporized primary liquid stream into a product vapor stream and a product liquid stream and to direct the product vapor stream and the product liquid stream to the main heat exchanger, wherein the heat exchanger is configured to warm both the product vapor stream and the product liquid stream.

2. The system of claim **1** wherein the main heat exchanger is also configured to receive and partially condense the primary vapor stream so that a primary mixed phase stream is formed, and further comprising:
- f. a secondary separation device in fluid communication with the main heat exchanger so as to receive and separate the primary mixed phase stream into a secondary vapor stream and a secondary liquid product stream;
- g. said main heat exchanger configured to:
  - i) receive and warm at least a portion of the secondary vapor stream to provide refrigeration for partially condensing the effluent fluid stream and the primary vapor stream; and
  - ii) receive, warm and partially vaporize the secondary liquid product stream.

3. The system of claim **2** wherein the product tank is also configured to receive and separate the partially vaporized secondary liquid stream into portions of the product vapor stream and the product liquid stream.

4. The system of claim **2** wherein the main heat exchanger is also configured to receive and partially condense the secondary vapor stream so that a secondary mixed phase stream is formed, and further comprising:
- h. a tertiary separation device in fluid communication with the main heat exchanger so as to receive and separate the secondary mixed phase stream into a tertiary vapor stream and a tertiary liquid product stream;
- i. said main heat exchanger configured to:
  - i) receive and warm the tertiary vapor stream to provide refrigeration for partially condensing the effluent fluid stream and the primary and secondary vapor streams; and
  - ii) receive, warm and partially vaporize the tertiary liquid product stream.

5. The system of claim **4** wherein the product tank is also configured to receive and separate the partially vaporized secondary and tertiary liquid streams into portions of the product vapor stream and a product liquid stream.

6. The system of claim **1** wherein the main heat exchanger includes a primary refrigeration passage and the mixed refrigerant compression system includes:
- i) a suction separation device configured to receive a mixed phase refrigerant stream from the primary refrigeration passage of the main heat exchanger;
- ii) a compressor having an inlet in fluid communication with the suction separation device;
- iii) a cooling device having an inlet in fluid communication with an outlet of the compressor;
- iv) a discharge separation device having an inlet in fluid communication with an outlet of the cooling device and a vapor outlet in fluid communication with the primary refrigeration passage of the main heat exchanger.

7. The system of claim **6** further comprising a second stage cooling device and wherein the compressor is a two-stage compressor including a first stage having an inlet in fluid communication with an outlet of the suction separation device and an outlet in fluid communication with the cooling device, an interstage separation device having an inlet in fluid communication with an outlet of the cooling device, the compressor also including a second stage having an inlet in fluid communication with the interstage separation device and an outlet in fluid communication with the second stage cooling device.

8. The system of claim **6** further comprising a warm turbo-expander including a warm turbine and a warm compressor, said warm compressor configured to receive a vapor stream from the discharge separation device and having a warm compressor outlet in fluid communication with a turbo-expander cooling passage in the main heat exchanger, said warm turbine configured to receive and expand a first cooled vapor stream from the turbo-expander cooling passage of the main heat exchanger and having a warm turbine outlet in fluid communication with the primary refrigeration passage, said warm compressor being powered by the warm turbine.

9. The system of claim **8** further comprising a first after-cooler in circuit between the warm compressor outlet and the turbo-expander cooling passage of the main heat exchanger.

10. The system of claim **8** further comprising a cold turbo-expander including a cold turbine and a cold compressor, said cold compressor configured to receive a compressed vapor stream from the warm compressor and having a cold compressor outlet in fluid communication with the turbo-expander cooling passage in the main heat exchanger, said cold turbine configured to receive and expand a second cooled vapor stream from the turbo-expander cooling passage of the main heat exchanger and having a cold turbine outlet in fluid communication with the primary refrigeration passage, said cold compressor being powered by the cold turbine.

11. The system of claim **10** further comprising a first after-cooler in circuit between the warm compressor outlet and an inlet of the cold compressor and a second after-cooler in circuit between the cold compressor outlet and the turbo-expander cooling passage of the main heat exchanger.

12. The system of claim **6** wherein the discharge separation device includes a liquid outlet and further comprising a junction, said junction configured to receive and combine discharge vapor from the discharge separation device vapor outlet and discharge liquid from the discharge separation device liquid outlet and said junction having a junction outlet in fluid communication with the primary refrigeration passage of the main heat exchanger.

