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(54) SYSTEM AND METHOD FOR LIQUEFACTION OF NATURAL GAS

(57) Systems and methods are provided for the production of liquefied natural gas. At least one of the systems may include a plurality of compression assemblies in fluid communication with a precooler assembly. One compression assembly may be a part of a precooling loop and may include at least one compressor driven by a variable or fixed speed motor. Another compression assembly may be part of a liquefaction loop and may include at least one pair of compressors, each compressor driven by a respective turbine. The liquefaction loop may be fluidly coupled to a main heat exchanger utilized to liquefy at least a portion of a feed gas stream containing natural gas flowing through the main heat exchanger, thereby producing liquefied natural gas.

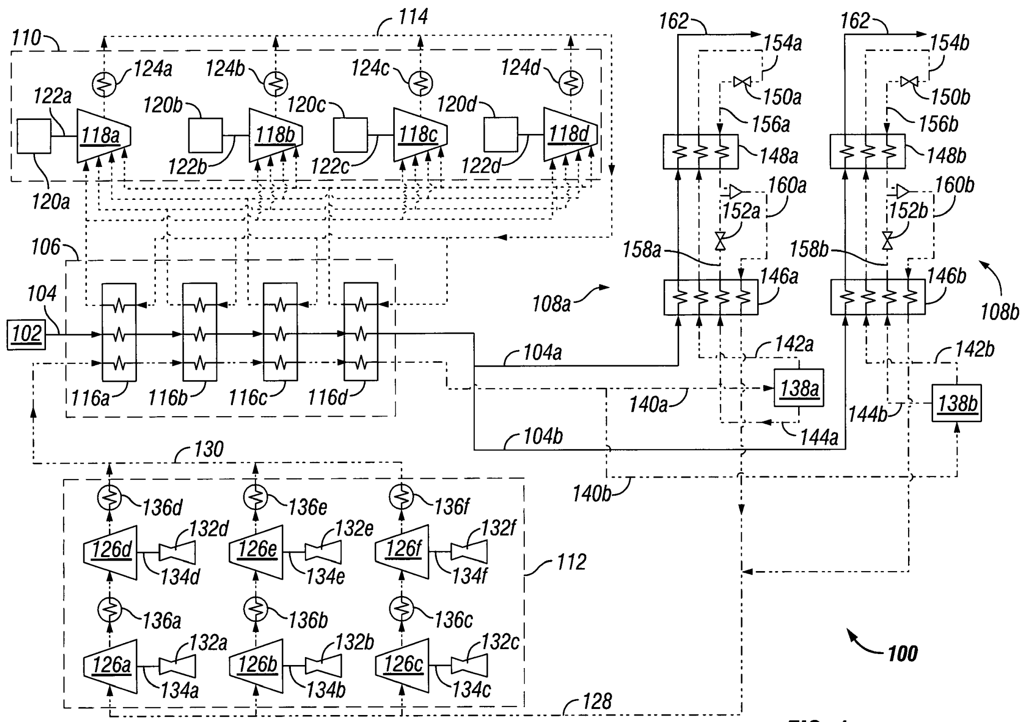

FIG. 1

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Description

Background

[0001] The combustion of conventional fuels, such as gasoline and diesel, has proven to be essential in a myriad of industrial processes. The combustion of gasoline and diesel, however, may often be accompanied by various drawbacks including increased production costs and increased carbon emissions. In view of the foregoing, recent efforts have focused on alternative fuels with decreased carbon emissions, such as natural gas, to combat the drawbacks of combusting conventional fuels. In addition to providing a "cleaner" alternative fuel with decreased carbon emissions, combusting natural gas may also be relatively safer than combusting conventional fuels. For example, the relatively low density of natural gas allows it to safely and readily dissipate to the atmosphere in the event of a leak. In contrast, conventional fuels (*e.g*., gasoline and diesel) have a relatively high density and tend to settle or accumulate in the event of a leak, which may present a hazardous and potentially fatal working environment for nearby operators.

[0002] While utilizing natural gas may address some of the drawbacks of conventional fuels, the storage and transport of natural gas often prevents it from being viewed as a viable alternative to conventional fuels. Accordingly, natural gas is routinely converted to liquefied natural gas (LNG) via one or more thermodynamic processes. The thermodynamic processes utilized to convert natural gas to LNG may often include circulating one or more refrigerants (*e.g*., single mixed refrigerants, duel mixed refrigerants, *etc.)* through a refrigerant cycle. While various thermodynamic processes have been developed for the production of LNG, conventional thermodynamic processes may often fail to produce LNG in quantities sufficient to meet increased demand. Further, the complexity of the conventional thermodynamic processes may often make the production of LNG cost prohibitive and/or impractical. For example, the production of LNG via conventional thermodynamic processes may often require the utilization of additional and/or cost-prohibitive equipment (*e.g*., compressors, heat exchangers, *etc.).*

[0003] What is needed, then, is an improved, simplified liquefaction system and method for producing liquefied natural gas (LNG).

Summary

[0004] Embodiments of this disclosure may provide a liquefaction system. The liquefaction system may include a first heat exchanger, a first compression assembly, a second compression assembly, and a precooler assembly. The first heat exchanger may be configured to receive a natural gas stream from a natural gas source and cool at least a first portion of the natural gas stream to liquefied natural gas. The first compression assembly may be fluidly coupled to the first heat exchanger and configured to circulate a first refrigerant through the first heat exchanger to cool the first portion of the natural gas stream to the liquefied natural gas. The first compression assembly may include a plurality of first refrigerant compressors configured to compress the first refrigerant, and a plurality of turbines configured to drive the plurality of first refrigerant compressors. The precooler assembly may be fluidly coupled to the first compression assembly and the first heat exchanger and configured to cool the natural gas stream and the first refrigerant compressed by the plurality of first refrigerant compressors prior to the natural gas stream entering the first heat exchanger. The precooler assembly may include a plurality of chillers configured to transfer thermal energy from the first refrigerant and the natural gas stream to a second refrigerant. The second compression assembly may be fluidly coupled to the precooler assembly. The second compression assembly may include a plurality of second refrigerant compressors configured to compress the second refrigerant and circulate the second refrigerant to the plurality of chillers. The second compression assembly may also include a plurality of drivers. Each driver may be coupled to at least one of the second refrigerant compressors and configured to drive at least one of the second refrigerant compressors.

[0005] Embodiments of this disclosure may provide another liquefaction system. The liquefaction system may include a plurality of liquefaction subsystems. Each liquefaction subsystem of the plurality of liquefaction subsystems may be configured to receive a portion of a natural gas stream from a natural gas source. Each liquefaction subsystem may include a heat exchanger, a first compression assembly, a second compression assembly, and a precooler assembly. The heat exchanger may be configured to receive the portion of natural gas stream from the natural gas source and cool at least a fraction of the portion of the natural gas stream to liquefied natural gas. The first compression assembly may be fluidly coupled to the heat exchanger and configured to circulate a first refrigerant through the heat exchanger to cool the fraction of the portion of the natural gas stream to the liquefied natural gas. The first compression assembly may include a plurality of first refrigerant compressors configured to compress the first refrigerant, and a plurality of turbines configured to drive the plurality of first refrigerant compressors. The precooler assembly may be fluidly coupled to the first compression assembly and the heat exchanger and configured to cool the portion of the natural gas stream and the first refrigerant compressed by the plurality of first refrigerant compressors prior to the portion of the natural gas stream entering the heat exchanger. The precooler assembly may include a plurality of chillers configured to transfer thermal energy from the first refrigerant and the natural gas stream to a second refrigerant. The second compression assembly may be fluidly coupled to the precooler assembly. The second compression assembly may include at least one second refrigerant compressor configured to compress the second refrigerant and circulate the second refrigerant to the plurality of chillers. The second compression assembly may also include at least one driver. The at least one driver may be coupled to the at least one second refrigerant compressor and configured to drive the at least one second refrigerant compressor.

[0006] Embodiments of this disclosure may further provide a method for producing liquefied natural gas from a natural gas source. The method may include feeding at least an initial portion of a natural gas stream to a plurality of chillers, and compressing a first refrigerant in at least one first refrigerant compressor. The at least one first refrigerant compressor may be driven by a variable speed drive or a fixed speed motor. The method may also include compressing a single mixed refrigerant in a plurality of second refrigerant compressors. Each of the plurality of second refrigerant compressors may be driven by a respective turbine. The method may further include transferring thermal energy from the single mixed refrigerant and the initial portion of the natural gas stream to the first refrigerant in the plurality of chillers. The method may also include feeding a first portion of the single mixed refrigerant and a first portion of the initial portion of the natural gas stream to a first heat exchanger to cool at least a fraction of the first portion of the natural gas stream flowing therethrough to thereby produce a first portion of the liquefied natural gas.

Brief Description of the Drawings

[0007] The present disclosure is best understood from the following detailed description when read with the accompanying Figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

Figure 1 illustrates a process flow diagram of an exemplary liquefaction system for producing liquefied natural gas (LNG) from a natural gas source, according to one or more embodiments disclosed.

Figure 2 illustrates a process flow diagram of another exemplary liquefaction system for producing LNG from a natural gas source, according to one or more embodiments disclosed.

Figure 3 illustrates a process flow diagram of another exemplary liquefaction system for producing LNG from a natural gas source, according to one or more embodiments disclosed.

Figure 4 illustrates a process flow diagram of another exemplary liquefaction system for producing LNG from a natural gas source, according to one or more embodiments disclosed.

Figure 5 illustrates a process flow diagram of another exemplary liquefaction system for producing LNG from a natural gas source, according to one or more embodiments disclosed.

Figure 6 illustrates a process flow diagram of another exemplary liquefaction system for producing LNG from a natural gas source, according to one or more embodiments disclosed.

Figure 7 is a flowchart depicting a method for producing liquefied natural gas, according to one or more embodiments disclosed.

Detailed Description

[0008] It is to be understood that the following disclosure describes several exemplary embodiments for implementing different features, structures, or functions of the invention. Exemplary embodiments of components, arrangements, and configurations are described below to simplify the present disclosure; however, these exemplary embodiments are provided merely as examples and are not intended to limit the scope of the invention. Additionally, the present disclosure may repeat reference numerals and/or letters in the various exemplary embodiments and across the Figures provided herein. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various exemplary embodiments and/or configurations discussed in the various Figures. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact. Finally, the exemplary embodiments presented below may be combined in any combination of ways, *i.e.,* any element from one exemplary embodiment may be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0009] Additionally, certain terms are used throughout the following description and claims to refer to particular components. As one skilled in the art will appreciate, various entities may refer to the same component by different names, and as such, the naming convention for the elements described herein is not intended to limit the scope of the invention, unless otherwise specifically defined herein. Further, the naming convention used herein is not intended to distinguish between components that differ in name but not function. Additionally, in the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to." All numerical values in this disclosure may be exact or approximate values unless otherwise specifically stated. Accordingly, various embodiments of the disclosure may deviate from the numbers, values, and ranges disclosed herein without departing from the intended scope. Furthermore, as it is used in the claims or specification, the term "or" is intended to encompass both exclusive and inclusive cases, *i.e.,* "A or B" is intended to be synonymous with "at least one of A and B," unless otherwise expressly specified herein.

[0010] Example embodiments disclosed herein provide improved systems and methods for producing liquefied natural gas from a natural gas source. Particularly, example embodiments disclosed herein may include improvements to propane pre-cooled mixed refrigerant (C3MR) systems and processes utilized for the production of liquefied natural gas from a natural gas source. As provided herein, each exemplary system and method for producing liquefied natural gas from a natural gas source may include a reduced number of turbines, compressors, and/or coolers as compared to conventional C3MR systems and processes while maintaining substantially similar production of liquefied natural gas. Such a reduction in the number of turbines, compressors, and/or coolers results in reduced capital expenditures, maintenance, and downtime resulting from failure of one or more process components.

[0011] Turning now to the Figures, Figure 1 illustrates a process flow diagram of an exemplary liquefaction system 100 for producing liquefied natural gas (LNG) from a natural gas source 102, according to one or more embodiments. As further discussed herein, the liquefaction system 100 may be configured to receive natural gas or feed gas from the natural gas source 102, direct or flow the feed gas through the liquefaction system 100 in the form of a product or feed gas stream 104 to cool at least a portion of the feed gas to LNG, and discharge or output the LNG. The liquefaction system 100 may also be configured to direct or flow process fluids containing one or more refrigerants through respective refrigerant loops or cycles (*e.g.*, pre-cooling cycle, liquefaction cycle, *etc.*) to cool at least a portion of the feed gas of the feed gas stream 104.

