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Kennedy et al.(10) **Pub. No.: US 2017/0059241 A1**(43) **Pub. Date: Mar. 2, 2017**(54) **GAS LIQUEFACTION SYSTEM AND METHODS**(52) **U.S. Cl.**CPC **F25J 1/0022** (2013.01)(71) Applicant: **GE Oil & Gas, Inc.**, Houston, TX (US)

(57)

ABSTRACT(72) Inventors: **David Allen Kennedy**, New Braunfels, TX (US); **Shukui Zhao**, Katy, TX (US)

A liquefaction system that is configured to use a single methane expander to provide primary refrigeration duty. The liquefaction system can include a heat exchanger and a fluid circuit coupled with the heat exchanger, the fluid circuit configured to circulate a process stream derived from an incoming feedstock of natural gas. The fluid circuit can comprise a methane expander coupled with the heat exchanger, a sub-cooling unit coupled with the methane expander, the sub-cooling unit configured to form a liquid natural gas (LNG) product from the process stream, and a first throttling device interposed between the heat exchanger and the sub-cooling unit. The methane expander and the first throttling device can be configured to expand the process stream to a process pressure that is between a first pressure of the incoming feedstock and a second pressure of the process that exits the sub-cooling unit.

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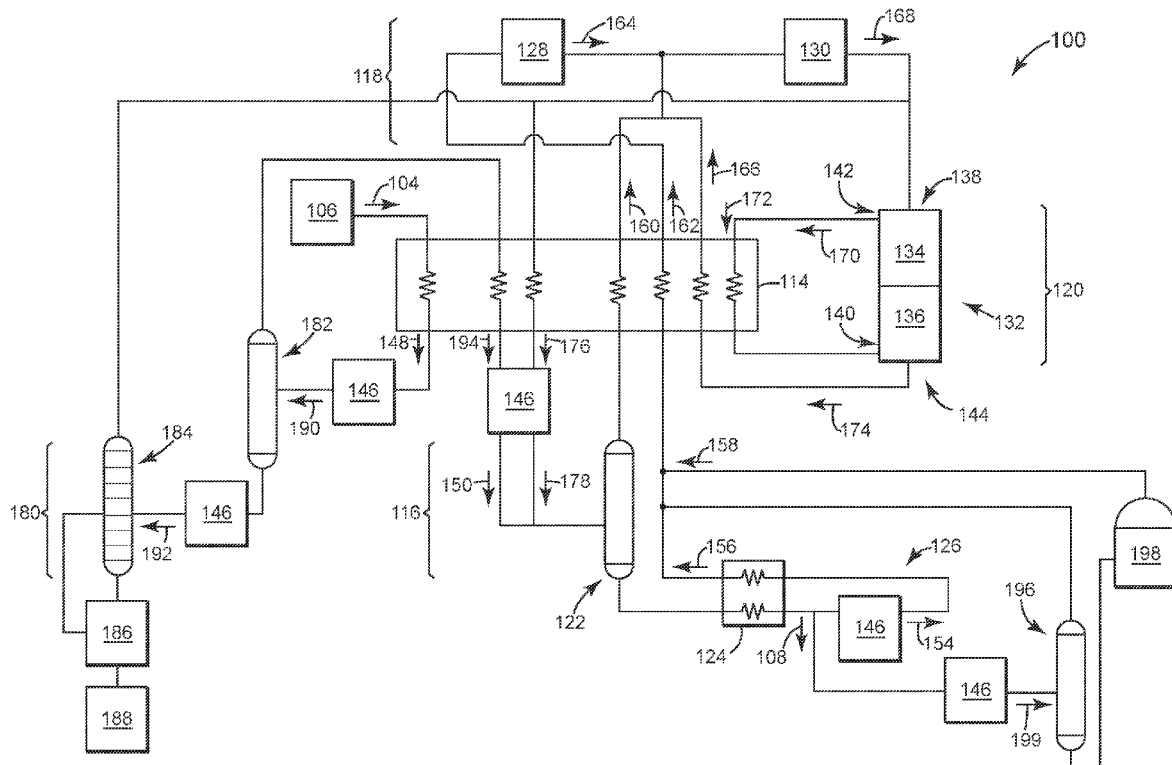
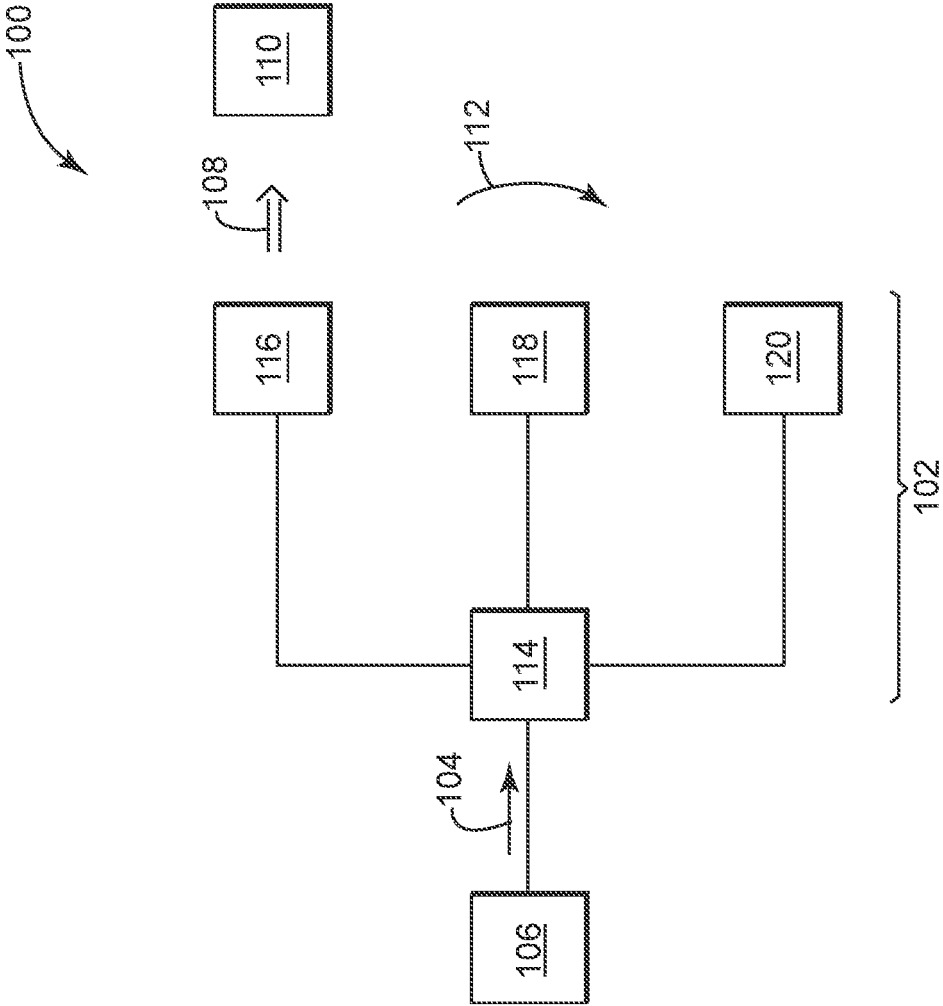


