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Coil wound heat exchanger
Wärmetauscher mit gewickelten Rohrschlangen
Echangeur de chaleur avec serpentins de tubes

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References cited:
US-B1- 6 347 532

'FPSO LNG Plant Delivers Optimal Performance'
AIR PRODUCTS-PROSPEKT 1998,

'BACH ET AL: 'IGT International Liquified Natural
gas Conference Proceedings’ SPIRAL WOUND
HEAT EXCHANGERS FOR LNG BASELOAD
PLANTS 14 May 2001, SEOUL PAPER SESSION,
ISSN 0197-2782

'AIR PRODUCTS PROSPEKT LNG TECHNOLOGY
2001 2001,

'NLNG THE MAGAZINE vol. 1, no. 1, 2001, pages
10,11, - 31
BACKGROUND OF THE INVENTION

[0001] Coil wound heat exchangers are used in the process industries for heating or cooling fluid streams at high heat transfer rates which require large heat transfer areas. Coil wound heat exchangers, also known as spiral wound or spool wound heat exchangers, are particularly useful for cooling and condensing high pressure gas streams. In the production of liquefied natural gas (LNG), for example, large surface areas are required for the indirect transfer of heat between refrigerants and the pressurized feed gas, which is cooled from ambient temperature to yield LNG at temperatures near -162°C (-260°F).

[0002] Coil wound heat exchangers utilize tubing bundles constructed of large numbers of long tubes which are helically wound about an axial central core or mandrel. Numerous tube layers are formed in the radial direction, each layer being separated from adjacent layers by axial spacers or spacer wires. One or more bundles can be installed in a pressure vessel with appropriate headers and piping for introducing streams to be cooled into the tubes and withdrawing cooled liquefied streams from the tubes.

Additional piping is used for fluid flow between bundles. Refrigeration typically is provided in these exchangers by mixed refrigerants vaporizing on the outer side, or shell side, of the tubes.

[0003] In the baseload LNG industry, natural gas is liquefied at remote sites and transported as a liquid to population centers, where it is vaporized and distributed for local consumption. A current trend in the baseload LNG industry is to increase individual liquefaction train sizes for improved economies of scale, and this requires larger main heat exchangers.

There is a continuing need in the process industries, for example in the baseload LNG industry, to improve process performance and achieve economies of scale despite limitations in coil wound bundle size. More effective use of heat transfer area and improved heat transfer coefficients for a given exchanger size will be required to realize improved process performance. The invention disclosed below and defined by the claims which follow offers an improved coil wound heat exchanger configuration which yields higher heat transfer performance and higher liquefaction production from a main heat exchanger of a given sizes.

[0004] US-B-6 347 532 discloses a method of producing liquefied natural gas, whereby refrigeration for cooling and liquefaction is provided by a mixed refrigerant system pre-cooled by another refrigeration system. At least one liquid stream is derived from the partial condensation and separation of the mixed refrigerant at a temperature higher than the lowest temperature provided by the cooling system when the mixed refrigerant is condensed at a final highest pressure, when the mixed refrigerant is condensed at a pressure lower than the final highest pressure condensation is effected at a temperature equal or higher than the lowest temperature provided by the pre-cooling system. The mixed refrigerant liquid is used to provide Refrigeration at a temperature lower than that provided by the pre-cooling system.

BRIEF SUMMARY OF THE INVENTION

[0005] The invention also relates to a coil wound heat exchanger system as set forth in claim 1.

[0006] In this coil wound heat exchanger system, the first coil wound tubing bundle may include:

(b1) a first mandrel having a first end and a second end;
(b2) a first set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the mandrel to form a first tube layer;
(b3) a first plurality of spacers disposed in contact with the first tube layer, each spacer having a thickness defined in a radial direction;
(b4) a second set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the first tube layer to form a second tube layer, wherein the second tube layer is in contact with the first plurality of spacers;
(b5) a plurality of additional successive layers of spacers and tubes similar to the spacers and tubes of (b3) and (b4), wherein the plurality of additional successive spacers and layers of tubes are disposed radially;

wherein the inlets and outlets of the tubes of (b2) through (b5) are proximate the first end and the second end respectively of the first mandrel.