[0012] The natural gas source 102 may be or include a natural gas pipeline, a stranded natural gas wellhead, or the like, or any combination thereof. The natural gas source 102 may contain natural gas at ambient temperature. The natural gas source 102 may contain natural gas having a temperature relatively greater than or relatively less than ambient temperature. The natural gas source 102 may also contain natural gas at a relatively high pressure (*e.g.*, about 3,400 kPa to about 8,400 kPa or greater) or a relatively low pressure (*e.g.*, about 100 kPa to about 3,400 kPa). For example, the natural gas source 102 may be a high pressure natural gas pipeline containing natural gas at a pressure from about 3,400 kPa to about 8,400 kPa or greater. In another example, the natural gas source 102 may be a low pressure natural gas pipeline containing natural gas at a pressure from about 100 kPa to about 3,500 kPa.

[0013] The natural gas from the natural gas source 102 may include one or more hydrocarbons. For example, the natural gas may include methane, ethane, propane, butanes, pentanes, or the like, or any combination thereof. Methane may be a major component of the natural gas. For example, the concentration of methane in the natural gas may be greater than about 80%, greater than about 85%, greater than about 90%, or greater than about 95%. The natural gas may also include one or more non-hydrocarbons. For example, the natural gas may be or include a mixture of one or more hydrocarbons and one or more non-hydrocarbons. Illustrative non-hydrocarbons may include, but are not limited to, water, carbon dioxide, helium, nitrogen, mercury, or any combination thereof.

[0014] The natural gas may be treated to separate or remove at least a portion of the non-hydrocarbons from the natural gas. For example, the natural gas may be flowed through a separator (not shown) containing one or more adsorbents (*e.g.*, molecular sieves, zeolites, metal-organic frameworks, *etc.)* configured to at least partially separate one or more of the non-hydrocarbons from the natural gas. In an exemplary embodiment, the natural gas may be treated to separate the non-hydrocarbons (*e.g.*, water and/or carbon dioxide) from the natural gas to increase a concentration of the hydrocarbon and/or prevent the natural gas from subsequently crystallizing (*e.g.*, freezing) in one or more portions of the liquefaction system 100. For example, in one or more portions of the liquefaction system 100, the feed gas containing the natural gas may be cooled to or below a freezing point of one or more of the non-hydrocarbons (*e.g.*, water and/or carbon dioxide). Accordingly, removing water and/or carbon dioxide from the natural gas may prevent the subsequent crystallization of the feed gas in the liquefaction system 100.

[0015] As illustrated in Figure 1, the liquefaction system 100 may include a precooler assembly 106, one or more main heat exchangers (two are shown 108a, 108b), and a plurality of compression assemblies 110, 112. The precooler assembly 106 may be fluidly coupled with the natural gas source 102 and configured to flow therethrough the feed gas stream 104. The plurality of compression assemblies 110, 112 may include a precooling compression assembly 110 and a liquefaction compression assembly 112, where each of the precooling compression assembly 110 and the liquefaction compression assembly 112 may be fluidly coupled with at least one of the precooler assembly 106 and the main heat exchangers 108a, 108b. For example, as illustrated in Figure 1 and as will be discussed in further detail below, the precooling compression assembly 110 may be fluidly coupled with the precooler assembly 106 as part of a precooling loop or cycle (indicated by the "···" line). The liquefaction compression assembly 112 may be fluidly coupled with each of the precooler assembly 106 and the main heat exchangers 108a, 108b as part of a liquefaction loop or cycle (indicated by the "-·-·-" line).

[0016] The precooling compression assembly 110 may be configured to compress a process fluid directed thereto via the precooling loop. The precooling loop may be a closed-loop refrigerant cycle. The process fluid directed through the precooling loop may be or include a refrigerant. In one or more embodiments, the refrigerant may be a hydrocarbon. Illustrative hydrocarbons may include, but are not limited to, methane, ethane, propane, butanes, pentanes, or the like. Accordingly, in one or more embodiments, the process fluid flowing through the precooling loop may be propane. As discussed above, the precooling compression assembly 110 may be fluidly coupled with the precooler assembly 106 as part of the precooling loop. As such, the precooling compression assembly 110 may compress the process fluid directed thereto from the precooler assembly 106 and discharge the process fluid therefrom to an outlet manifold 114, whereby the process fluid may be directed back to the precooler assembly 106 via the precooling loop. The precooler assembly 106 may include a plurality of chillers 116a-d configured to transfer thermal energy from the feed gas in the feed gas stream 104 and the contents of the liquefaction loop to the process fluid flowing through the precooling loop, thereby vaporizing at least a portion of the process fluid flowing through the chillers 116a-d prior to the process fluid being returned to the precooling compression assembly 110. In turn, the feed gas in the feed gas stream 104 and the contents of the liquefaction loop flowing through the precooler assembly 106 may be cooled before entering the main heat exchangers 108a, 108b.

[0017] The precooling compression assembly 110 may include one or more compressors (four are shown 118a-d) configured to compress the process fluid flowing through the precooling loop. As shown in Figure 1, the compressors 118a-d may be fluidly arranged in parallel with one another and fluidly coupled with the precooler assembly 106 in the precooling loop. Illustrative compressors 118a-d may include, but are not limited to, supersonic compressors, centrifugal compressors, axial flow compressors, reciprocating compressors, rotating screw compressors, rotary vane compressors, scroll compressors, diaphragm compressors, or the like, or any combination thereof. Each of the compressors 118a-d may include one or more stages (four shown). For example, each of the compressors 118a-d may include a first stage, a final stage, and/or one or more intermediate stages disposed between the first stage and the final stage. In some embodiments, one or more stages of each of the compressors 118a-d may be associated with a respective inlet flange (not shown) of the compressor. Generally, the number of chillers 116a-d utilized in the precooler assembly 106 may be based on the number of inlet flanges of each of the compressors 118a-d. The selection of the compressors 118a-d, and correspondingly, the number of chillers 16a-d may be based, amongst other factors, on the site ambient temperature and/or the composition of the feed gas.

[0018] The precooling compression assembly 110 may also include one or more drivers (four are shown 120a-d) operatively coupled with and configured to drive each of the compressors 118a-d and/or the respective compressor stages thereof. For example, as illustrated in Figure 1, each driver 120a-d may be coupled with and configured to drive a respective compressor 118a-d via a respective rotary shaft 122a-d. Each driver 120a-d may be a fixed speed motor or a variable speed motor. In one or more embodiments, each driver 120a-d may be a variable speed drive (VSD). Each of the rotary shafts 122a-d may be a single segment or may be formed from multiple segments coupled with one another via one or more gears (not shown) and/or one or more couplers. It should be appreciated that the manner of coupling the multiple segments of the rotary shaft 122a-d may allow each of the multiple segments of the rotary shaft 122a-d to rotate or spin at the same or different rates or speeds.

[0019] The precooling compression assembly 110 may further include one or more aftercoolers (four shown 124a-d) as part of the precooling loop. As illustrated in Figure 1, each aftercooler 124a-d may be fluidly coupled with and downstream from a respective compressors 118a-d, where the respective outputs from the aftercoolers 124a-d are collectively discharged into the outlet manifold 114. Each of the aftercoolers 124a-d may further be fluidly coupled with and disposed upstream from the precooler assembly 106. In one or more embodiments, each of the aftercoolers 124a-d may be a condenser configured to absorb or remove heat from the process fluid (*e.g.*, the refrigerant) flowing therethrough. Each of the aftercoolers 124a-d may be configured to remove at least a portion of the thermal energy or heat generated in the respective compressors 118a-d. For example, compressing the process fluid (*e.g.,* the refrigerant) in the compressors 118a-d may generate heat (*e.g.,* heat of compression) in the process fluid, and the aftercoolers 124a-d may be configured to remove at least a portion of the heat of compression from the process fluid and/or the refrigerants contained therein.

[0020] In at least one embodiment, a heat transfer medium may flow through each of the aftercoolers 124a-d to absorb the heat in the process fluid flowing therethrough. Accordingly, the heat transfer medium may have a higher temperature when discharged from the aftercoolers 124a-d and the process fluid may have a lower temperature when discharged from the aftercoolers 124a-d. The heat transfer medium may be or include water, steam, a refrigerant, air, a process gas, such as carbon dioxide, propane, or natural gas, or the like, or any combination thereof. In an exemplary embodiment, the heat transfer medium discharged from each of the aftercoolers 124a-d may provide supplemental heating to one or more portions and/or assemblies of the liquefaction system 100.

[0021] As discussed above, the liquefaction compression assembly 112 may be fluidly coupled with each of the precooler assembly 106 and the main heat exchangers 108a, 108b via the liquefaction loop (indicated by the

"-·-·-" line). The liquefaction compression assembly 112 may be configured to compress a process fluid directed thereto via the liquefaction loop from the main heat exchangers 108a, 108b and to discharge the compressed process fluid to the precooler assembly 106 via the liquefaction loop. The liquefaction loop may be a closed-loop refrigerant cycle. The process fluid directed through the liquefaction loop may be or include a single mixed refrigerant. The single mixed refrigerant may be a multicomponent fluid mixture containing one or more hydrocarbons. Illustrative hydrocarbons may include, but are not limited to, methane, ethane, propane, butanes, pentanes, or the like, or any combination thereof.

[0022] In at least one embodiment, the single mixed refrigerant may be a multicomponent fluid mixture containing one or more hydrocarbons and one or more non-hydrocarbons. For example, the single mixed refrigerant may be or include a mixture of one or more hydrocarbons and one or more non-hydrocarbons. Illustrative non-hydrocarbons may include, but are not limited to, carbon dioxide, nitrogen, argon, or the like, or any combination thereof. In another embodiment, the single mixed refrigerant may be or include a mixture containing one or more non-hydrocarbons. In an exemplary embodiment, the process fluid directed through the liquefaction loop may be a single mixed refrigerant containing methane, ethane, propane, butanes, and/or nitrogen. In at least one embodiment, the single mixed refrigerant may include R42, R410a, or the like.

[0023] The liquefaction compression assembly 112 may include a plurality of compressors (six are shown 126a-f) configured to compress the process fluid directed thereto via the liquefaction loop. As arranged in Figure 1, the compressors 126a-f may be fluidly coupled in pairs, such that the discharge of a compressor of the pair may be fed to the inlet of the other compressor of the pair. For example, the process fluid compressed and discharged from compressors 124a-c may be received by and compressed in compressors 124d-f, respectively. Such a configuration provides for one compressor in the pair to discharge the compressed process fluid at a lower pressure than the other compressor of the pair. Accordingly, as a pair, one compressor may be referred to as the low pressure compressor and the other compressor of the pair receiving the compressed process fluid from the low pressure compressor may be referred to as the high pressure compressor. Thus, as illustrated in Figure 1, the compressors 126a-c may be referred to as low pressure compressors, and the compressors 126d-f may be referred to as high pressure compressors. In addition, each pair may be fluidly arranged in parallel with the other pairs of the liquefaction compression assembly 112. Accordingly, each pair of the compressors 126a-f may be fluidly coupled with the main heat exchangers 108a, 108b via an inlet manifold 128 and with the precooling assembly via an outlet manifold 130.

[0024] The liquefaction compression assembly 112 may also include one or more drivers (six are shown 132a-f) operatively coupled with and configured to drive each of the compressors 126a-f and/or the respective compressor stages thereof. For example, as illustrated in Figure 1, each driver 132a-f may be coupled with and configured to drive a respective compressor 126a-f via a rotary shaft 134a-f. Each of the drivers may be a turbine (*e.g.*, industrial gas turbines, aeroderivative gas turbines, steam turbines, *etc.* In one embodiment, each driver 132a-f may be an aeroderivative gas turbine. An exemplary aeroderivative gas turbine may be the Industrial Trent 60 gas turbine manufactured by Siemens AG of Munich, Germany.