FIG. 1



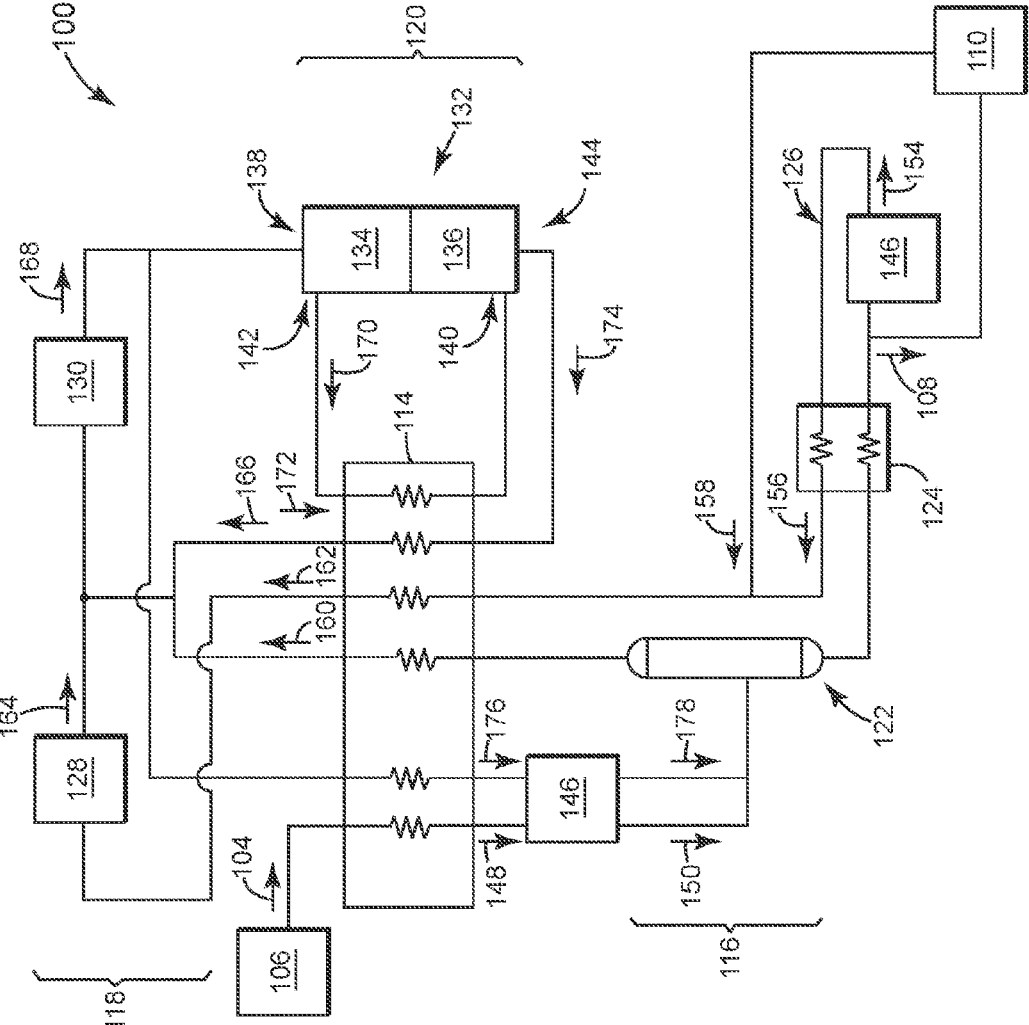