[0007] In this coil wound heat exchanger system, the second coil wound tubing bundle includes:

(c1) a second mandrel having a first end and a second end;
(c2) a first set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the mandrel to form a first tube layer;
(c3) a first plurality of spacers disposed in contact with the first tube layer, each spacer having a thickness defined
in a radial direction;
(c4) a second set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about
the first tube layer to form a second tube layer, wherein the second tube layer is in contact with the first plurality of
spacers; and
(c5) a plurality of additional successive layers of spacers and tubes similar to the spacers and tubes of (c3) and
(c4), wherein the plurality of additional successive spacers and layers of tubes are disposed radially;

wherein the inlets and outlets of the tubes of (c2) through (c5) are proximate the first end and the second end respectively
of the second mandrel.

[0008] The coil wound heat exchanger system further comprises:

(d) means for aggregating the outlet ends of two or more sets of tubes in the first coil wound tubing bundle to form
a first group of tube outlets;
(e) means for aggregating the inlet ends of two or more sets of tubes in the second coil wound tubing bundle to form
a first group of tube inlets; and
(f) means for placing the first group of tube outlets in the first coil wound tubing bundle in fluid flow communication
with the first group of tube inlets in the second coil wound tubing bundle, and
(g) a third coil wound tubing bundle disposed axially in a second section of the heat exchanger vessel above the
second wound tubing bundle, wherein the second section has a diameter which is different than the first diameter,
and wherein the third coil wound tubing bundle includes

(g1) a third mandrel having a first end and a second end;
(g2) a first set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about
the mandrel to form a first tube layer;
(g3) a first plurality of spacers disposed in contact with the first tube layer, each spacer having a thickness
defined in a radial direction;
(g4) a second set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound
about the first tube layer to form a second tube layer, wherein the second tube layer is in contact with the first
plurality of spacers;
(g5) a plurality of additional successive layers of spacers and tubes similar to the spacers and tubes of (g3) and
(g4), wherein the plurality of additional successive spacers and layers of tubes are disposed radially;

wherein the inlets and outlets of the tubes of (g2) through (g5) are proximate the first end and the second end
respectively of the third mandrel.

[0009] The coil wound heat exchanger system may further comprise means for aggregating the outlet ends of a plurality
of tubes in the first coil wound tubing bundle to form a second group of tube outlets, means for aggregating the inlet
ends of a plurality of tubes in the second coil wound tubing bundle to form a second group of tube inlets, and means for
placing the second group of tube outlets in the first coil wound tubing bundle in fluid flow communication with the second
group of tube inlets in the second coil wound tubing bundle. The coil wound heat exchanger system also may further
comprise means for aggregating the outlet ends of a plurality of tubes in the first coil wound tubing bundle to form a third
group of tube outlets, means for aggregating the inlet ends of a plurality of tubes in the second coil wound tubing bundle
to form a third group of tube inlets, and means for placing the third group of tube outlets in the first coil wound tubing
bundle in fluid flow communication with the third group of tube inlets in the second coil wound tubing bundle.

[0010] The coil wound heat exchanger system also may further comprise means for aggregating the inlet ends of a plurality
of tubes in the first coil wound tubing bundle to form a first group of tube inlets, and means for placing the first
group of tube inlets in the first coil wound tubing bundle in fluid flow communication with a feed gas inlet line. Also, the
system may include means for aggregating the inlet ends of a plurality of tubes in the first coil wound tubing bundle
to form a second group of tube inlets, and means for placing the second group of tube inlets in the first coil wound tubing
bundle in fluid flow communication with a vapor refrigerant inlet line. In addition, the system also may comprise means
for aggregating the inlet ends of a plurality of tubes in the first coil wound tubing bundle to form a third group of tube
inlets, and means for placing the third group of tube inlets in the first coil wound tubing bundle in fluid flow communication
with a liquid refrigerant inlet line. Further, the system may include means for aggregating the outlet ends of a plurality
of tubes in the second coil wound tubing bundle to form a first group of tube outlets, means for aggregating the outlet
ends of a plurality of tubes in the second coil wound tubing bundle to form a second group of tube outlets, and means
for aggregating the outlet ends of two or more additional sets of tubes in the second coil wound tubing bundle to form
a third group of tube outlets.