[0025] In another embodiment, each compressor 126a-f in the respective pair of compressors 126a-f is driven by a different type of driver 132a-f. Accordingly, each driver 132a-f may have a different power rating. For example, in each pair of compressors 126a-f, the low pressure compressor 126a-c may be driven by an aeroderivative gas turbine, such as the Industrial Trent 60 gas turbine, and the high pressure compressor 126d-f may be driven by an industrial gas turbine. An exemplary industrial gas turbine may be the SGT-750 gas turbine manufactured by Siemens AG of Munich, Germany. Each of the rotary shafts 134a-f may be a single segment or may be formed from multiple segments coupled with one another via one or more gears (not shown) and/or one or more couplers. It should be appreciated that the manner of coupling the multiple segments of the rotary shaft 134a-f may allow each of the multiple segments of the rotary shaft 134a-f to rotate or spin at the same or different rates or speeds.

[0026] The liquefaction compression assembly 112 may also include a plurality of coolers or heat exchangers (six are shown 136a-f) configured to absorb or remove heat from the process fluid *(e.g.,* the single mixed refrigerant) flowing therethrough. The plurality of coolers 136a-f may include at least one intercooler (three shown 136a-c), where a respective intercooler 136a-c may be fluidly coupled with and disposed in between the compressors 126a-f in each pair of compressors 126a-f. As shown in Figure 1, each pair of compressors 126a-f includes an intercooler 136a-c disposed therebetween. The plurality of coolers 136a-f may further include at least one aftercooler (three shown 136d-f), where a respective aftercooler 136d-f may be fluidly coupled with a discharge of each pair of compressors 126a-f. Accordingly, each aftercooler 136d-f may be fluidly disposed between a respective pair of the compressors 126a-f and the outlet manifold 130. Each of the aftercoolers 136d-f may be a condenser. Each cooler 136a-f of the plurality of coolers 136a-f may be configured to remove at least a portion of the thermal energy or heat generated in the respective pair of compressors 126a-f. For example, compressing the process fluid *(e.g.,* the refrigerant) in the compressors 126a-f may generate heat *(e.g.,* heat of compression) in the process fluid, and the coolers 136a-f may be configured to remove at least a portion of the heat of compression from the process fluid and/or the refrigerants contained therein.

[0027] The liquefaction system 100 may further include one or more liquid separators (two shown 138a, 138b) forming part of the liquefaction loop. The liquid separators 138a, 138b may be fluidly coupled with and disposed downstream from the chillers 116a-d of the precooler assembly 106 in the liquefaction loop. For example, as illustrated in Figure 1, each of the liquid separators 138a, 138b may be arranged to receive a respective portion 140a, 140b of the process fluid flowing from the precooler assembly 106. Accordingly, each of the liquid separators 138a, 138b may be configured to receive a process fluid containing a liquid phase (*e.g.*, a liquid refrigerant) and a gaseous phase (*e.g.*, a vapor or gaseous refrigerant), and separate the liquid phase and the gaseous phase from one another. For example, as further described herein, each of the liquid separators 138a, 138b may be configured to separate a liquid phase containing relatively high boiling point refrigerants (e.g., liquid refrigerant) and a gaseous phase containing relatively lower boiling point refrigerants *(e.g.,* a vapor or gaseous refrigerant) from one another. Illustrative liquid separators 138a, 138b may include, but are not limited to, scrubbers, liquid-gas separators, rotating separators, stationary separators, or the like.

[0028] The main heat exchangers 108a, 108b may be fluidly coupled with and disposed downstream from the respective liquid separators 138a, 138b and configured to receive one or more process fluids therefrom. For example, as illustrated in Figure 1, the main heat exchanger 108a may be fluidly coupled with and disposed downstream from the liquid separator 138a via line 142a and line 144a and configured to receive a process fluid therefrom. Correspondingly, as shown in Figure 1, the main heat exchanger 108b may be fluidly coupled with and disposed downstream from the liquid separator 138b via line 142b and line 144b and configured to receive a process fluid therefrom. As arranged, the main heat exchangers 108a, 108b may operate in parallel with one another as illustrated in Figure 1.

[0029] In another embodiment, the main heat exchangers 108a, 108b may be fluidly coupled with and disposed downstream from a pump (not shown) and configured to receive a process fluid therefrom. The pump may be fluidly coupled with and downstream from the precooler assembly 106 and configured to direct a process fluid containing a liquid phase (*e.g.,* a liquid refrigerant) from the precooler assembly 106 to the main heat exchangers 108a, 108b. The pump may be an electrically driven pump, a mechanically driven pump, a variable frequency driven pump, or the like.

[0030] As arranged, each of the heat exchangers 108a, 108b may be fluidly coupled with and disposed upstream of the liquefaction compression assembly 112 and configured to direct one or more process fluids thereto via the liquefaction loop. For example, as illustrated in Figure 1, each of the main heat exchangers 108a, 108b may be disposed upstream of and fluidly coupled with the liquefaction compression assembly 112 via the inlet manifold 128. As further illustrated in Figure 1, each of the main heat exchangers 108a, 108b may be fluidly coupled with and disposed downstream from the natural gas source 102 and configured to receive at least a respective portion 104a, 104b of the feed gas stream 104 therefrom.

[0031] Each of the main heat exchangers 108a, 108b may be any device capable of directly or indirectly cooling and/or sub-cooling at least a portion of the feed gas flowing therethrough via the feed gas stream 104. For example, each main heat exchanger 108a, 108b may be a wound coil heat exchanger, a plate-fin heat exchanger, a shell and tube heat exchanger, a kettle type heat exchanger, or the like. In one or more embodiments, each main heat exchanger 108a, 108b may be a wound coil heat exchanger. In at least one embodiment, each main heat exchanger 108a, 108b may include one or more regions or zones (two zones are shown for each 146a, 148a and 146b, 148b). For example, as illustrated in Figure 1, a first zone 146a, 146b of each main heat exchanger 108a, 108b may be a pre-cooling zone, and a second zone 148a, 148b of each main heat exchanger 108a, 108b may be a liquefaction zone. As further described herein, each main heat exchanger 108a, 108b may be configured to pre-cool the refrigerants and/or the feed gas flowing through the pre-cooling zone 146a, 146b. Each main heat exchanger 108a, 108b may also be configured to liquefy at least a portion of the feed gas in the feed gas stream 104 to LNG in the liquefaction zone 148a, 148b.

[0032] The liquefaction system 100 may include a plurality of expansion elements (four are shown 150a, 150b, 152a, 152b) configured to receive and expand a process fluid to thereby decrease a temperature and pressure thereof. Illustrative expansion elements 150a, 150b, 152a, 152b may include, but are not limited to, a turbine or turbo-expander, a geroler, a gerotor, an expansion valve, such as a Joule-Thomson (JT) valve, or the like, or any combination thereof. In at least one embodiment, any of the expansion elements 150a, 150b, 152a, 152b may be a turbo-expander (not shown) configured to receive and expand a portion of the process fluid to thereby decrease a temperature and pressure thereof. The turbo-expander (not shown) may be configured to convert the pressure drop of the process fluid flowing therethrough to mechanical energy, which may be utilized to drive one or more devices (e.g., generators, compressors, pumps, *etc.).* In another embodiment, illustrated in Figure 1, each of the expansion elements 150a, 150b, 152a, 152b may be an expansion valve, such as a JT valve.

[0033] As illustrated in Figure 1, each of the expansion valves 150a, 152a may be fluidly coupled with the main heat exchanger 108a and configured to receive and expand a process fluid *(e.g.,* the single mixed refrigerant) from the main heat exchanger 108a to thereby decrease a temperature and pressure thereof. Correspondingly, each of the expansion elements 150b, 152b may be fluidly coupled with the main heat exchanger 108b and configured to receive and expand a process fluid (*e.g.*, the single mixed refrigerant) from the main heat exchanger 108b to thereby decrease a temperature and pressure thereof. For example, expansion valves 150a, 150b may be disposed downstream from the respective heat exchangers 108a, 108b via respective lines 154a and 154b, and may further be disposed upstream of the respective main heat exchangers 108a, 108b via respective lines 156a and 156b. In another example, expansion valves 152a, 152b may be disposed downstream from the respective main heat exchangers 108a, 108b via respective lines 158a and 158b, and may further be disposed upstream of the respective main heat exchangers 108a, 108b via respective lines 160a and 160b. In at least one embodiment, the expansion of the process fluid through any one or more of the expansion valves 150a, 150b, 152a, 152b may flash the process fluid into a two-phase fluid including a gaseous or vapor phase and a liquid phase.

[0034] Turning now to an exemplary operation of the liquefaction system 100, a process fluid containing a refrigerant, such as propane, may be compressed and directed to the aftercoolers 124a-d, where the process fluid is cooled and condensed. The condensed process fluid may be collectively discharged from the aftercoolers 124 into the outlet manifold 114 of the precooling loop. The condensed process fluid may then be directed into respective chillers 116a-d. The process fluid may be vaporized in each chiller 116a-d via the heat transferred thereto from the feed gas stream 104 and the process fluid including a single mixed refrigerant flowing through the liquefaction loop in each of the respective chillers 116a-d. The process fluid may be discharged from the chillers 116a-d and fed to respective stages of the compressors 118a-d for recompression.

[0035] In some embodiments, the compressors 118a-d may be fluidly arranged in parallel. As such, each compressor 118a-d may be selectively fluidly coupled to the precooling loop via isolating valves (not shown) to allow for one or more compressors 118a-d to be taken offline while maintaining the precooling loop in operation. In addition, in one or more embodiments, the precooling loop may include a plurality of drums or separators (not shown) configured to separate the liquid and gaseous phases of the refrigerant prior to the refrigerant entering the compressors 118a-d and/or the chillers 116a-d. In such embodiments, the precooling loop may include additional lines to redirect the liquid and gaseous phases to the proper components of the precooling loop.

[0036] The cycle of compression may be repeated in the precooling loop, thereby creating a propane refrigerant, pre-cooling loop in the exemplary operation of the liquefaction system 100. The precooler assembly 106 thereby is utilized to cool both the single mixed refrigerant in the liquefaction loop flowing therethrough and the feed gas stream 104 flowing therethrough prior to each of the single mixed refrigerant in the liquefaction loop and the feed gas stream 104 entering the main heat exchangers 108a, 108b. The operation of the precooling loop may be dependent on the operating characteristics of the liquefaction loop. Conversely, the operation of the liquefaction loop may be dependent on at least the operating characteristics of the precooling loop. For example, the operation of the liquefaction loop may depend at least in part on the volume of refrigerant flowing through the precooling loop. Conversely, the operation of the precooling loop may depend at least in part on the volume of refrigerant flowing through the liquefaction loop.

[0037] The cooled single mixed refrigerant exiting the precooler assembly 106 in the liquefaction loop may be split into the two portions 140a, 140b and directed to the respective liquid separators 138a, 138b. Each of the liquid separators 138a, 138b may receive the respective portion 140a, 140b of the cooled single mixed refrigerant and separate the cooled single mixed refrigerant into a liquid phase and a gaseous phase. For example, each of the liquid separators 138a, 138b may separate at least a portion of the liquid phase containing the condensed portions of the single mixed refrigerant (*e.g.*, the relatively high molecular weight hydrocarbons) from the gaseous phases containing the non-condensed portions of the single mixed refrigerant (*e.g.*, the relatively low molecular weight hydrocarbons). The separated liquid and gaseous phases may then be directed from each of the liquid separators 138a, 138b to the respective main heat exchangers 108, 108b. For the sake of brevity, the operation of only main heat exchanger 108a will be discussed below; however, those of skill in the art will appreciate that the main heat exchanger 108b may operate in a similar manner as the manner disclosed in reference to the main heat exchanger 108a.

[0038] As shown in Figure 1, the liquid phase from the liquid separator 138a may be directed to the main heat exchanger 108a as a first portion of the single mixed refrigerant via line 144a. The gaseous phase from the liquid separator 138a may be directed to the main heat exchanger 108a as a second portion of the single mixed refrigerant via line 142a. The first portion of the single mixed refrigerant (*e.g.*, the liquid phase) may be directed through the pre-cooling zone 146a of the main heat exchanger 108a to pre-cool the second portion of the single mixed refrigerant (*e.g.*, the gaseous phase) flowing through the main heat exchanger 108a. The first portion of the single mixed refrigerant may also be directed through the pre-cooling zone 146a to pre-cool the feed gas flowing through the feed gas stream 104a. The first portion of the single mixed refrigerant may then be directed to the expansion valve 152a via line 158a, and the expansion valve 152a may expand the first portion of the single mixed refrigerant to thereby decrease the temperature and pressure thereof. The first portion of the single mixed refrigerant from the expansion valve 152a may then be combined with the second portion of the single mixed refrigerant exiting the liquefaction zone 148a and directed to and through the main heat exchanger 108a from line 160a to provide further cooling or precooling to the second portion of the single mixed refrigerant and/or the feed gas flowing through the precooling zone 146a of the main heat exchanger 108a.