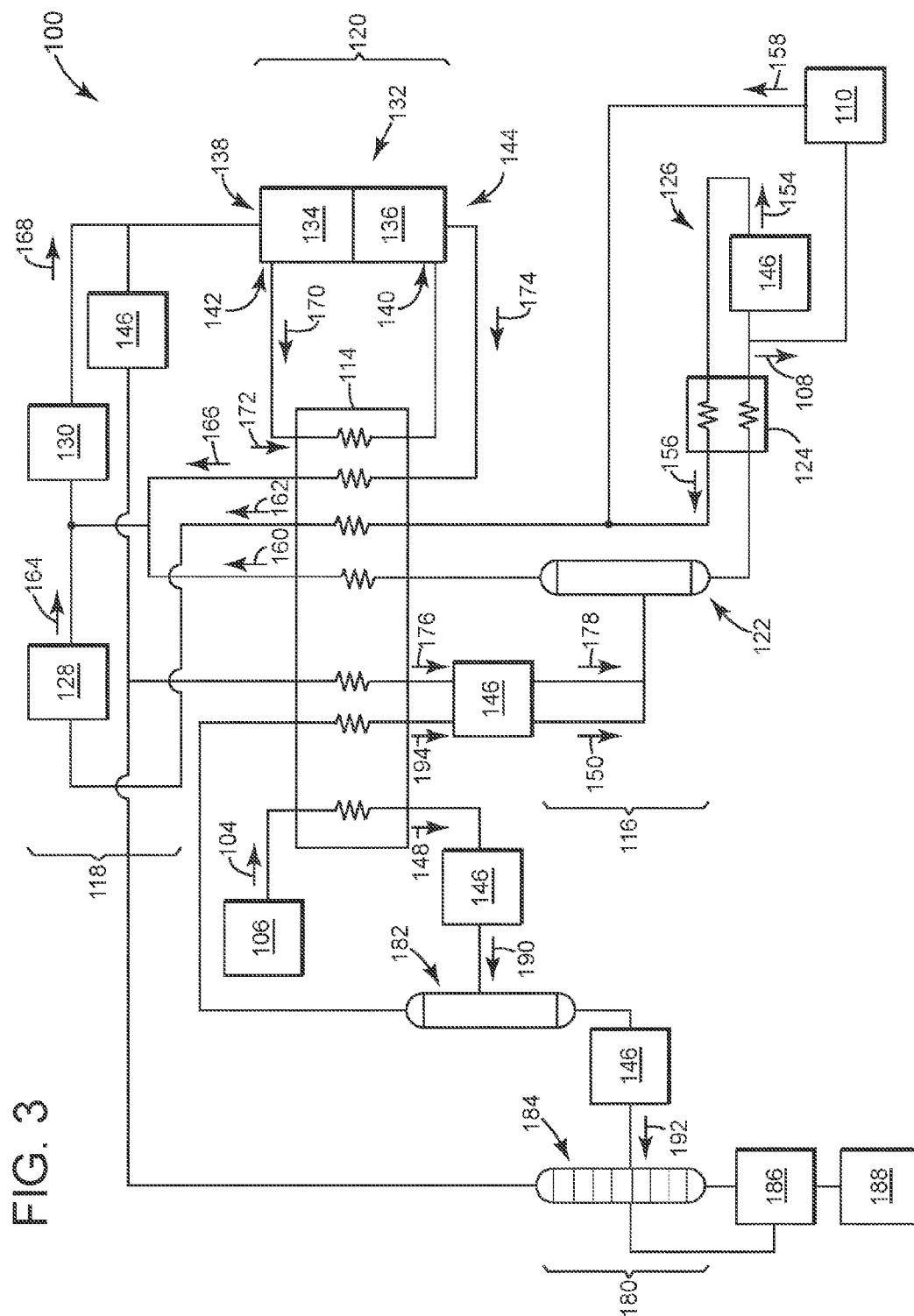
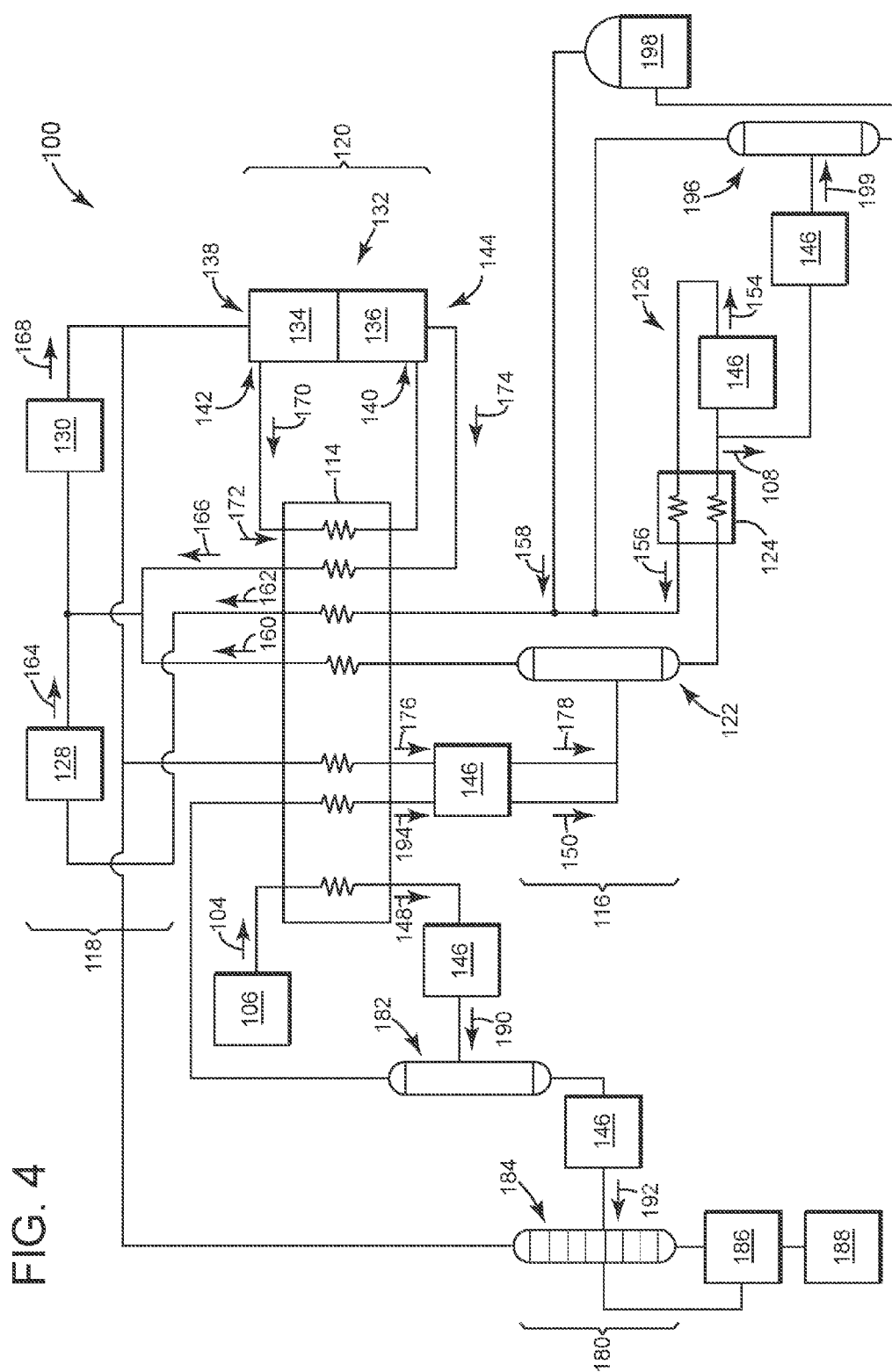