[0011] The coil wound heat exchanger system may further include means for aggregating the inlet ends of a plurality
of tubes in the third coil wound tubing bundle to form a first group of tube inlets and means for placing the first group of tube inlets in the third coil wound tubing bundle in fluid flow communication with the first group of tube outlets in the second coil wound tubing bundle.

[0012] The coil wound heat exchanger system may further comprise means for aggregating the inlet ends of a plurality of tubes in the third coil wound tubing bundle to form a second group of tube inlets and means for placing the second group of tube inlets in the third coil wound tubing bundle in fluid flow communication with the second group of tube outlets in the second coil wound tubing bundle. Also, the system may utilize means for aggregating the outlet ends of a plurality of tubes in the third coil wound tubing bundle to form a first group of tube outlets, and means for placing the first group of tube outlets in the third coil wound tubing bundle in fluid flow communication with a cooled liquid product outlet line.

[0013] Another embodiment may include a refrigerant distributor disposed above the third coil wound tubing bundle. In this embodiment, the coil wound heat exchanger system may further comprise means for aggregating the outlet ends of a plurality of tubes in the third coil wound tubing bundle to form a second group of tube outlets and means for placing the second group of tube outlets in the third coil wound tubing bundle in fluid flow communication with the refrigerant distributor above the third wound coil tubing bundle. Piping means may be included for withdrawing refrigerant vapor from the vertical heat exchanger vessel at a location below the first coil wound tubing bundle.

[0014] The coil wound heat exchanger system utilizes a refrigerant redistributor disposed below the second coil wound tubing bundle and above the first coil wound tubing bundle.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

[0015] Fig. 1 is a schematic illustration of a heat exchanger according to the prior art.
[0016] Fig. 2 is a schematic illustration of an exemplary heat exchanger according to the present invention.
[0017] Fig. 3 is a schematic flow diagram of an exemplary liquefaction process which uses the heat exchanger of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Coil wound heat exchangers have been used for many years in cryogenic gas liquefaction and the cryogenic separation of gas mixtures. This type of exchanger has found particularly widespread application in the liquefaction of low-boiling gases such as helium, hydrogen, and methane. Most of the world’s baseload LNG production uses wound coil heat exchangers for gas liquefaction and for intermediate cooling of mixed component refrigerants.

[0019] The present invention may be used in any process application of coil wound heat exchangers, particularly those operating at cryogenic temperatures. These applications often involve high heat transfer rates, large heat transfer areas, and/or large temperature changes between a process stream inlet and outlet. The invention is illustrated by, but is not limited to, the liquefaction of natural gas as described below.

[0020] A main heat exchanger of a type known in the natural gas liquefaction field is shown in the schematic drawing of Fig. 1. This particular exchanger utilizes two coil wound bundles for the final cooling and liquefaction of a pretreated natural gas feed. Main heat exchanger 1 comprises pressure vessel 3, warm heat exchange zone 5, and cold heat exchange zone 9. A first coil wound heat exchanger 1 bundle is utilized in cold heat exchange zone 5 in which a feed gas provided in line 11 is initially cooled in tube circuit 13 against a vaporizing refrigerant (later described) on the shell side of the bundle. Tube circuit 13 represents multiple tubes which are part of a coil wound bundle, wherein the bundle also includes tube circuits 31 and 39 as described later. Tubes typically may be made of aluminum. Feed gas in line 15 which has been cooled and at least partially condensed optionally is reduced in pressure across throttling valve 17. The reduced-pressure feed then flows via line 19 into tube circuit 21 in cold heat exchange zone 9, wherein the feed is further cooled and withdrawn as product via line 23.