13. The system of claim **12** further comprising a pump in circuit between the discharge separation device liquid outlet and the junction.

14. The system of claim **6** wherein the discharge separation device includes a liquid outlet in fluid communication with the primary refrigeration passage of the main heat exchanger.

15. The system of claim **6** wherein the main heat exchanger includes a secondary refrigeration passage and the discharge separation device includes a liquid outlet in fluid communication with the secondary refrigeration passage of the main heat exchanger.

16. The system of claim **15** further comprising a second stage cooling device and wherein the compressor is a two-stage compressor including a first stage having an inlet in fluid communication with an outlet of the suction separation device and an outlet in fluid communication with the cooling device, an interstage separation device having an inlet in fluid communication with an outlet of the cooling device, the compressor also including a second stage having an inlet in fluid communication with the interstage separation device and an outlet in fluid communication with the second stage cooling device and wherein the secondary refrigeration passage has an outlet that is in fluid communication with the interstage separation device.

17. The system of claim **6** wherein the suction separation device includes a liquid outlet and further comprising a pump configured to pump liquid from the suction separation device liquid outlet to a junction in fluid communication with the outlet of the compressor at a discharge pressure of compressor.

18. A method for separating olefinic hydrocarbon and hydrogen in an effluent fluid stream from a dehydrogenation reactor comprising the steps of:

partially condensing the effluent fluid stream in a main heat exchanger so that a mixed phase effluent stream is formed;

separating the mixed phase effluent stream into a primary vapor stream and a primary liquid product stream;

warming at least a portion of the primary vapor stream to provide refrigeration for partially condensing the effluent fluid stream; and

partially vaporizing the primary liquid product stream and separating the partially vaporized primary liquid product stream in a product tank into a product vapor stream and a product liquid stream; and

warming the product vapor stream and the product liquid stream in the main heat exchanger.

19. The method of claim **18** wherein the step of partially condensing the effluent fluid stream is accomplished using a mixed refrigerant.

20. The method of claim **18** further comprising the steps of:

partially condensing the primary vapor stream so that a mixed phase primary stream is formed;

separating the mixed phase primary stream into a secondary vapor stream and a secondary liquid product stream;

warming at least a portion of the secondary vapor stream to provide refrigeration for partially condensing the effluent fluid stream and the primary vapor stream; and

partially vaporizing the secondary liquid product stream.

21. The method of claim **20** wherein the step of partially condensing the primary vapor stream is accomplished using a mixed refrigerant.

22. The method of claim **20** further comprising the steps of:

partially condensing the secondary vapor stream so that a mixed phase secondary stream is formed;

separating the mixed phase secondary stream into a tertiary vapor stream and a tertiary liquid product stream;

warming the tertiary vapor stream to provide refrigeration for partially condensing the effluent fluid stream, the primary vapor stream and the secondary vapor stream; and

partially vaporizing the tertiary liquid product stream.

23. The method of claim **22** wherein the step of partially condensing the secondary vapor stream is accomplished using a mixed refrigerant.

24. A system for separating olefinic hydrocarbon and hydrogen in an effluent fluid stream from a dehydrogenation reactor comprising:

a. a main heat exchanger configured to receive and partially condense the effluent fluid stream so that a mixed phase effluent stream is formed;

b. a primary separation device configured to receive and separate the mixed phase effluent stream into a primary vapor stream including hydrogen and a primary liquid stream including an olefinic hydrocarbon;

c. said main heat exchanger configured to:

i) receive and warm at least a portion of the primary vapor stream to provide refrigeration for partially condensing the effluent fluid stream; and

ii) receive, warm and partially vaporize the primary liquid stream;

d. a refrigerant compression system configured to provide refrigeration in the main heat exchanger; and

e. a product tank configured to receive and separate at least the partially vaporized primary liquid stream into a product vapor stream and a product liquid stream and to direct the product vapor stream and the product liquid stream to the main heat exchanger, wherein the heat exchanger is configured to warm both the product vapor stream and the product liquid stream.

25. The method of claim **20** further comprising separating the partially vaporized primary liquid product and the secondary liquid product stream in the product tank into portions of the product vapor stream and the product liquid stream.

26. The method of claim **22** further comprising separating the partially vaporized secondary liquid product and tertiary liquid product streams in the product tank into portions of the product vapor stream and the product liquid stream.

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