FIG. 2





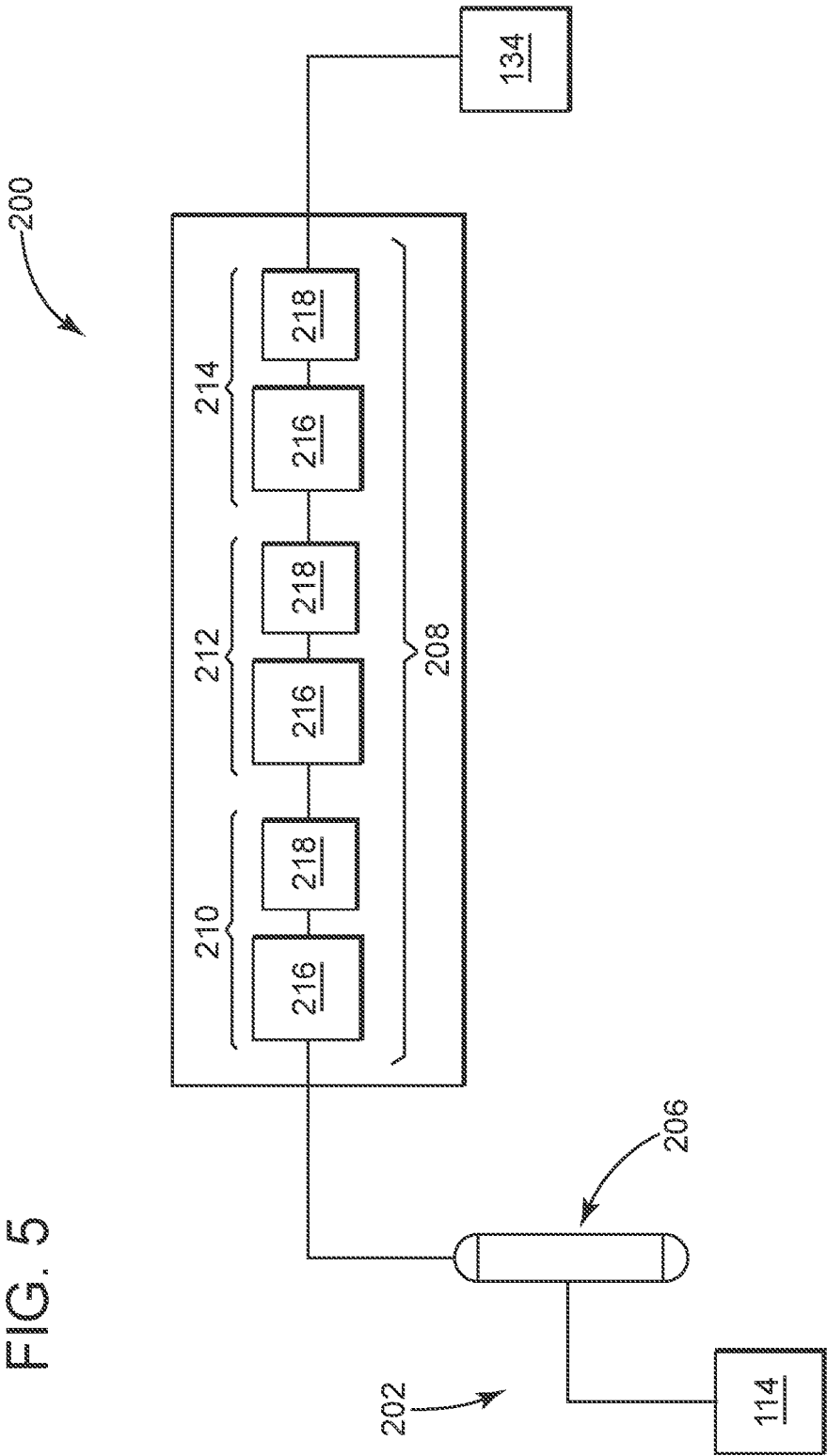
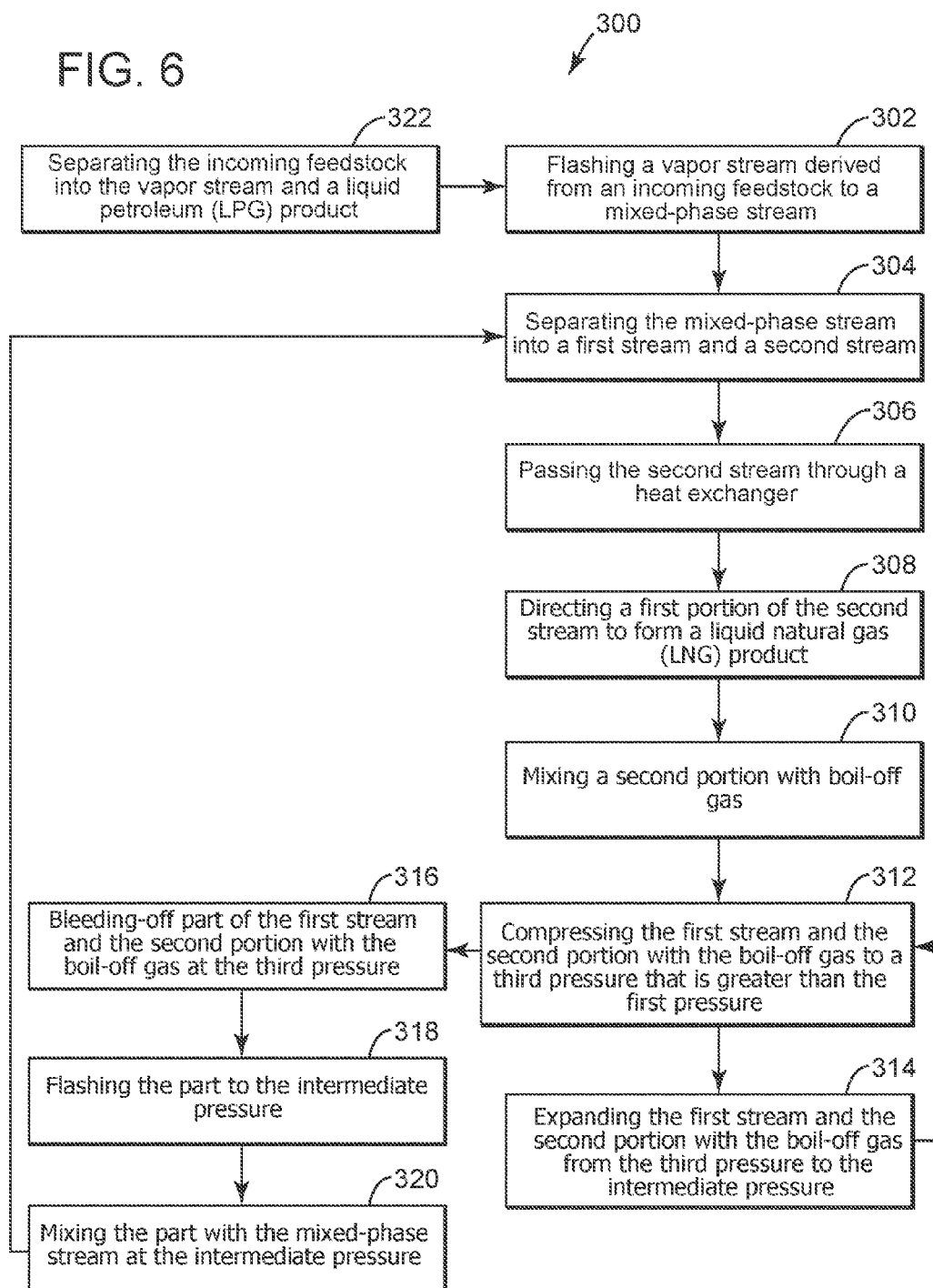


FIG. 6



GAS LIQUEFACTION SYSTEM AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority to U.S. Provisional Application Ser. No. 62/210,827, filed on Aug. 27, 2015, and entitled "SYSTEM AND PROCESS FOR PRODUCTION OF LIQUID NATURAL GAS," the content of which is herein incorporated by reference in its entirety.

BACKGROUND

[0002] Liquefying natural gas can facilitate transport and storage of hydrocarbons and related material. Generally, the processes greatly reduce the volume of gas. The resulting liquid is well-suited to transit long distances, for example, by rail and road transport tankers. It is particularly economical for transport overseas and/or to areas that are not accessible by such pipeline infrastructure.

SUMMARY

[0003] The subject matter of this disclosure relates generally to systems that can liquefy an incoming hydrocarbon stream. These systems can be configured to provide cooling, typically at a heat exchanger, to closely match the cooling curve for natural gas. In this way, the system can form a liquefied natural gas (LNG) stream. Some systems may provide refrigeration duty by circulating a refrigerant through the heat exchanger. This "refrigeration" process is often suited for small scale LNG facilities. On the other hand, the embodiments herein can be configured for an "expander" process that circulates fluid derived from the incoming natural gas to effectuate cooling at the heat exchanger. In one implementation, the embodiment can be configured to circulate the fluid at an intermediate pressure that is between the pressure of the incoming hydrocarbon stream and the pressure of a stream (e.g., boil off gas) that enters from a storage facility. This feature reduces the expansion ratio so as to provide sufficient refrigeration duty with a single methane expander to form the LNG stream. These improvements can reduce the capital costs and operational complexity of the embodiments as compared necessary to perform the liquefaction process.