[0021] A two-phase compressed refrigerant, typically a multicomponent refrigerant containing light hydrocarbons and optionally nitrogen, is supplied via line 25 from a refrigerant compression system (not shown) and flows into phase separator 27. Refrigerant liquid is withdrawn via line 29, subcooled in tube circuit 31, and reduced in pressure across throttling valve 33. Optionally, a hydraulic expansion turbine may be used to extract work from the refrigerant liquid prior to throttling valve 33.

[0022] The refrigerant from throttling valve 33 is combined with refrigerant flowing downward from cold heat exchange zone 9 (described later) and the combined refrigerant is distributed via distributor 35. The combined refrigerant flows downward over the outer or shell side of the coil wound bundle wherein vaporizing and warming to provide a portion of the refrigeration for cooling the feed gas in tube circuit 13 as earlier described. In addition, the vaporizing refrigerant provides some of the refrigeration to subcool the refrigerant vapor in tube circuit 31 and to cool the liquid refrigerant in tube circuit 39 (described below).

[0023] Vapor refrigerant is withdrawn from separator 27 via line 37, is cooled and may be partially condensed in tube circuit 39 in warm heat exchange zone 5, and finally passes through tube circuit 41 in cold heat exchange zone 9, wherein
Two-phase refrigerant leaving the shell side of cold heat exchange zone 9 enters warm heat exchange zone 5 and joins with the refrigerant discharged from throttling valve 33. The combined refrigerant is distributed via distributor 35 and flows downward over the outer or shell side of the coil wound bundle in warm heat exchange zone 5. The refrigerant is typically totally vaporized upon reaching the bottom of heat exchanger pressure vessel 3, and is withdrawn as vapor via line 47. This vapor is compressed in the refrigerant compression system (not shown) and optionally precooled to provide the two-phase cooled compressed refrigerant via line 25 as earlier described.

Tubes circuits 13, 31, and 39 in warm heat exchange zone 5 are parts of a single coil wound tubing bundle which is installed in warm heat exchange zone 5 of heat exchanger pressure vessel 3. This coil wound tubing bundle can be fabricated by methods known in the art of coil wound heat exchanger fabrication in which groups of long aluminum tubes of similar length are helically wound about an axial central core or mandrel. The mandrel may be a cylindrical pipe having a length, outer diameter, and wall thickness which impart the required structural strength to support the desired layers of tubing. In one method of bundle fabrication, solid rods may be wound helically about and in contact with the mandrel, spacers may be installed on the wound rods parallel to the mandrel axis, and then tubes may be helically wound in a first layer in contact with the spacers.

Numerous tube layers are formed in the radial direction, and each layer typically is separated from adjacent layers by axial or helical spacers or spacer wires. Winding can be done with the mandrel axis oriented vertically in a fixed position while the tubing is wound onto the coil bundle from reels adapted to move circumferentially about the axis, and also to move upward and downward parallel to the axis. These exchangers are often known as spool-wound exchangers. Alternatively, the bundles can be built by rotating the mandrel and bundle on a lathe about a fixed horizontal axis while tubing is wound onto the coil from reels adapted to move axially, i.e., from side to side. This coil wound tubing bundle is characterized by a number of fabrication or dimensional parameters which include the mandrel outer diameter, spacer thickness, number of spacers, number of tubes, tubing inner diameter, tubing outer diameter, bundle outer diameter, tube length, tube pitch, and tube winding angle.

The tubes in each of tube circuits 13, 31, and 39 typically are aggregated at each end, for example by gathering the multiple tubes from each circuit into one or more tube sheets which can be connected to inlet and outlet lines.