[0039] The second portion of the single mixed refrigerant (*e.g.*, the gaseous phase) from the liquid separator 138a may be directed through the pre-cooling zone 146a of the main heat exchanger 108a via line 142a. As discussed above, the second portion of the single mixed refrigerant flowing through the main heat exchanger 108a from line 142a may be pre-cooled by the first portion of the single mixed refrigerant in the pre-cooling zone 146a. The pre-cooled second portion of the single mixed refrigerant may then be directed through the liquefaction zone 148a cooling the feed gas stream 104 and flowing to the expansion valve 150a via line 154a, and the expansion valve 150a may expand the second portion of the single mixed refrigerant to thereby decrease the temperature and pressure thereof. The second portion of the single mixed refrigerant from the expansion valve 150a may then be directed back to and through the liquefaction zone 148a of the main heat exchanger 108a via line 156a to further cool at least a portion of the feed gas flowing through the feed gas stream 104a. The second portion of the single mixed refrigerant may then be combined with the first portion of the single mixed refrigerant as discussed above and returned to the precooling zone 146a. In at least one embodiment, the first and second portions of the single mixed refrigerant flowing through the main heat exchanger 108a may sufficiently cool at least a portion of the feed gas flowing through the feed gas stream 104 to LNG. The LNG produced may be discharged from the main heat exchanger 108a via line 162. The discharged LNG in line 162 may be directed to a storage tank (not shown) via a flow control valve (not shown).

[0040] The heated or "spent" first portion of the single mixed refrigerant and the "spent" second portion of the single mixed refrigerant from each of the heat exchangers 108a, 108b may be collectively directed to the liquefaction compression assembly 112. The "spent" first and second portions of the single mixed refrigerant from the main heat exchangers 108, 108b may be split into three flow portions in the inlet manifold 128, where each flow portion is directed to the respective low pressure compressor 126a-c of the pairs of compressors 126a-f fluidly arranged in parallel in the liquefaction compression assembly 112. The single mixed refrigerant may be compressed in each flow portion and fed to a respective intercooler 136a-c. Each of the intercoolers 136a-c may be disposed between respective low pressure compressors 126a-c and high pressure compressors 126d-f of the liquefaction compression assembly 112. The single mixed refrigerant may be cooled in each intercooler 136a-c and fed to a respective high pressure compressor 126d-f. Each of the compressors 126a-f in the liquefaction compression assembly 112 may be driven by separate drivers 132a-f. In one embodiment, each of the low pressure compressors 126a-c may be driven by an aeroderivative gas turbine, and each of the high pressure compressors 126d-f may be driven by an industrial gas turbine. The single mixed refrigerant discharged from each of the high pressure compressors 126d-f may be fed through a respective aftercooler 136d-f, where each flow portion of the single mixed refrigerant may be cooled. The respective flow portions may then be collectively discharged into the outlet manifold 130 and directed to the precooler assembly 106 via the liquefaction loop. The compressed process fluid containing the single mixed refrigerant may then be re-directed through the liquefaction loop as described above.

[0041] Referring now to Figure 2 with continued reference to Figure 1, Figure 2 illustrates a process flow diagram of another exemplary liquefaction system 200 for producing LNG from the natural gas source 102, according to one or more embodiments disclosed. The liquefaction system 200 may be similar in some respects to the liquefaction system 100 described above and thus may be best understood with reference to Figure 1 and the description thereof, where like numerals designate like components and will not be described again in detail. In the liquefaction system 200 of Figure 2, the liquefaction system 200 may be configured to operate with a single main heat exchanger 208. The main heat exchanger 208 may be sized and configured to cool the volume of feed gas provided thereto. In one or more embodiments, the main heat exchanger 208 may be sized and configured such that the main heat exchanger 208 is capable of receiving and cooling a greater volume of feed gas to LNG than either of the two main heat exchangers 108a and 108b depicted in Figure 1. Accordingly, the single main heat exchanger 208 may be sized and configured to cool at least an equivalent volume of feed gas to LNG as the combined volume of feed gas cooled to LNG in the main heat exchangers 108a and 108b of Figure 1. Thus, as illustrated, the main heat exchanger 208 in Figure 2 may be used in place of the main heat exchangers 108a and 108b, and may be fluidly coupled with and downstream from the precooling assembly 106 and a single liquid separator 238 via lines 242 and 244, and further disposed upstream of and fluidly coupled with the liquefaction compression assembly 112 via the inlet manifold 128.

[0042] Referring now to Figure 3 with continued reference to Figure 1, Figure 3 illustrates a process flow diagram of another exemplary liquefaction system 300 for producing LNG from the natural gas source 102, according to one or more embodiments disclosed. The liquefaction system 300 may be similar in some respects to the liquefaction system 100 described above and thus may be best understood with reference to Figure 1 and the description thereof, where like numerals designate like components and will not be described again in detail. In the liquefaction system 300 of Figure 3, the liquefaction system 300 includes a precooling compression assembly 310 having two compressors 318a and 318b fluidly arranged in parallel, where each compressor 318a, 318b is fluidly coupled to a respective aftercooler 324a, 324b.

Each of the two compressors 318a and 318b may be capable of receiving and compressing a greater volume of process fluid than any of the four compressors 118a-d depicted in Figure 1. For example, the two compressors 318a, 318b may be sized and configured to compress at least an equivalent volume of the process fluid as the combined volume of process gas compressed in the four compressors 118a-d of Figure 1. As such, the two aftercoolers 324a and 324b may be configured to cool the volume of process fluid provided thereto from respective compressors 318a and 318b and collectively discharge the process fluid to manifold 314, where the process fluid may be directed to the precooler assembly.

[0043] Referring now to Figure 4, Figure 4 illustrates a process flow diagram of another exemplary liquefaction system 400 for producing LNG from the natural gas source 102, according to one or more embodiments disclosed. The liquefaction system 400 may be similar in some respects to the liquefaction systems 100 and 300 described above and thus may be best understood with reference to Figures 1 and 3 and the description thereof, where like numerals designate like components and will not be described again in detail. In the liquefaction system 400 of Figure 4, the liquefaction system 400 includes a liquefaction compression assembly 412 having a high pressure compressor header 420 fluidly coupling the discharged compressed process fluid from each of the low pressure compressors 126a-c.

[0044] Referring now to Figure 5, Figure 5 illustrates a process flow diagram of another exemplary liquefaction system 500 for producing LNG from the natural gas source 102, according to one or more embodiments disclosed. The liquefaction system 500 may be similar in some respects to the liquefaction systems 100 and 200 described above and thus may be best understood with reference to Figures 1 and 2 and the description thereof, where like numerals designate like components and will not be described again in detail. As illustrated in Figure 5, the liquefaction system 500 may include a plurality of liquefaction subsystems (three shown 502a-c) fluidly coupled to the natural gas source 102 and configured to cool at least a portion of the feed gas provided therefrom to LNG. In at least one other embodiment, the liquefaction subsystem 500 may include more than three liquefaction subsystems. The feed gas stream 104 may be divided into a plurality of feed gas stream portions (three shown 104a-c). Each of the feed gas stream portions 104a-c may be equivalent in volume to one another, or in some embodiments, one or more of the feed gas stream portions 104a-c may be greater in volume than the other feed gas stream portion(s) 104a-c.

[0045] As illustrated in Figure 5, each feed gas stream portion 104a-c may be fluidly coupled to and may feed a respective liquefaction subsystem 502a-c. Each liquefaction subsystem 502a-c may be similar to the liquefaction system 200. However, in place of the four compressors 118a-d in the precooling compression assembly 110, each liquefaction subsystem 502a-c may include a precooling compression assembly 506 having a single compressor 518 and aftercooler 524 as part of the precooling loop. The compressor 518 may have four stages in fluid communication with and receiving the process fluid from the four chillers 116a-d for compression. As noted above, the number of stages of the compressor 518 and the number of chillers 116a-d may vary based, amongst other factors, on the site ambient temperature and/or the composition of the feed gas. The compressor 518 may compress the process fluid and discharge the compressed process fluid to be cooled in the aftercooler 524 before being directed back to the precooler assembly 106. Each liquefaction subsystem 502a-c may further include a liquefaction compression assembly 512 having a single pair of low pressure and high pressure compressors 526a and 526b. An intercooler 536a may be disposed between the low pressure compressor 526a and the high pressure compressor 526b and an aftercooler 536d may be fluidly coupled with the discharge of the high pressure compressor 526b. Each of the liquefaction subsystems 502a-c may have a single main heat exchanger 508 similar to the main heat exchanger of Figure 2. As configured, the liquefaction system 500 of Figure 5 may cool an equivalent volume of feed gas as the liquefaction systems 100 provided above.

[0046] Referring now to Figure 6, Figure 6 illustrates a process flow diagram of another exemplary liquefaction system 600 for LNG from the natural gas source 102, according to one or more embodiments disclosed. The liquefaction system 600 may be similar in some respects to the liquefaction systems 100, 200, 300, and 500 described above and thus may be best understood with reference to Figures 1-3 and 5 and the description thereof, where like numerals designate like components and will not be described again in detail. As illustrated in Figure 6, the liquefaction system 600 may include a plurality of liquefaction subsystems 602a, 602b fluidly coupled to the natural gas source 102 and configured to cool at least a portion of the feed gas provided therefrom to LNG. The feed gas stream 104 may be divided into a plurality of feed gas stream portions 104a, 104b. Each of the feed gas stream portions 104a, 104b may be equivalent in volume to one another, or in some embodiments, one feed gas stream portion 104a or 104b may be greater in volume than the other feed gas stream portion 104a or 104b.

[0047] As illustrated in Figure 6, each feed gas stream portion 104a, 104b may be fluidly coupled to and may feed a respective liquefaction subsystem 602a, 602b. Each liquefaction subsystem 602a, 602b may be similar to the liquefaction system 300 in that each liquefaction subsystem 602a, 602b may include a precooling compression assembly 610 having two compressors 618a and 618b fluidly arranged in parallel and fluidly coupled to respective aftercoolers 624a and 624b. Each compressor 618a, 618b may have four stages in fluid communication with and receiving the process fluid from the four chillers 116a-d for compression. As noted above, the number of stages of the compressors 618a, 618b and the number of chillers 116a-d may vary based, amongst other factors, on the site ambient temperature and/or the composition of the feed gas. Each compressor 618a, 618b may compress the process fluid and discharge the compressed process fluid to be cooled in the respective aftercooler 624a, 624b and condensed in one or more embodiments. The condensed process fluid may be collectively discharged to an outlet manifold 614 before being directed back to the precooler assembly 106. Each liquefaction subsystem 602a, 602b may further include a liquefaction compression assembly 612 having two pairs of low pressure and high pressure compressors 626a, 626b and 626c, 626d fluidly arranged in parallel with one another. A respective intercooler 636a 636b may be disposed between the low pressure compressor 626a, 626b and the high pressure compressor 626c, 626d of each pair of compressors 626a-d and a respective aftercooler 636c, 636d may be fluidly coupled with the discharge of each of the high pressure compressors 626c, 626d. Each of the liquefaction subsystems 602a, 602b may have a single main heat exchanger 608 similar to the main heat exchanger of Figure 2. As configured, the liquefaction system 600 of Figure 6 may cool an equivalent volume of feed gas as the liquefaction system 100 provided above.