[0004] The embodiments may find use in many different types of processing facilities. These facilities may be found onshore and/or offshore. In one application, the embodiments can incorporate into and/or as part of processing facilities that reside on land, typically on (or near) shore. These processing facilities can process natural gas feedstock from production facilities found both onshore and offshore. Offshore production facilitates use pipelines to transport feedstock extracted from gas fields and/or gas-laden oil-rich fields, often from deep sea wells, to the processing facilities. For LNG processing, the processing facility can turn the feedstock to liquid using suitably configured refrigeration equipment or "trains." In other applications, the embodiments can incorporate into production facilities on board a ship (or like floating vessel), also known as a floating liquefied natural gas (FLNG) facility.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Reference is now made briefly to the accompanying drawings, in which:

[0006] FIG. 1 depicts a schematic diagram of an exemplary embodiment of a liquefaction system;

[0007] FIG. 2 depicts a schematic diagram of an example of components to implement the liquefaction system of FIG. 1;

[0008] FIG. 3 depicts a schematic diagram of an example of components to implement the liquefaction system of FIG. 1;

[0009] FIG. 4 depicts a schematic diagram of an example of components to implement the liquefaction system of FIG. 1;

[0010] FIG. 5 depicts a schematic diagram of a compression circuit for use in the liquefaction system of FIGS. 1, 2, 3, and 4; and

[0011] FIG. 6 depicts a flow diagram of an exemplary embodiment of a process to liquefy an incoming feedstock.

[0012] Where applicable like reference characters designate identical or corresponding components and units throughout the several views, which are not to scale unless otherwise indicated. The embodiments disclosed herein may include elements that appear in one or more of the several views or in combinations of the several views. Moreover, methods are exemplary only and may be modified by, for example, reordering, adding, removing, and/or altering the individual stages.

DETAILED DESCRIPTION

[0013] The discussion below describes various embodiments that are useful to process hydrocarbons for storage as liquid natural gas (LNG). These embodiments include a fluid circuit that flashes and then cools the circulating hydrocarbon stream at an intermediate pressure between the "high" pressure of an incoming hydrocarbon feedstock and the "low" pressure of a boil-off gas that originates from a storage facility. Other embodiments are within the scope of the disclosed subject matter.

[0014] FIG. 1 illustrates a schematic diagram of an exemplary embodiment of a liquefaction system **100** (also, "system **100**") for use to liquefy a hydrocarbon stream. At a high level, the system **100** can have a fluid circuit **102** that receives a feedstock **104** from a source **106**. The incoming feedstock **104** may be in vapor form (also, "gas" or "natural gas") with a composition that is predominantly methane. Embodiments of the system **100** may be compatible with compositions having methane in a first concentration that is approximately 93% (930,000 ppmV) or greater. In use, the system **100** can form one or more products (e.g., a first product **108**), typically liquid natural gas (LNG) that meets specifications for storage. These specifications may specify a second concentration of methane for the LNG product **108** that is lower than the first concentration of incoming feedstock **104**. In one example, the second concentration of methane in the first product **108** may be approximately 99% or more (990,000 ppmV). The fluid circuit **102** can distribute the LNG product **108** to a storage facility **110** and/or other collateral process equipment.

[0015] The fluid circuit **102** may be configured to form and circulate fluids (e.g., gasses and liquids). For clarity, these fluids are identified in FIG. 1 as a process stream **112**. In one implementation, the fluid circuit **102** may include a

first heat exchanger **114** (also, “main heat exchanger **114**”). Examples of the main heat exchanger **114** can have multiple passes, each in the form of a passage that may include brazed aluminum fins (“plate-fin exchanger”) and/or tubular coils (“coil wound exchanger”). Such configurations can facilitate indirect exchange of thermal energy among the fluids that pass through the main heat exchanger **114**. The passages can couple with or more processing units to exchange the process stream **112** at various temperatures. Examples of the process stream **112** can be in vapor, liquid, and mixed-phase forms. However, in one implementation, the fluid circuit **102** is configured to maintain the process stream **112** in a single phase, either vapor phase or liquid phase. The processing units can be arranged as a sub-cooling unit **116**, a compression unit **118**, and methane expander **120**.

[0016] Broadly, use of the sub-cooling unit **116** in the system **100** can improve operation of the fluid circuit **102**. The sub-cooling unit **116** can be configured to flash the process stream **112** to a pressure that is between the pressure of the incoming feedstock **104** and the pressure of a secondary incoming stream like boil-off gas and/or similar streams that originate from the storage facility **110**. Liquid that results from flashing at this “intermediate” pressure may be at a temperature that is suitable for storage, e.g., at the storage facility **110**. Moreover, forming liquid at this intermediate pressure effectively reduces the expansion ratio of the fluid circuit **102** to permit the system **100** to operate efficiently with only one methane expander (e.g., methane expander **120**). This improvement simplifies the construction of the fluid circuit **102** to reduce capital and operational expenses of the system **100** and, thus, lower the overall costs of the liquefaction process of the incoming feedstock **104** to the LNG product **108**.

[0017] FIG. 2 illustrates an example of components to implement the liquefaction system **100** that renders the first product **108** from incoming feedstock **104**. At the sub-cooling unit **116**, the fluid circuit **102** can have a first vessel **122** that couples with a second heat exchanger **124**. Examples of the second heat exchanger **124** can have two passes, although additional passes may be useful in certain implementations of the system **100**. The fluid circuit **102** can form a fluid path **126** that couples the passes of the second heat exchanger **124** together. In the compression unit **118**, the fluid circuit **102** can incorporate one or more compression circuits (e.g., a first compression circuit **128** and a second compression circuit **130**). The first compression circuit **128** can couple with the sub-cooling unit **116** via the main heat exchanger **114**. In the methane expander **120**, the fluid circuit **102** can form an open loop circuit with a turbo-machine **132**, preferably having a turbo-compressor **134** that is configured to operate in response to work from a turbo-expander **136**. The turbo-machine **132** can have a pair of inlets (e.g., a first inlet **138** and a second inlet **140**) and a pair of outlets (e.g., a first outlet **142** and a second outlet **144**). The inlets **138**, **140** and the outlets **142**, **144** couple the turbo-machine **132** with the main heat exchanger **114** and the second compression circuit **130**.

[0018] The fluid circuit **102** may benefit from one or more auxiliary or peripheral components that can facilitate processes to generate the LNG product **108**. For example, the fluid circuit **102** may include one or more throttling devices **146**. Examples of the throttling devices **146** can include valves (e.g., Joule-Thompson valves) and/or devices that are similarly situated to throttle the flow the process stream **112**

(FIG. 1). In use, the throttling devices **146** can be interposed between components in the fluid circuit **102** as necessary to achieve certain changes in fluid parameters (e.g., temperature, pressure, etc.).