Tube circuits 21 and 41 are part of a single coil wound tubing bundle which is installed in cold heat exchange zone 9 of heat exchanger pressure vessel 3. This coil wound tubing bundle can be fabricated by the same methods described above for the wound coil in warm heat exchange zone 5. Each of tube circuits 21 and 41 is aggregated at each end, for example by gathering the multiple tubes from each circuit into one or more tube sheets which can be connected to inlet and outlet lines.

As vaporizing refrigerant flows downward over the coil wound tubing bundle in warm heat exchange zone 5, the net vapor fraction increases and the heat transfer mechanism changes gradually from predominantly two-phase boiling heat transfer at the cold or top end to single-phase vapor heat transfer at the warm or bottom end. While the nature of the heat transfer mechanism changes significantly from top to bottom of the bundle, none of the fabrication parameters of the coil wound bundle change from top to bottom. Certain of these parameters determine the basic fluid flow and heat transfer characteristics of the bundle. These parameters include but are not limited to the outer tube diameter, the radial tube spacing between tube layers (which is fixed by the spacer thickness), tube pitch (distance between tubes in a given layer), and the tube winding angle. The cross-sectional annular open flow area between the tube layers is essentially constant from the top to the bottom of the bundle. The design of the heat transfer and fluid flow characteristics of the coil wound tubing bundle in warm heat exchange zone 5 therefore is a compromise among boiling heat transfer, condensing heat transfer, and single phase vapor heat transfer for the tube and shell side fluids.

As discussed earlier, a current trend in the baseload LNG industry is to increase individual liquefaction train sizes for improved economies of scale, and this requires larger main heat exchangers. The long individual coil wound tubing bundles required in large exchangers must be designed using average overall heat transfer coefficients for streams which are cooled and condensed in the exchanger tubes and other streams which are warmed and vaporized on the outside of the tubes. This is a design compromise in which the potential maximum heat transfer efficiency for the exchanger may not be realized.

In one embodiment, the present invention addresses these problems by splitting the coil wound tubing bundle in warm heat exchange zone 5 into at least two smaller coil wound tubing bundles. Each of these smaller bundles may be fabricated with fewer manufacturing restrictions compared with the fabrication of a single large bundle. Smaller tubing bundles use smaller mandrels, which may result in higher heat transfer area per unit bundle length. Each of the split bundles can be designed to match more closely the nature of the heat exchange and fluid flow phenomena which occur...
in each bundle. For example, heat transfer coefficient correlations which utilize the liquid fraction as an important design parameter can be individually tailored to a selected range of liquid fractions encountered in each of the smaller bundles.

An embodiment of the invention is illustrated in Fig. 2, in which warm heat exchange zone 5 of Fig. 1 has been replaced by lower or warm heat exchange zone 201 and middle heat exchange zone 203. This drawing is for illustration only and is not meant to indicate the relative scale of any components of main heat exchanger 2. Lower heat exchange zone 201 contains tube circuits 205, 207, and 209 which make up a single coil wound tubing bundle installed in heat exchanger pressure vessel 3. This coil wound tubing bundle may be fabricated by any of the known methods described above. Tubes containing the feed gas may be wound on any layer along with tubes containing high pressure refrigerants. Middle heat exchange zone 203 may contain tube circuits 211, 213, and 215 which make up another coil wound tubing bundle which may be installed above the coil wound tubing bundle in lower heat exchange zone 201. This coil wound tubing bundle also may be fabricated by any of the known methods described above. Tubes containing the feed gas also may be wound on any layer along with tubes containing high pressure refrigerants.

Each of the coil wound tubing bundles in heat exchange zones 201 and 203 is characterized by a number of fabrication or dimensional parameters which include the mandrel outer diameter, spacer thickness, number of spacers, number of tubes, tubing inner diameter, tubing outer diameter, bundle outer diameter, tube length, tube pitch, and tube winding angle. Other fabrication or dimensional parameters may be used to characterize coil wound tubing bundles as desired. The two coil wound tubing bundles differ in one or more of the parameters described above, and may be designed such that the overall operating performance of main heat exchanger 2 is optimized.