[0048] Figure 7 illustrates a flowchart of a method 700 for producing liquefied natural gas, according to one or more embodiments. The method 700 may include feeding at least an initial portion of a natural gas stream to a plurality of chillers, as shown at 702. The method 700 may also include compressing a first refrigerant in at least one first refrigerant compressor, the at least one first refrigerant compressor driven by a variable speed drive or a fixed speed motor, as shown at 704. The method 700 may further include compressing a single mixed refrigerant in a plurality of second refrigerant compressors, each of the plurality of second refrigerant compressors being driven by a respective turbine, as shown at 706. The method 700 may also include transferring thermal energy from the single mixed refrigerant and the initial portion of the natural gas stream to the first refrigerant in the plurality of chillers, as shown at 708. The method 700 may also include feeding a first portion of the single mixed refrigerant and a first portion of the initial portion of the natural gas stream to a first heat exchanger to cool at least a fraction of the first portion of the natural gas stream flowing therethrough to thereby produce a first portion of the liquefied natural gas, as shown at 710.

[0049] The method 700 may also include feeding a second portion of the single mixed refrigerant and a second portion of the initial portion of the natural gas stream to a second heat exchanger to cool at least a fraction of the second portion of the natural gas stream flowing therethrough to thereby produce a second portion of the liquefied natural gas. The method 700 may also include cooling the first refrigerant in an aftercooler after compressing the first refrigerant in the at least one first refrigerant compressor and prior to the first refrigerant being circulated to the plurality of chillers.

[0050] It should be appreciated that the ability to reduce the number of process components including turbines, compressors, and/or coolers may reduce the cost, energy consumption, and/or complexity of the liquefaction systems 100, 200, 300, 400, 500, 600. For example, the ability to power the compressors of the precooling compression assembly with fixed speed motors or variable speed drives may reduce the number of compressors utilized in the liquefaction systems 100, 200, 300, 400, 500, 600, as the medium pressure compressor utilized in a conventional liquefaction compression assembly may be omitted. In addition, driving the compressors of the precooling compression assembly with fixed speed motors or variable speed drives may reduce the number of turbines comparatively used in conventional precooling compression assemblies. In another example, the ability to simplify intercooling in the liquefaction compression assembly by reducing the number of intercoolers may reduce cost, energy consumption, and/or complexity of the liquefaction systems 100, 200, 300, 400, 500, 600. The foregoing may be achieved by utilizing a single intercooler between the low and high pressure compressors instead of utilizing one intercooler between the low pressure and medium pressure compressors, and another intercooler between the medium pressure and high pressure compressors as is typically provided in conventional liquefaction compression assemblies.

[0051] The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

Embodiments

[0052]

1. A liquefaction system, comprising:

    a first heat exchanger configured to receive a natural gas stream from a natural gas source and cool at least a first portion of the natural gas stream to liquefied natural gas;

    a first compression assembly fluidly coupled to the first heat exchanger and configured to circulate a first refrigerant through the first heat exchanger to cool the first portion of the natural gas stream to the liquefied natural gas, the first compression assembly comprising

a plurality of first refrigerant compressors configured to compress the first refrigerant; and
a plurality of turbines configured to drive the plurality of first refrigerant compressors;

a precooler assembly fluidly coupled to the first compression assembly and the first heat exchanger and configured to cool the natural gas stream and the first refrigerant compressed by the plurality of first refrigerant compressors prior to the natural gas stream entering the first heat exchanger, the precooler assembly comprising a plurality of chillers configured to transfer thermal energy from the first refrigerant and the natural gas stream to a second refrigerant; and
a second compression assembly fluidly coupled to the precooler assembly and comprising

a plurality of second refrigerant compressors configured to compress the second refrigerant and circulate the second refrigerant to the plurality of chillers; and
a plurality of drivers, each driver coupled to at least one of the second refrigerant compressors and configured to drive at least one of the second refrigerant compressors.

2. The liquefaction system of embodiment 1, wherein each driver of the plurality of drivers is a fixed speed motor.

3. The liquefaction system of embodiment 1, wherein each driver of the plurality of drivers is a variable speed drive.

4. The liquefaction system of embodiment 1, wherein:

the plurality of second refrigerant compressors comprises four second refrigerant compressors; and
the plurality of drivers comprises four drivers, each driver being coupled to a respective second refrigerant compressor.

5. The liquefaction system of embodiment 1, wherein:

the plurality of second refrigerant compressors comprises two second refrigerant compressors; and
the plurality of drivers comprises two drivers, each driver being coupled to a respective second refrigerant compressor.

6. The liquefaction system of embodiment 1, wherein:

the first refrigerant is a single mixed refrigerant;
the plurality of first refrigerant compressors comprises six first refrigerant compressors;
the plurality of turbines comprises six turbines, each turbine being coupled to a respective first refrigerant compressor; and
at least one turbine is an aeroderivative gas turbine, and at least one other turbine is an industrial gas turbine.

7. The liquefaction system of embodiment 6, wherein the first compression assembly further comprises three intercoolers, each intercooler of the three intercoolers fluidly coupling two first refrigerant compressors of the six refrigerant compressors.

8. The liquefaction system of embodiment 1, wherein:

the second refrigerant comprises propane;
the plurality of chillers comprises four chillers; and
each second refrigerant compressor comprises four stages, each stage of the second refrigerant compressor being in fluid communication with a respective chiller of the four chillers.

9. The liquefaction system of embodiment 1, wherein the second compression assembly further comprises a plurality of aftercoolers, each aftercooler fluidly coupling a respective second refrigerant compressor with a respective chiller of the plurality of chillers.

10. The liquefaction system of embodiment 1, further comprising a second heat exchanger disposed in parallel with the first heat exchanger, wherein the second heat exchanger is in fluid communication with the precooler assembly and the first compression assembly and is configured to receive another natural gas stream from the natural gas source and cool at least a second portion of the natural gas stream to liquefied natural gas.

11. A liquefaction system comprising:

a plurality of liquefaction subsystems, each liquefaction subsystem of the plurality of liquefaction subsystems configured to receive a portion of a natural gas stream from a natural gas source, each liquefaction subsystem comprising

a heat exchanger configured to receive the portion of natural gas stream from the natural gas source and cool at least a fraction

of the portion of the natural gas stream to liquefied natural gas;
a first compression assembly fluidly coupled to the heat exchanger and configured to circulate a first refrigerant through the heat exchanger to cool the fraction of the portion of the natural gas stream to the liquefied natural gas, the first compression assembly comprising

a plurality of first refrigerant compressors configured to compress the first refrigerant; and
a plurality of turbines configured to drive the plurality of first refrigerant compressors;

a precooler assembly fluidly coupled to the first compression assembly and the heat exchanger and configured to cool the portion of the natural gas stream and the first refrigerant compressed by the plurality of first refrigerant compressors prior to the portion of the natural gas stream entering the heat exchanger, the precooler assembly comprising a plurality of chillers configured to transfer thermal energy from the first refrigerant and the natural gas stream to a second refrigerant; and
a second compression assembly fluidly coupled to the precooler assembly and comprising

at least one second refrigerant compressor configured to compress the second refrigerant and circulate the second refrigerant to the plurality of chillers; and
at least one driver, the at least one driver coupled to the at least one second refrigerant compressor and configured to drive the at least one second refrigerant compressor.

12. The liquefaction system of embodiment 11, wherein:

the plurality of liquefaction subsystems comprises three liquefaction subsystems; and
at least one turbine of the plurality of turbines is an aeroderivative gas turbine, and at least one other turbine of the plurality of turbines is an industrial gas turbine.

13. The liquefaction system of embodiment 12, wherein:

the plurality of first refrigerant compressors comprises two first refrigerant compressors;
the plurality of turbines comprises two turbines, each turbine being coupled to a respective first refrigerant compressor;
the first compression assembly further comprises an intercooler fluidly coupling the two first refrigerant compressors; and
the at least one driver is a variable speed drive or a fixed speed motor.

14. The liquefaction system of embodiment 11, wherein:

the plurality of liquefaction subsystems comprises two liquefaction subsystems;
each second compression assembly comprises two second refrigerant compressors;
each second compression assembly comprises two drivers, each driver being coupled to a respective second refrigerant compressor; and
each driver is a variable speed drive or a fixed speed motor.

15. The liquefaction system of embodiment 14, wherein:

the plurality of first refrigerant compressors comprises four first refrigerant compressors;
the plurality of turbines comprises four turbines, each turbine being coupled to a respective first refrigerant compressor; and
the first compression assembly further comprises two intercoolers, each intercooler of the two intercoolers fluidly coupling two first refrigerant compressors of the four refrigerant compressors.

16. A method for producing liquefied natural gas from a natural gas source, comprising:

feeding at least an initial portion of a natural gas stream to a plurality of chillers;
compressing a first refrigerant in at least one first refrigerant compressor, the at least one first refrigerant compressor driven by a variable speed drive or a fixed speed motor;
compressing a single mixed refrigerant in a plurality of second refrigerant compressors, each of the plurality of second refrigerant compressors being driven by a respective turbine;
transferring thermal energy from the single mixed refrigerant and the initial portion of the natural gas stream to the first refrigerant in the plurality of chillers; and
feeding a first portion of the single mixed refrigerant and a first portion of the initial portion of the natural gas stream to a first heat exchanger to cool at least a fraction of the first portion of

the natural gas stream flowing therethrough to thereby produce a first portion of the liquefied natural gas.

17. The method of embodiment 16, wherein:

at least one turbine of the plurality of turbines is an aeroderivative gas turbine, and at least one other turbine of the plurality of turbines is an industrial gas turbine; and
an intercooler fluidly couples at least two second refrigerant compressors of the plurality of second refrigerant compressors.

18. The method of embodiment 16, wherein compressing the first refrigerant in at least one first refrigerant compressor further comprises compressing the first refrigerant in a plurality of first refrigerant compressors, and each first refrigerant compressor is driven by a respective variable speed drive.

19. The method of embodiment 16, further comprising:

feeding a second portion of the single mixed refrigerant and a second portion of the initial portion of the natural gas stream to a second heat exchanger to cool at least a fraction of the second portion of the natural gas stream flowing therethrough to thereby produce a second portion of the liquefied natural gas.

20. The method of embodiment 16, further comprising:

cooling the first refrigerant in at least one aftercooler after compressing the first refrigerant in the at least one first refrigerant compressor and prior to the first refrigerant being circulated to the plurality of chillers.

Claims

1. A liquefaction system, comprising:

a first heat exchanger configured to receive a natural gas stream from a natural gas source and cool at least a first portion of the natural gas stream to liquefied natural gas;
a first compression assembly fluidly coupled to the first heat exchanger and configured to circulate a first refrigerant through the first heat exchanger to cool the first portion of the natural gas stream to the liquefied natural gas, the first compression assembly comprising

a plurality of first refrigerant compressors configured to compress the first refrigerant; and
a plurality of turbines configured to drive the plurality of first refrigerant compressors;

a precooler assembly fluidly coupled to the first compression assembly and the first heat exchanger and configured to cool the natural gas stream and the first refrigerant compressed by the plurality of first refrigerant compressors prior to the natural gas stream entering the first heat exchanger, the precooler assembly comprising a plurality of chillers configured to transfer thermal energy from the first refrigerant and the natural gas stream to a second refrigerant; and
a second compression assembly fluidly coupled to the precooler assembly and comprising

a plurality of second refrigerant compressors configured to compress the second refrigerant and circulate the second refrigerant to the plurality of chillers; and
a plurality of drivers, each driver coupled to at least one of the second refrigerant compressors and configured to drive at least one of the second refrigerant compressors.

2. The liquefaction system of claim 1, wherein each driver of the plurality of drivers is a fixed speed motor or a variable speed drive.

3. The liquefaction system of claim 1 or 2, wherein:

the plurality of second refrigerant compressors comprises two or four second refrigerant compressors; and
the plurality of drivers comprises two or four drivers, respectively, each driver being coupled to a respective second refrigerant compressor.

4. The liquefaction system of any of the preceding claims, wherein:

the first refrigerant is a single mixed refrigerant;
the plurality of first refrigerant compressors comprises six first refrigerant compressors;
the plurality of turbines comprises six turbines, each turbine being coupled to a respective first refrigerant compressor; and

at least one turbine is an aeroderivative gas turbine, and at least one other turbine is an industrial gas turbine,wherein the first compression assembly in particular further comprises three intercoolers, each intercooler of the three intercoolers fluidly coupling two first refrigerant compressors of the six refrigerant compressors.

5. The liquefaction system of any of the preceding claims, wherein:

the second refrigerant comprises propane;
the plurality of chillers comprises four chillers; and
each second refrigerant compressor comprises four stages, each stage of the second refrigerant compressor being in fluid communication with a respective chiller of the four chillers.