[0019] Starting at the left side of the diagram in FIG. 2, the fluid circuit **102** can direct the process stream **112** (FIG. 1) through the various components to generate the LNG product **108**. In one implementation, incoming feedstock **104** can enter a first pass of the main heat exchanger **114** at a first pressure and a first temperature, typically ambient temperature that prevails at the system **100** and/or the surrounding facility. The first pressure may depend on operation of the facility and/or installation. Exemplary pressure may be approximately 720 psig, but is likely to fall in a range of approximately 500 psig to approximately 900 psig. Incoming feedstock **104** exits the device (at **148**) at a second temperature in a range from approximately -150° F. to approximately -220° F.

[0020] The fluid circuit **102** can direct the cooled incoming feedstock **104** to a first throttling device (e.g., throttling device **146**). This first throttling device “flashes” incoming feedstock **104** upstream of the first vessel **122**, effectively reducing the pressure from the first pressure to the intermediate pressure mentioned above. Flashing at this intermediate pressure is beneficial to simplify construction of the system **100**. In one implementation, incoming feedstock **104** may exit the first throttling device (at **150**) at a pressure that is less than the first pressure, for example, in a range of approximately 90 psig to approximately 150 psig. Temperature may vary in a range from approximately -200° F. to approximately -240° F.

[0021] The fluid circuit **102** can direct incoming feedstock **104** at the reduced pressure and/or reduced temperature to the first vessel **122**. Processes in the first vessel **122** may separate incoming feedstock **104** at the intermediate pressure (and in mixed-phase form) into a top product and a bottom product, one each in vapor form and liquid form, respectively. In one implementation, the fluid circuit **102** can direct the liquid bottom product to a first pass of the second heat exchanger **124**. This first pass further reduces the temperature of the liquid bottom product so that the temperature of the LNG product **108** is in a range of approximately -230° F. to approximately -265° F.

[0022] The fluid circuit **102** can split the liquid bottom product into one or more portions downstream of the second heat exchanger **124**. The fluid circuit **102** can direct a first portion as the LNG product **108**. The fluid circuit **102** can direct a second portion back to a second pass of the second heat exchanger **124** via the fluid path **126**. This second portion is useful to sub-cool of the liquid bottom product that flows through the first pass of the second heat exchanger **124**. In one implementation, the fluid circuit **102** may include a second throttling device (e.g., throttling device **146**) interposed between the first pass and the second pass of the second heat exchanger **124**. This second throttling device can be configured so that the second portion exits (at **154**) at a pressure of the second portion to a range of approximately 2 psig to approximately 30 psig. During operation, the second portion exits the second pass (at **156**) of the second heat exchanger **124** as vapor at this pressure and a temperature from approximately -205° F. to approximately -255° F.

[0023] The fluid circuit **102** can combine the vapor from the second heat exchanger **124** with a stream **158**. This feature can form a “boil-off” vapor stream upstream of the

main heat exchanger **114**. Examples of the stream **158** can include boil-off vapor from a storage tank and/or vapor that results from processes at the storage facility **110**. Typically, pressure of the stream **158** is at “low” pressure relative to the pressure of the incoming stream **104**. This pressure can depend on specifications at the storage facility **110**, which may call for pressure from approximately 1 psig (or “unpressurized”) to approximately 30 psig (“pressurized”). As discussed above, the second throttling device in the fluid circuit **102** can be configured to match the pressure of the stream **158**.

[0024] The fluid circuit **102** can direct the vapor streams from the first vessel **122** and the second heat exchanger **124** to the compression unit **118** via separate passes of the main heat exchanger **114**. The vapor stream from the first vessel **122** can enter a second pass of the main heat exchanger **114**. The boil-off vapor stream can enter a third pass of the main heat exchanger **114**. Each of the second pass and the third pass warms the respective stream so that the streams exit (at **160**, **162**) at a temperature from approximately 90° F. to approximately 110° F. In one implementation, this temperature may also be within approximately 3° F. of desuperheaters found in the compression circuits **128**, **130**.

[0025] The fluid circuit **102** can direct the boil-off vapor stream from the third pass to the first compression circuit **128**. Configurations of the first compression circuit **128** can have one or more compression stages to raise the pressure of the boil-off vapor stream from the “low” pressure of the stream **158**. For many applications, however, two and/or three stages may be appropriate. In one implementation, the boil-off vapor stream may exit the last of the compression stages (at **164**) at a pressure from approximately 90 psig to approximately 150 psig.

[0026] The fluid circuit **102** can direct the boil-off vapor stream at this pressure to the second compression circuit **130**. The second compression circuit **130** may include one or more compression stages. For many applications, however, two and/or three stages may be appropriate. The compression stages of the second compression circuit **130** may be independent or separate from the compression stages of the first compression circuit **128**. This discussion does also contemplate applications for the system **100** that may benefit from combinations of the stages of compression circuits **128**, **130**, in whole or in part. In one implementation, the fluid circuit **102** can combine the boil-off vapor stream with a “recycle” stream from the methane expander **120**. The combination can occur upstream of the second compression circuit **130** to result in a combined vapor stream that enters the second compression circuit **130**. In one implementation, the vapor stream can exit (at **168**) the last of the compression stages at a pressure from approximately 550 psig to approximately 600 psig.

[0027] The fluid circuit **102** can direct the compressed vapor stream at this pressure to the turbo-compressor **134**. This apparatus can be configured to further increase pressure of the compressed vapor stream. In one implementation, the compressed vapor stream may exit (at **170**) the turbo-compressor **134** at a pressure at approximately 1200 psig or less. This upper limit or “cap” on the pressure is useful to maintain the flange class to 600 lbs or less.

[0028] The fluid circuit **102** can direct the compressed vapor stream from the turbo-compressor **134** to a fourth pass of the main heat exchanger **114**. This fourth pass provides the refrigeration duty for the main heat exchanger **114**. In

one implementation, the fluid circuit **102** may be configured with a cooler (or like device) interposed between the main heat exchanger **114** and the turbo-compressor **134**. This cooler can cool the compressed vapor stream so that the compressed vapor stream enters the fourth pass (at **172**) at a temperature of approximately 110° F. However, this temperature may vary within in a range from approximately 90° F. to approximately 110° F. The compressed vapor stream can exit the fourth pass at a temperature to optimize refrigeration in the main heat exchanger **114**. This temperature may be in a range from approximate -20° F. to approximately 40° F.

[0029] The fluid circuit **102** can direct the cooled vapor stream from the fourth pass to the turbo-expander **136**. This apparatus operates in a manner so that the vapor stream exits (at **174**) at a pressure from approximately 90 psig to approximately 150 psig and temperature of approximately 3° F. colder than the vapor streams that exit the main heat exchanger **114** (at **148** and **176**). Notably, the pressure of the vapor stream (at **174**) is equal to, or substantially the same as, the pressure at the exit (at **150**) of the first throttling valve, discussed above. The fluid circuit **102** can direct the expanded vapor stream to a fifth pass of the main heat exchanger **114**. This fifth pass provides additional refrigeration at the main heat exchanger **114**. As noted above, the fluid circuit **102** may combine the expanded vapor stream with the top vapor product from the first vessel **122** to form the “recycle” stream for use in the second compression circuit **130**.