A coil wound tubing bundle is defined as a fabricated assembly which comprises a plurality of long aluminum tubes which are helically wound about an axial central core or mandrel.

Heat exchanger pressure vessel 3 typically is oriented vertically, the axes of the coil wound tubing bundles typically are vertical, and the bundles are typically coaxial with the exchanger pressure vessel.

The tube winding angle may be defined as the included angle formed between the tube axis and a plane perpendicular to the bundle axis (i.e., the mandrel axis). The tube winding angle may be between 2 and 25 degrees. Tube pitch may be defined as the center-to-center distance between adjacent wound tubes in which the center-to-center distance is measured perpendicular to the axes of the tubes. Tube pitch may vary between 1.0 and 2.0 times the tube diameter. The tubing inner and outer diameters have the usual meaning. The bundle outer diameter is the diameter based on the outer surface of the tubes in the last layer of the bundle. The tube length in a bundle may be defined as the average length of the tubes in the bundle including the coiled portion and the tails at either end of the tubes.

The spacer may be a cylindrical rod or wire, or alternatively may be a rod of generally rectangular or other desired cross section. The meaning of the term "spacer thickness" is the radial distance between the opposite sides of the spacer which are in contact with the tubes in two successive layers in a bundle. The number of spacers means the total number of spacers in the bundle. Each spacer may be oriented generally parallel to the axis of the mandrel, may be oriented helically in relation to the bundle axis, or may use any other desired orientation.

The tubes in tube circuits 205, 207, and 209 may extend beyond the actual wound coil in "tails" which may be aggregated or gathered together into groups so that each tail in the group can be inserted and fixed into a tube sheet. For example, the outlet ends of a plurality of tubes in a coil wound tubing bundle may be aggregated by insertion and fixing in a tube sheet to form a group of tube outlets. Similar means may be used to aggregate the inlet ends of the plurality of tubes in the coil wound tubing bundle. These tube sheets in turn may be joined, for example by means of flanges, to sections of pipes to carry fluid to and from the wound tubing bundle. One or more tube sheets at the lower end of tube circuit 205 may be connected to feed gas inlet line 11, one or more tube sheets at the lower end of tube circuit 207 may be connected to refrigerant vapor inlet line 37, and one or more tube sheets at the lower end of tube circuit 209 may be connected to refrigerant liquid inlet line 29. In like manner, the tube sheets at the upper end of tube circuit 205 are connected to refrigerant transfer line 219, the tube sheets at the upper end of tube circuit 207 are connected to refrigerant transfer line 219, and the tube sheets at the upper end of tube circuit 209 are connected to refrigerant transfer line 221.

The connection of a tube sheet in one coil wound tubing bundle to a tube sheet in another tubing bundle provides for fluid flow communication between the respective tube circuits in the two bundles. The term "fluid flow communication" means that some or all of the fluid leaving one bundle may flow through this connection into the other bundle. For example, fluid leaving one bundle may be withdrawn from heat exchanger pressure vessel 3, subjected to another process step, and returned to the other bundle at a different composition and/or flow rate. The term "direct fluid flow communication" means that all of the fluid leaving one bundle flows through this connection at a constant composition and flow rate into the other bundle.

Optionally, feed transfer line 217 may be extended through the wall of heat exchanger vessel 3 to connect with the lower end of tube circuit 211. Similarly, line 219 may be extended through the wall of heat exchanger vessel 3 to connect with the lower end of tube circuit 213.

The tubes in tube circuits 211, 213, and 215 may extend beyond the actual wound bundle in "tails" which may
The term "coil wound tubing bundle" as used herein includes the coiled section of the bundle as well as the tails at either end of the coiled section.

Feed transfer line 223 optionally may be connected via line 15 to throttling valve 17, if used, which if used is connected via line 16 to tube circuit 21. If throttling valve 17 is not used, feed transfer line 223 directly connects tube circuits 21 and 21.