6. The liquefaction system of any of the preceding claims, wherein the second compression assembly further comprises a plurality of aftercoolers, each aftercooler fluidly coupling a respective second refrigerant compressor with a respective chiller of the plurality of chillers and/or further comprising a second heat exchanger disposed in parallel with the first heat exchanger, wherein the second heat exchanger is in fluid communication with the precooler assembly and the first compression assembly and is configured to receive another natural gas stream from the natural gas source and cool at least a second portion of the natural gas stream to liquefied natural gas.

7. A liquefaction system comprising:

a plurality of liquefaction subsystems, in particular according to any of the claims 1 to 6, each liquefaction subsystem of the plurality of liquefaction subsystems configured to receive a portion of a natural gas stream from a natural gas source, each liquefaction subsystem comprising

a heat exchanger configured to receive the portion of natural gas stream from the natural gas source and cool at least a fraction of the portion of the natural gas stream to liquefied natural gas;
a first compression assembly fluidly coupled to the heat exchanger and configured to circulate a first refrigerant through the heat exchanger to cool the fraction of the portion of the natural gas stream to the liquefied natural gas, the first compression assembly comprising

a plurality of first refrigerant compressors configured to compress the first refrigerant; and
a plurality of turbines configured to drive the plurality of first refrigerant compressors;

a precooler assembly fluidly coupled to the first compression assembly and the heat exchanger and configured to cool the portion of the natural gas stream and the first refrigerant compressed by the plurality of first refrigerant compressors prior to the portion of the natural gas stream entering the heat exchanger, the precooler assembly comprising a plurality of chillers configured to transfer thermal energy from the first refrigerant and the natural gas stream to a second refrigerant; and
a second compression assembly fluidly coupled to the precooler assembly and comprising

at least one second refrigerant compressor configured to compress the second refrigerant and circulate the second refrigerant to the plurality of chillers; and
at least one driver, the at least one driver coupled to the at least one second refrigerant compressor and configured to drive the at least one second refrigerant compressor.

8. The liquefaction system of claim 7, wherein:

the plurality of liquefaction subsystems comprises three liquefaction subsystems; and
at least one turbine of the plurality of turbines is an aeroderivative gas turbine, and at least one other turbine of the plurality of turbines is an industrial gas turbine.

9. The liquefaction system of claim 8, wherein:

the plurality of first refrigerant compressors comprises two first refrigerant compressors;
the plurality of turbines comprises two turbines, each turbine being coupled to a respective first refrigerant compressor;
the first compression assembly further comprises an intercooler fluidly coupling the two first refrigerant compressors; and
the at least one driver is a variable speed drive or a fixed speed motor.

10. The liquefaction system of any of the claims 7 to 9, wherein:

the plurality of liquefaction subsystems comprises two liquefaction subsystems;
each second compression assembly comprises two second refrigerant compressors;
each second compression assembly comprises two drivers, each driver being coupled to a respective second refrigerant compressor; and
each driver is a variable speed drive or a fixed speed motor.

11. The liquefaction system of claim 10, wherein:

the plurality of first refrigerant compressors comprises four first refrigerant compressors;
the plurality of turbines comprises four turbines, each turbine being coupled to a respective first refrigerant compressor; and
the first compression assembly further comprises two intercoolers, each intercooler of the two intercoolers fluidly coupling two first refrigerant compressors of the four refrigerant compressors.

12. A method for producing liquefied natural gas from a natural gas source, comprising:

feeding at least an initial portion of a natural gas stream to a plurality of chillers;
compressing a first refrigerant in at least one first refrigerant compressor, the at least one first refrigerant compressor driven by a variable speed drive or a fixed speed motor;
compressing a single mixed refrigerant in a plurality of second refrigerant compressors, each of the plurality of second refrigerant compressors being driven by a respective turbine;
transferring thermal energy from the single mixed refrigerant and the initial portion of the natural gas stream to the first refrigerant in the plurality of chillers; and
feeding a first portion of the single mixed refrigerant and a first portion of the initial portion of the natural gas stream to a first heat exchanger to cool at least a fraction of the first portion of the natural gas stream flowing therethrough to thereby produce a first portion of the liquefied natural gas.

13. The method of claim 12, wherein:

at least one turbine of the plurality of turbines is an aeroderivative gas turbine, and at least one other turbine of the plurality of turbines is an industrial gas turbine; and
an intercooler fluidly couples at least two second refrigerant compressors of the plurality of second refrigerant compressors.

14. The method of claim 12 or 13, wherein compressing the first refrigerant in at least one first refrigerant compressor further comprises compressing the first refrigerant in a plurality of first refrigerant compressors, and each first refrigerant compressor is driven by a respective variable speed drive.

15. The method of any of the claims 12 to 14, further comprising:

feeding a second portion of the single mixed refrigerant and a second portion of the initial portion of the natural gas stream to a second heat exchanger to cool at least a fraction of the second portion of the natural gas stream flowing therethrough to thereby produce a second portion of the liquefied natural gas, and/or cooling the first refrigerant in at least one aftercooler after compressing the first refrigerant in the at least one first refrigerant compressor and prior to the first refrigerant being circulated to the plurality of chillers.

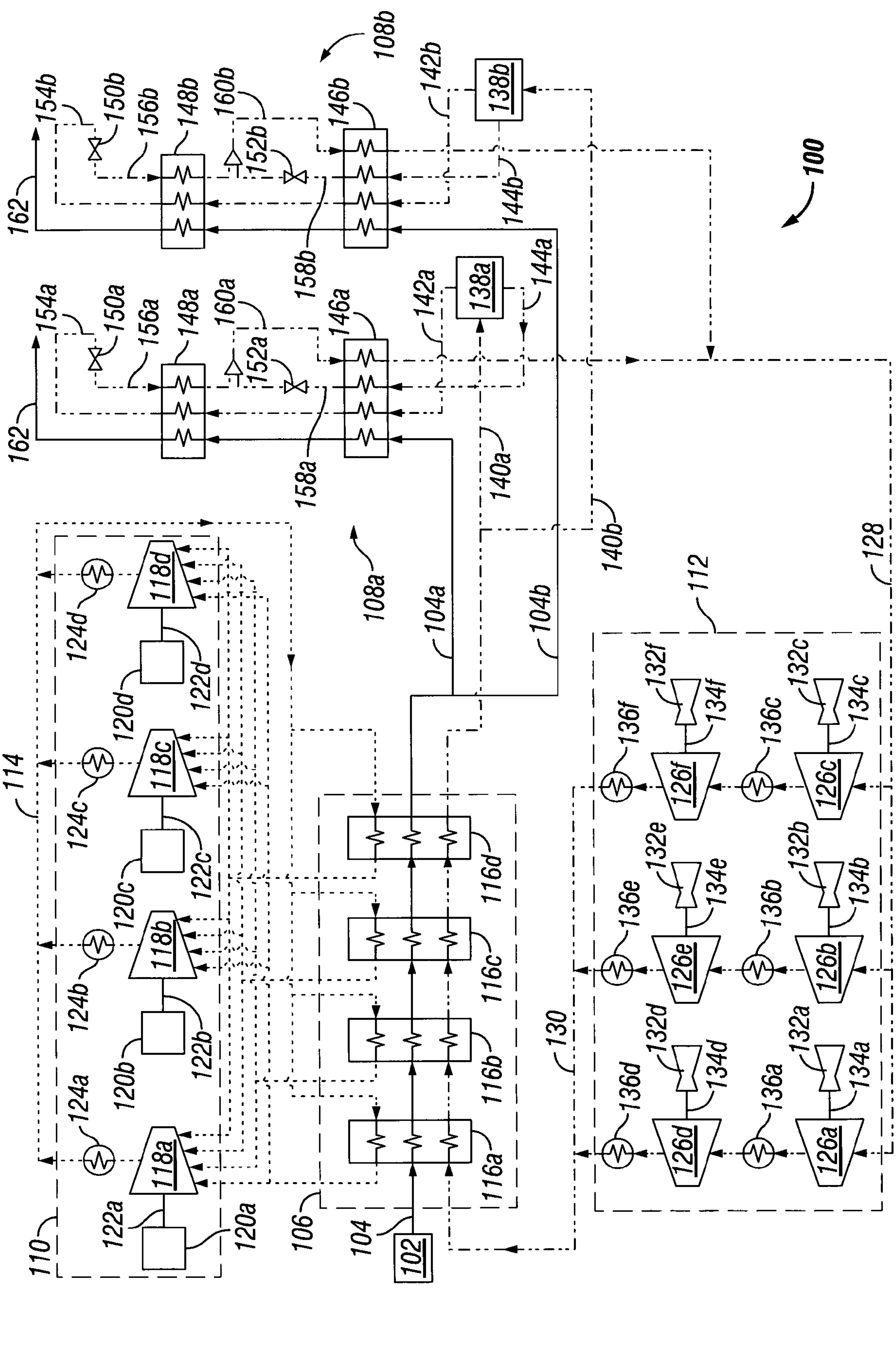
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FIG. 1

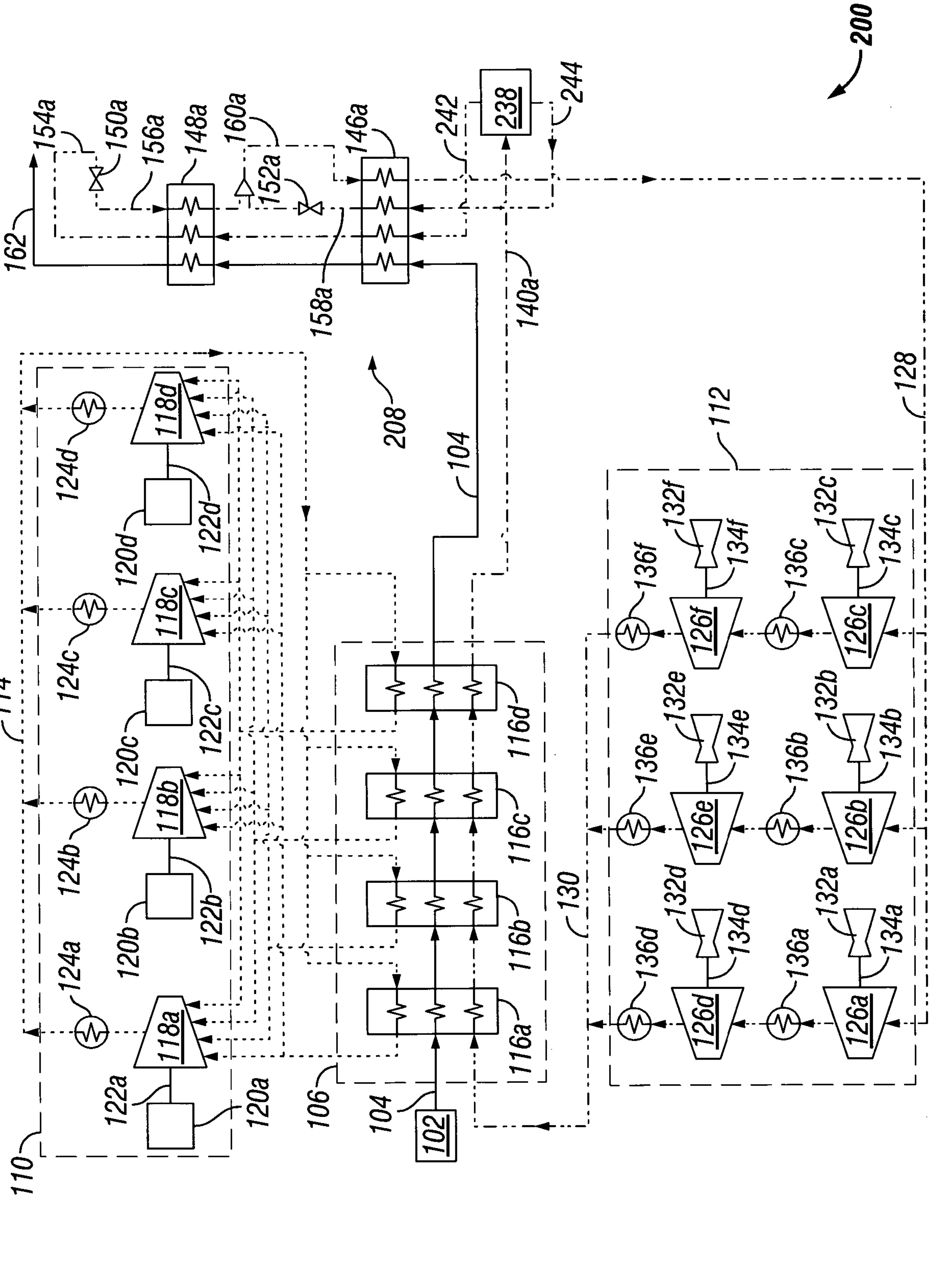
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FIG. 2