[0030] The fluid circuit **102** can be configured to form a “bleed-off” stream from the compressed stream that exits the second compressions circuit **130**. During operation, the fluid circuit **102** can direct this “bleed-off” stream to the first throttling device (e.g., throttling device **146**) via a sixth pass of the main heat exchanger **114**. In one implementation, the fluid circuit **102** may include a flow control valve (or similar device) between the second compression circuit **130** and the turbo-compressor **134**. The flow control valve can operate in response to changes in flow rate of the vapor in the fluid circuit **102**. The “bleed-off” stream can exit (at **176**) the sixth pass at a temperature of from approximately 90° F. to approximately 110° F. and exit the first throttling device (at **178**) at a pressure that is less than the first pressure (e.g., in a range of from approximately 90 psig to approximately 150 psig).

[0031] FIG. 3 depicts an example of additional components that may be helpful to implement the liquefaction system **100**. The fluid circuit **102** may include a separation unit **180** to remove impurities (e.g., heavy hydrocarbons) from incoming feedstock **104**. Examples of the separation unit **180** may include a pair of vessels (e.g., a second vessel **182** and a third vessel **184**). The third vessel **184** may also benefit from use of one or more peripheral components (e.g., a peripheral component **186**). Examples of the peripheral component **186** can include pumps, boilers, heaters, and like devices that can facilitate operation of one or more of the vessels **182**, **184**. In one implementation, the peripheral component **186** may embody a boiler that couples the third vessel **184** with a pipeline **188** and/or like collateral equipment (e.g., conduit, tank, etc.).

[0032] The fluid circuit **102** may be configured to couple the main heat exchanger **114** with the separation unit **180**. This configuration can direct incoming feedstock **104** from the first pass to a fourth throttling device (e.g., throttling

device 146). This fourth throttling device can reduce the pressure of incoming feedstock 104 so that the incoming feedstock 104 exits (at 190) at a pressure that is less than 720 psig. This expansion stage may be necessary based on the composition of the incoming feedstock 104. For example, the expansion stage may be configured to maintain pressure of the products from the vessels 182, 184 at or below the critical pressure of impurities (e.g., heavy hydrocarbons) found in compositions of incoming feedstock 104. This configuration allows the vessels 182, 184 to operate at low pressure to ensure the composition of the bottom products are rich in these impurities.

[0033] The fluid circuit 102 can process incoming feedstock 104 at the reduced pressure in the vessel 182. These processes can form a top product and a bottom product in vapor form and liquid form, respectively. In one implementation, the fluid circuit 102 can direct the liquid bottom product from the second vessel 182 to the third vessel 184. A fifth throttling device (e.g., throttling device 146) may be useful to further reduce the pressure and/or temperature of the liquid bottom product upstream of the third vessel 184. The liquid bottom product can exit the fifth throttling device (at 192) at a pressure from approximately 200 psig to approximately 250 psig and a temperature of from approximately -80° F. to approximately -120° F. Examples of the third vessel 184 can operate as a stabilizer column to remove light hydrocarbons to form a liquid bottom product that is "stable" for storage. This liquid bottom product may be a liquid petroleum product (LPG). In use, the stabilizer column 184 can be fabricated from standard pipe size and schedule for use with a wide range of output rates. In one example, the stabilizer column can use twelve trays so that the top vapor product meets specifications for the LNG product 108. The fluid circuit 102 may include a condenser, but such configuration may not be necessary because the incoming feedstock 110 may enter the stabilizer column at less than approximately -100° F. and the vapor top product may exit the stabilizer column at -50° F. or warmer.

[0034] The fluid circuit 102 can direct the vapor top products from the vessels 182, 184 to individual passes of the main heat exchanger 114. These vapor top products can have a composition that meets the specifications for the LNG product 108. In one implementation, the vapor top product from the second vessel 182 exits a seventh pass (at 194) at a temperature in a range from approximately -80° F. to approximately -120° F. The vapor top product from the stabilizer column 184 may be combined with the "bleed-off" vapor stream from the methane expander 120 upstream of the sixth pass of the main heat exchanger 114. In this respect, the fluid circuit 102 may include a sixth throttling device (e.g., throttling device 146) to reduce pressure in the bleed-off vapor stream to match the pressure of the vapor top product from the stabilizer column 184. On the other hand, if the pressure of the bleed-off vapor stream is higher than the pressure of incoming feedstock 104, then the bleed-off vapor stream can be combined with incoming feedstock 104.

[0035] FIG. 4 depicts an example of the liquefaction system 100. The storage facility 110 may include a fourth vessel 196 and tank 198. A fifth throttling device (e.g., throttling device 146) may be used to reduce pressure and/or temperature of the LNG product 108 upstream of the fourth vessel 196. In one example, the LNG product 108 can exit the fifth throttling device (at 199) at a pressure from approximately 2 psig to approximately 30 psig. Temperature may

vary in a range from approximately -250° F. to approximately -265° F. Processes in the fourth vessel 196 can form a top product and a bottom product, one each in vapor form and liquid form. The liquid bottom product can transit to the tank 198. In one implementation, the vapor top product from the fourth vessel 196 and the boil-off gas from the tank 198 can form the stream 158 that the fluid circuit 102 combines with the stream from the sub-cooling unit 116.

[0036] FIG. 5 depicts an example of a compression circuit 200. This example may find use to implement one or both of the compression circuits 138, 140 (FIGS. 2, 3, and 4). The compression circuit 200 has a first end 202 and a second end 204. The end 202 can couple with the main heat exchanger 114. When used as the second compression circuit 130, the second end 204 may couple with the turbo-compressor 134.

[0037] The compression circuit 200 may be configured to increase the pressure without increasing the temperature of the process stream 116 from the first end 202 to the second end 204. This functionality may be embodied in various components (e.g., coolers, compressors, etc.). In one implementation, the compression circuit 200 may include a vessel 206 at the first end 202 (or "inlet"). Examples of the vessel 206 can embody a desuperheater or like device to reduce the temperature of incoming gas to make it less superheated. This device can couple with a compression path 208 with one or more compression stages (e.g., a first stage 210, a second stage 212, and a third stage 214). Nominally, each stage may include a cooler 216 and a compressor 218. Examples of the cooler 216 may be air-cooled, although this disclosure does not limit selection to any particular type or variation for these devices. The compressor 218 may be gas, motor, and turbine driven devices that are disposed between coolers 216 of adjacent compression stages 210, 212, 214 to maintain and/or raise the pressure of process stream 116 noted herein. The number of compression stages may depend on the application, with one implementation of the system 100 being configured with the first compression circuit 138 having two or three stages and the second compression circuit 140 having three stages.