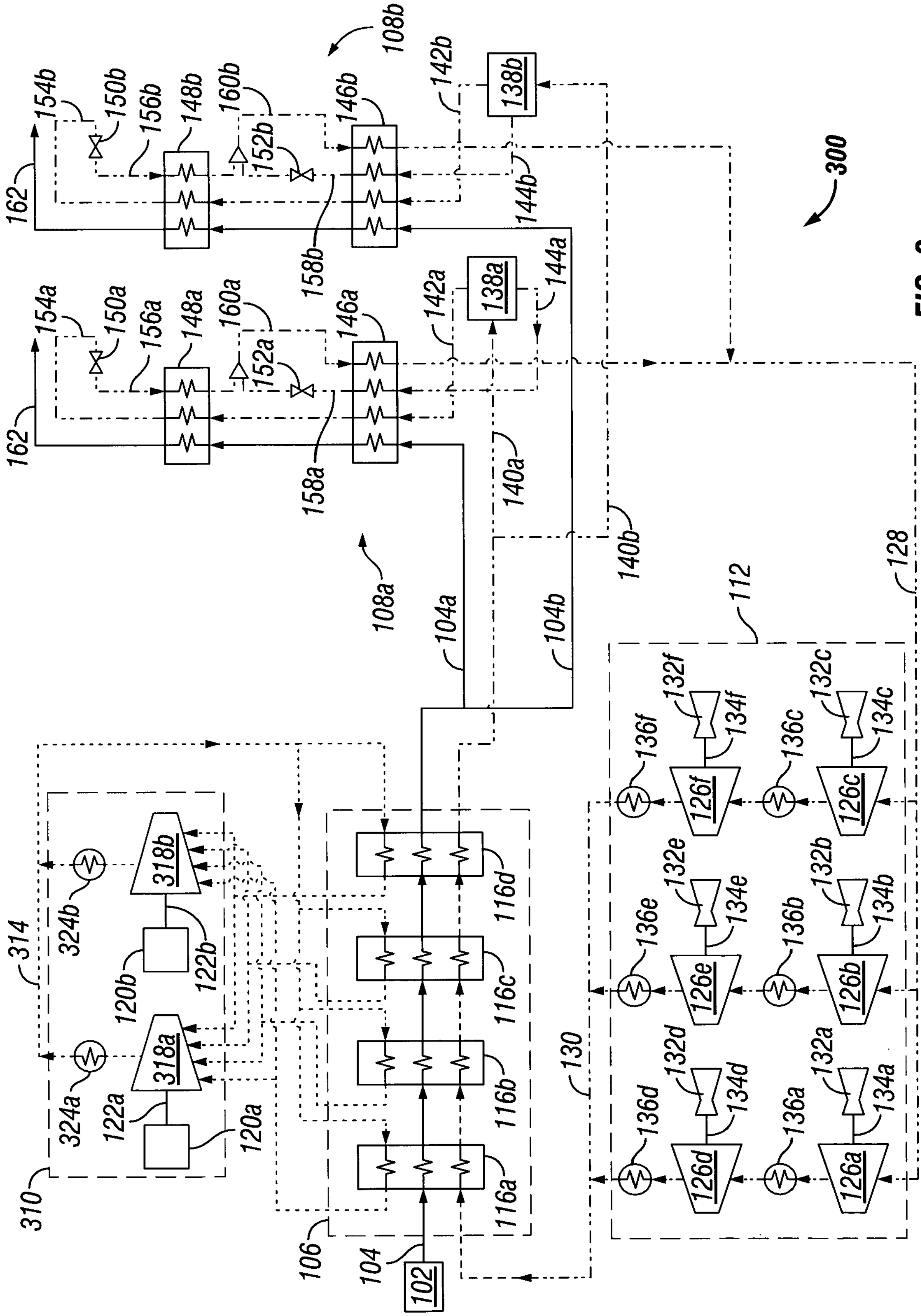

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FIG. 3

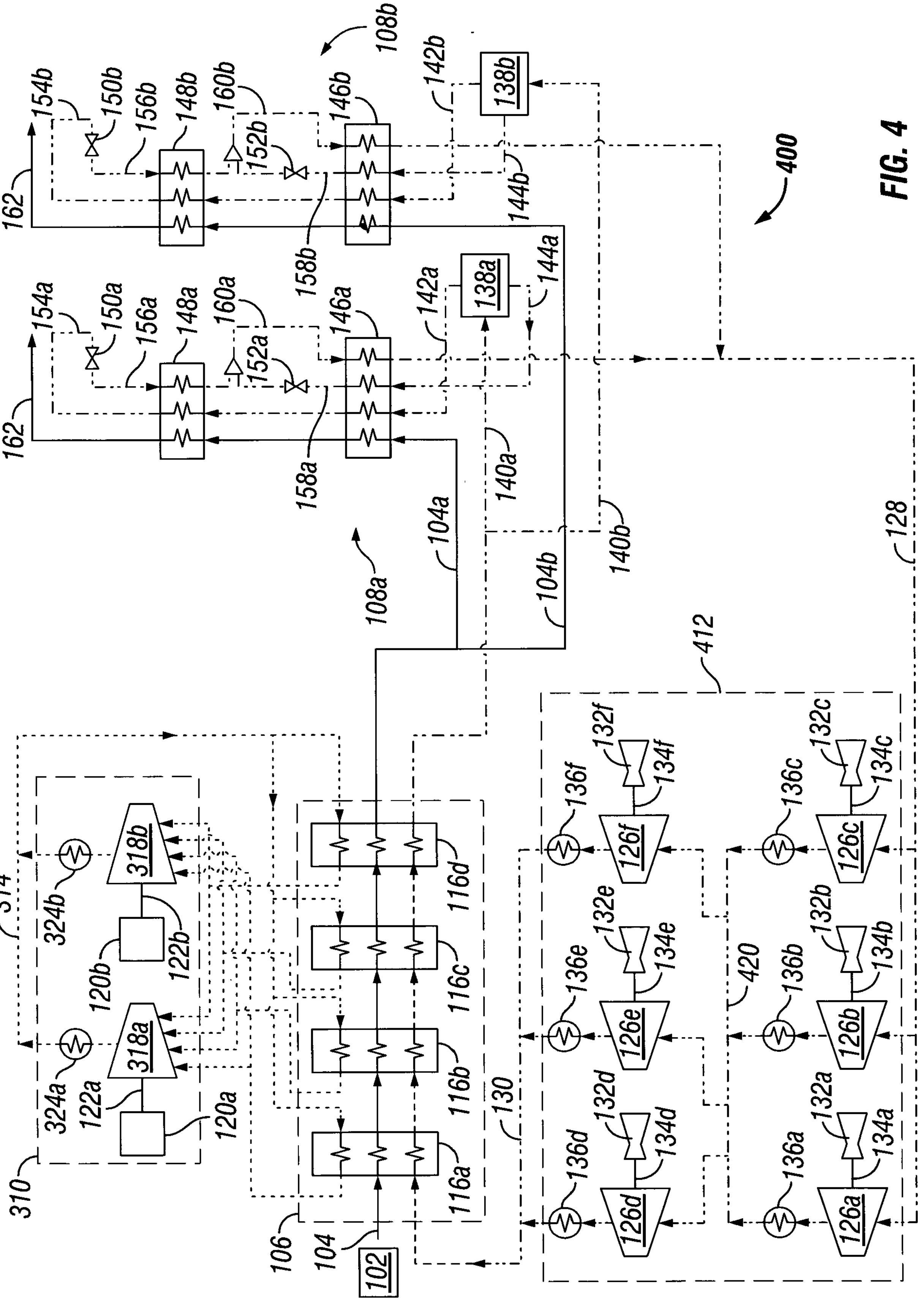
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FIG. 4

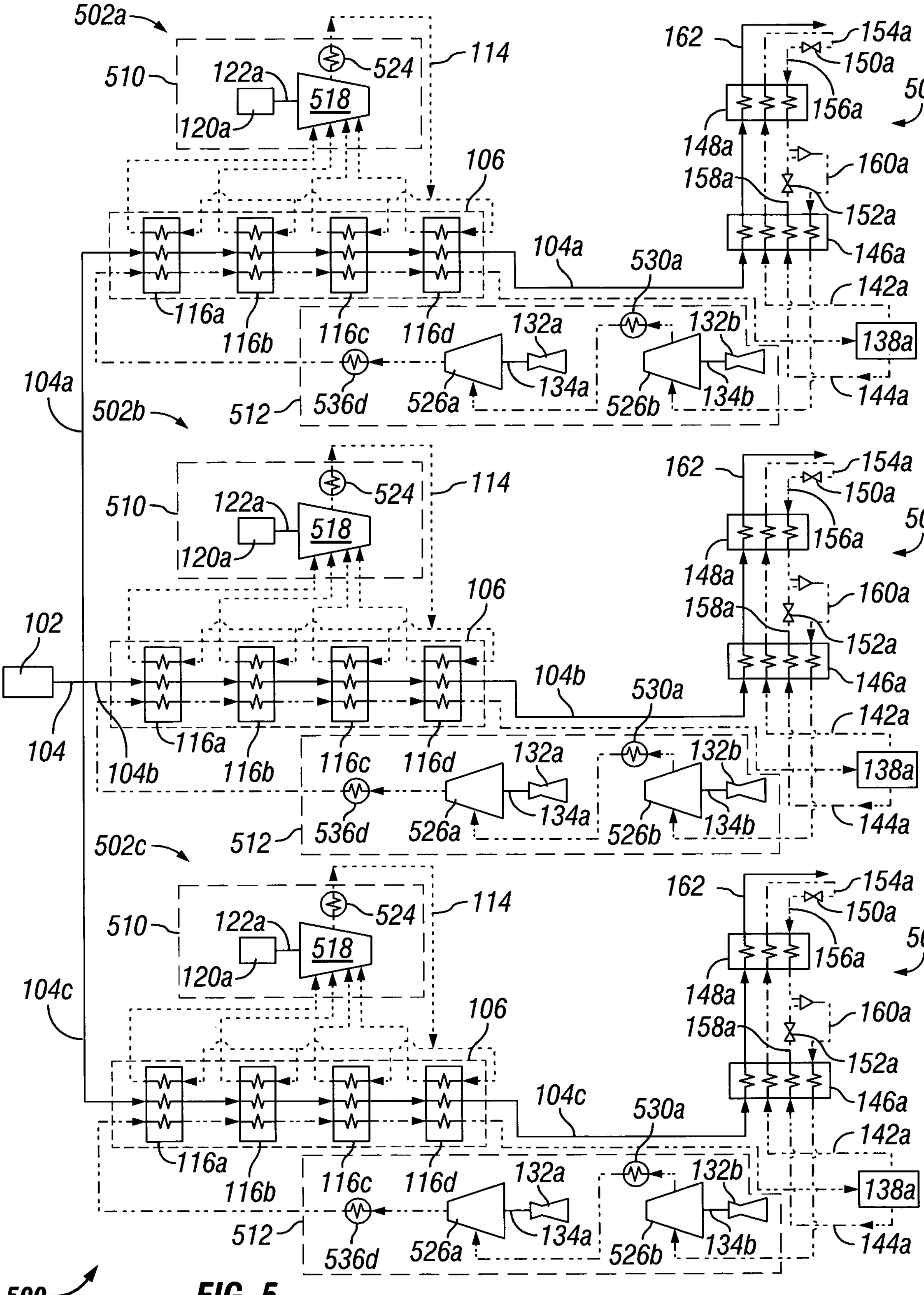
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FIG. 5

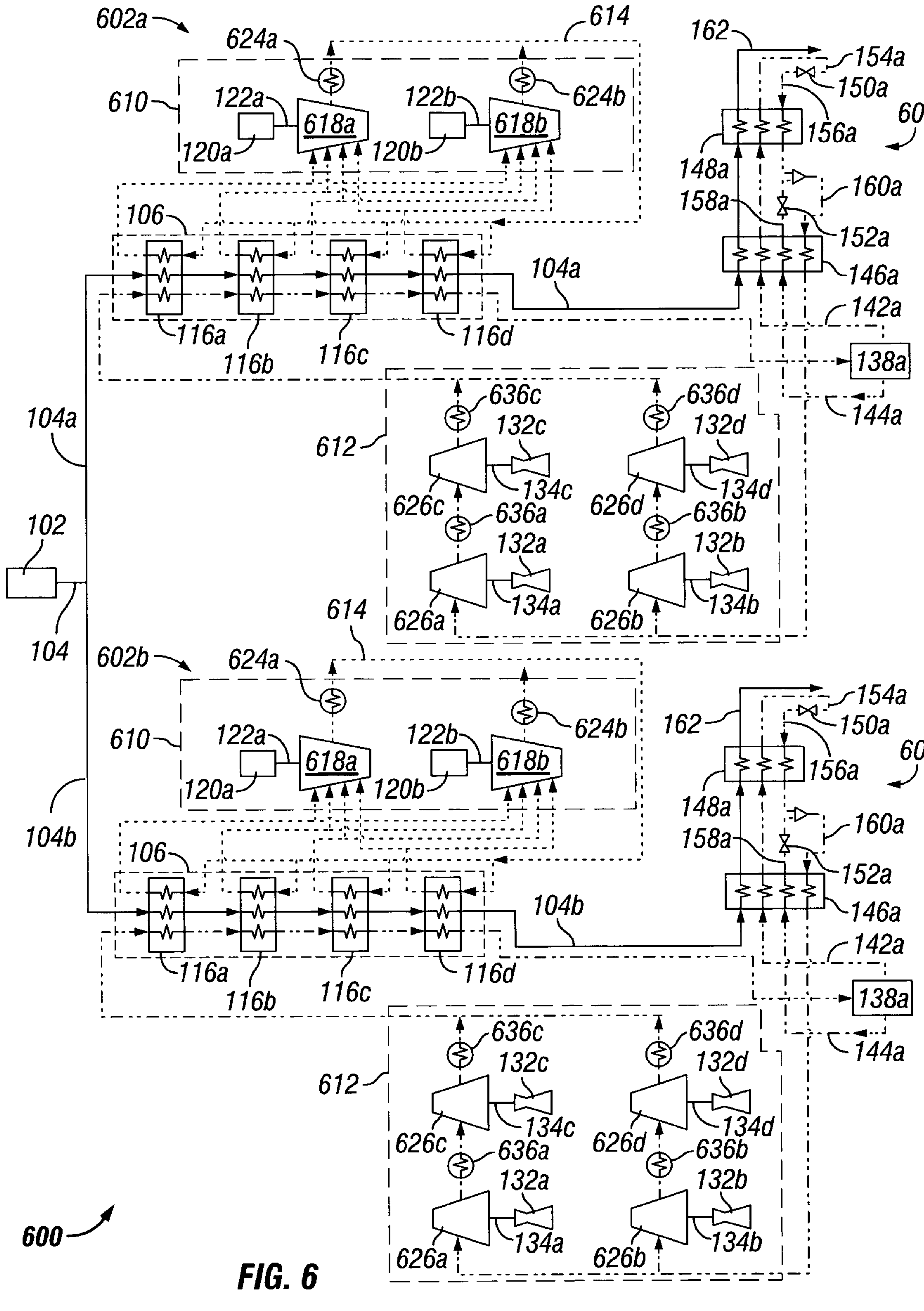
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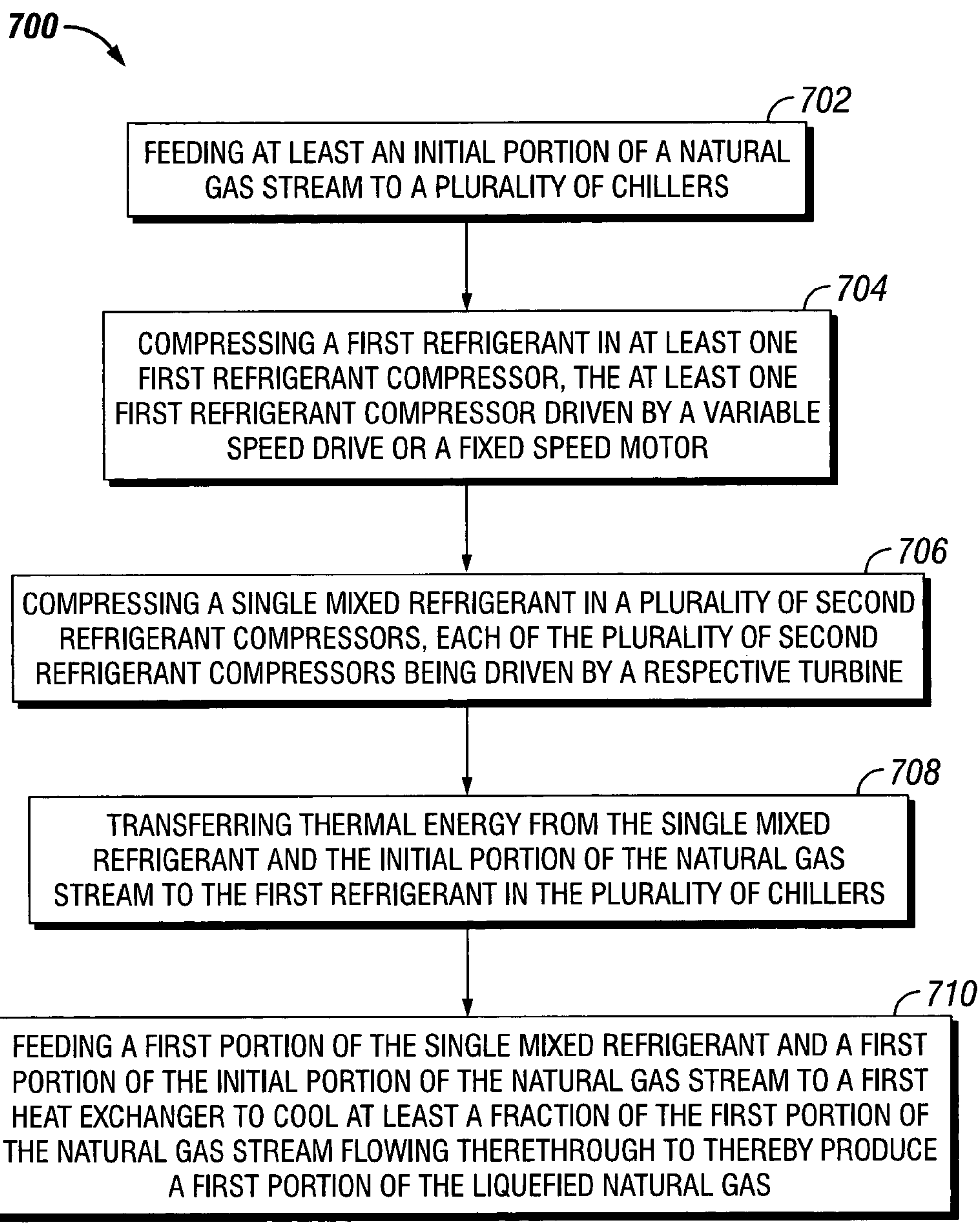
FIG. 6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702
FEEDING AT LEAST AN INITIAL PORTION OF A NATURAL GAS STREAM TO A PLURALITY OF CHILLERS
704
COMPRESSING A FIRST REFRIGERANT IN AT LEAST ONE FIRST REFRIGERANT COMPRESSOR, THE AT LEAST ONE FIRST REFRIGERANT COMPRESSOR DRIVEN BY A VARIABLE SPEED DRIVE OR A FIXED SPEED MOTOR
706
COMPRESSING A SINGLE MIXED REFRIGERANT IN A PLURALITY OF SECOND REFRIGERANT COMPRESSORS, EACH OF THE PLURALITY OF SECOND REFRIGERANT COMPRESSORS BEING DRIVEN BY A RESPECTIVE TURBINE
708
TRANSFERRING THERMAL ENERGY FROM THE SINGLE MIXED REFRIGERANT AND THE INITIAL PORTION OF THE NATURAL GAS STREAM TO THE FIRST REFRIGERANT IN THE PLURALITY OF CHILLERS
710
FEEDING A FIRST PORTION OF THE SINGLE MIXED REFRIGERANT AND A FIRST PORTION OF THE INITIAL PORTION OF THE NATURAL GAS STREAM TO A FIRST HEAT EXCHANGER TO COOL AT LEAST A FRACTION OF THE FIRST PORTION OF THE NATURAL GAS STREAM FLOWING THERETHROUGH TO THEREBY PRODUCE A FIRST PORTION OF THE LIQUEFIED NATURAL GAS

FIG. 7

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PARTIAL EUROPEAN SEARCH REPORT

under Rule 62a and/or 63 of the European Patent Convention. This report shall be considered, for the purposes of subsequent proceedings, as the European search report

Application Number
EP 17 29 0042

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	"A 6MTPA TRAIN CONCEPT USING THE PROPANE PRE-COOLED MIXED REFRIGERANT TECHNOLOGY", IP.COM JOURNAL, IP.COM INC., WEST HENRIETTA, NY, US, 10 May 2012 (2012-05-10), XP013151130, ISSN: 1533-0001	1-3,5,6, 12,14	INV. F25J1/00 F25J1/02
A	* page 9; figure 4 * -----	4,13	
A	VINK K J ET AL: "COMPARISON OF BASELOAD LIQUEFACTION PROCESSES//COMPARISON DES PROCEDES DE LIQUEFACTION DES USINES DE GRANDE CAPACITE", INTERNATIONAL CONFERENCE AND EXHIBITION ON LIQUEFIED NATURAL, XX, XX, no. 12TH, 4 May 1998 (1998-05-04), pages 3.6/1-15, XP009081893, * figure 1 * ----- -/--	1,12	
			TECHNICAL FIELDS SEARCHED (IPC)
			F25J

INCOMPLETE SEARCH

The Search Division considers that the present application, or one or more of its claims, does/do not comply with the EPC so that only a partial search (R.62a, 63) has been carried out.

Claims searched completely :

Claims searched incompletely :

Claims not searched :

Reason for the limitation of the search:

see sheet C

2

Place of search	Date of completion of the search	Examiner
The Hague	4 December 2017	Schopfer, Georg

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04E07)

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European Patent Office
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PARTIAL EUROPEAN SEARCH REPORT

Application Number
EP 17 29 0042

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (IPC)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
A	RICHARDSON F W ET AL: "COMPRESSOR AND DRIVER ENHANCEMENTS FOR LARGE LNG PLANTS-LOOK AGAIN AT COMBINED CYCLE OPTIONS//PERFECTIONNEMENTS DU COMPRESSEUR ET DU MOTEUR POUR DES SITES DE PRODUCTION IMPORTANTE DE GNL-AUTRE REGARD SUR LES OPTIONS A CYCLE COMBINÉ", INTERNATIONAL CONFERENCE AND EXHIBITION ON LIQUEFIED NATURAL, XX, XX, 14 May 2001 (2001-05-14), pages PS5-6.01, XP009025964, * Section 6.1; page 13 * -----	4	
			TECHNICAL FIELDS SEARCHED (IPC)

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INCOMPLETE SEARCH SHEET C

Application Number
EP 17 29 0042

Claim(s) completely searchable:
1-6, 12-15

Claim(s) not searched:
7-11

Reason for the limitation of the search:

The search has been restricted to the subject-matter indicated by the applicant in his letter of 23.11.2017 filed in reply to the invitation pursuant to Rule 62a(1) and/or Rule 63(1) EPC: claims 1-6 and 12-15.

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Application Number
EP 17 29 0042

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☒ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

1-5, 12-14(completely); 6(partially)

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION SHEET B

Application Number
EP 17 29 0042

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-5, 12-14(completely); 6(partially)

   Searched Invention

   ---

2. claims: 15(completely); 6(partially)

   Two parallel liquefaction heat exchangers.