[0038] FIG. 6 depicts a flow diagram of an exemplary embodiment of a process 300 to liquefy an incoming feedstock. The process 300 can include, at stage 302 flashing a vapor stream derived from an incoming feedstock to a mixed-phase stream. The process 300 can also include, at stage 304, separating the mixed-phase stream into a first stream and a second stream. The process 300 may include, at stage 306, passing the second stream through a heat exchanger, and a stage 308, directing a first portion of the second stream to form a liquid natural gas (LNG) product, and, at stage 310, mixing a second portion with boil-off gas. The mixed-phase stream can be at an intermediate pressure that is between a first pressure of the incoming feedstock and a second pressure for the boil-off gas. In one implementation, the process 300 may include, at stage 312, compressing the first stream and the second portion with the boil-off gas to a third pressure that is greater than the first pressure. The process 300 may also include, at stage 314, expanding the first stream and the second portion with the boil-off gas from the third pressure to the intermediate pressure. The process 300 can then be configured to return to stage 314, effectively forming a circulating loop that is useful to provide refrigeration duty at the heat exchanger. In one implementation, the process 300 may also include, at stage 316, bleeding-off part of the first stream and the second portion with the

boil-off gas at the third pressure and, at stage **318**, flashing the part to the intermediate pressure. The process **300** can further include, at stage **320**, mixing the part with the mixed-phase stream at the intermediate pressure. The process **300** can then return to stage **304**. As also shown in FIG. **6**, the process **300** may include, at stage **322**, separating the incoming feedstock into the vapor stream and a liquid petroleum (LPG) product.

[0039] In view of the foregoing, process efficiency for some embodiments compare favorably with a nitrogen expander process but require more horsepower than an equivalent sized mixed refrigerant system. Some embodiments include only a single expander, which is less than certain systems that may employ two expanders that work in parallel. Moreover, unlike systems that implement mixed-refrigeration processes, some embodiments do not require refrigerants, thus eliminating the need for use, handling, and on-site storage of refrigerants.

[0040] As used herein, an element or function recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural said elements or functions, unless such exclusion is explicitly recited. Furthermore, references to “one embodiment” of the claimed invention should not be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

[0041] This written description uses examples to disclose the embodiments, including the best mode, and also to enable any person skilled in the art to practice the embodiments, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the embodiments is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

What is claimed is:

1. A liquefaction system, comprising:
 - a first heat exchanger; and
 - a fluid circuit coupled with the first heat exchanger, the fluid circuit configured to circulate a process stream derived from an incoming feedstock of natural gas through the first heat exchanger, the fluid circuit comprising:
 - a methane expander coupled with the first heat exchanger;
 - a sub-cooling unit coupled with the methane expander, the sub-cooling unit configured to form a liquid natural gas (LNG) product from the process stream; and
 - a first throttling device interposed between the first heat exchanger and the sub-cooling unit,
 wherein the first throttling device is configured to expand the process stream to an intermediate pressure that is between a first pressure of the incoming feedstock and a second pressure of the process stream that exits the sub-cooling unit.
2. The liquefaction system of claim **1**, wherein the second pressure is in a range of from 1 psig to 30 psig.
3. The liquefaction system of claim **1**, wherein the methane expander expands the process stream to the intermediate pressure.

4. The liquefaction system of claim **1**, wherein the fluid circuit is configured to receive and mix a stream with the process stream downstream of the sub-cooling unit and upstream of the first heat exchanger.

5. The liquefaction system of claim **5**, wherein the fluid circuit comprises a compression circuit configured to receive the process stream from the sub-cooling unit via the first heat exchanger.

6. The liquefaction system of claim **1**, wherein the fluid circuit comprises a first vessel interposed between the first throttling device and the sub-cooling unit, wherein the first vessel is configured to form a first stream and a second stream from the process stream, and wherein the second stream forms the LNG product.

7. The liquefaction system of claim **1**, wherein the sub-cooling unit comprises a second heat exchanger that is configured to cool the process stream from a first temperature to a second temperature that is less than the first temperature.

8. The liquefaction system of claim **7**, wherein the second heat exchanger has a first pass and a second pass, and wherein the fluid circuit couples the first pass to the second pass.

9. The liquefaction system of claim **8**, wherein the fluid circuit comprises a second throttling device interposed between the first pass and the second pass, and wherein the second throttling device is configured to reduce pressure of the process stream to the second pressure.

10. The liquefaction system of claim **1**, further comprising a second vessel coupled with the first heat exchanger to separate the incoming feedstock into vapor and liquid, wherein the fluid circuit directs the vapor from the second vessel to the first throttling device via the first heat exchanger.

11. The liquefaction system of claim **10**, further comprising a third vessel coupled with the second vessel and the first heat exchanger to separate the liquid from the second vessel into vapor and liquid, wherein the fluid circuit directs the vapor to from the third vessel to the first throttling device via the first heat exchanger.

12. An apparatus, comprising:

- a first heat exchanger; and
 - a second heat exchanger coupled with the first heat exchanger,
- wherein said apparatus is configured to circulate fluid derived from incoming natural gas so that fluid that enters the second heat exchanger is at an intermediate pressure that is less than a first pressure of the incoming natural gas and greater than a second pressure of fluid that exits the second heat exchanger.

13. The apparatus of claim **12**, further comprising:

- a first throttling device coupled downstream of the first heat exchanger and upstream of the second heat exchanger, wherein the first throttling device is configured to expand fluid to the intermediate pressure.

14. The apparatus of claim **12**, further comprising:

- a second throttling device coupled downstream of the second heat exchanger, wherein the second throttling device is configured to expand fluid to the second pressure.

15. The apparatus of claim **14**, wherein the second heat exchanger comprises a first pass and a second pass, and wherein the second throttling device is disposed between the first pass and the second pass.

16. A liquefaction process, comprising:
flashing a vapor stream derived from an incoming feedstock to a mixed-phase stream;
separating the mixed-phase stream into a first stream and a second stream;
passing the second stream through a heat exchanger;
directing a first portion of the second stream to form a liquid natural gas (LNG) product; and
mixing a second portion with boil-off gas,
wherein the mixed-phase stream is at an intermediate pressure that is between a first pressure of the incoming feedstock and a second pressure for the boil-off gas.

17. The liquefaction process of claim **16**, further comprising:
compressing the first stream and the second portion with the boil-off gas to a third pressure that is greater than the first pressure.

18. The liquefaction process of claim **17**, further comprising:
expanding the first stream and the second portion with the boil-off gas from the third pressure to the intermediate pressure.

19. The liquefaction process of claim **17**, further comprising:
bleeding-off part of the first stream and the second portion with the boil-off gas at the third pressure;
flashing the part to the intermediate pressure; and
mixing the part with the mixed-phase stream at the intermediate pressure.

20. The liquefaction process of claim **19**, further comprising:
separating the incoming feedstock into the vapor stream and a liquid petroleum (LPG) product.

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