The coil wound tubing bundle in lower or warm heat exchange zone 201 and the coil wound tubing bundle in middle heat exchange zone 203 together form an exemplary coil wound tube assembly which replaces the single coil wound tubing bundle in warm heat exchange zone 5 of Fig. 1.

The tubes in tube circuits 21 and 41 may extend beyond the actual wound bundle in "tails" which may be aggregated or gathered together into groups so that each tail in the group can be inserted and fixed into a tube sheet. The tube sheets in turn may be joined, for example by means of flanges, to pipe sections which carry fluid to and from the coil wound tubing bundle. One or more tube sheets at the lower end of tube circuit 21 may be connected to feed transfer line 21, and one or more tube sheets at the lower end of tube circuit 41 may be connected to refrigerant transfer line 42.

Refrigerant transfer line 42 is connected to throttling valve 43 and refrigerant distributor 45. This distributor is shown schematically and may include means for phase separation and distribution of separate vapor and liquid refrigerant streams to heat exchange zone 201.

The term "coil wound tubing bundle" is used herein to include the coiled section of the bundle as well as the tails at either end of the coiled section.

Feed transfer line 223 optionally may be connected via line 15 to throttling valve 17, if used, which if used is connected via line 16 to tube circuit 21. If throttling valve 17 is not used, feed transfer line 223 directly connects tube circuits 21 and 21.

The term "coil wound tubing bundle" is used herein to include the coiled section of the bundle as well as the tails at either end of the coiled section.

Feed transfer line 223 optionally may be connected via line 15 to throttling valve 17, if used, which if used is connected via line 16 to tube circuit 21. If throttling valve 17 is not used, feed transfer line 223 directly connects tube circuits 21 and 21.

The coil wound tubing bundle in lower or warm heat exchange zone 201 and the coil wound tubing bundle in middle heat exchange zone 203 together form an exemplary coil wound tube assembly which replaces the single coil wound tubing bundle in warm heat exchange zone 5 of Fig. 1.

The tubes in tube circuits 21 and 41 may extend beyond the actual wound bundle in "tails" which may be aggregated or gathered together into groups so that each tail in the group can be inserted and fixed into a tube sheet. The tube sheets in turn may be joined, for example by means of flanges, to pipe sections which carry fluid to and from the coil wound tubing bundle. One or more tube sheets at the lower end of tube circuit 21 may be connected to feed transfer line 21, and one or more tube sheets at the lower end of tube circuit 41 may be connected to refrigerant transfer line 42.

Refrigerant transfer line 42 is connected to throttling valve 43 and refrigerant distributor 45. This distributor is shown schematically and may include means for phase separation and distribution of separate vapor and liquid refrigerant streams to heat exchange zone 201.

The term "coil wound tubing bundle" is used herein to include the coiled section of the bundle as well as the tails at either end of the coiled section.

Feed transfer line 223 optionally may be connected via line 15 to throttling valve 17, if used, which if used is connected via line 16 to tube circuit 21. If throttling valve 17 is not used, feed transfer line 223 directly connects tube circuits 21 and 21.

The coil wound tubing bundle in lower or warm heat exchange zone 201 and the coil wound tubing bundle in middle heat exchange zone 203 together form an exemplary coil wound tube assembly which replaces the single coil wound tubing bundle in warm heat exchange zone 5 of Fig. 1.
Two well-known processes for the production of LNG are the propane precooled mixed refrigerant process and the dual mixed refrigerant process. Each of these processes utilizes one or more coil wound heat exchangers, and can utilize the present invention for improved process performance. In the propane precooled mixed refrigerant process, propane refrigeration is used to precool the natural gas feed, and final cooling and liquefaction of the clean, precooled gas is provided by a mixed refrigerant system. Compressed mixed refrigerant in the mixed refrigerant loop may be cooled and partially condensed by propane refrigeration. In the dual mixed refrigerant process, a first mixed refrigerant system may be precooled to precool the natural gas feed and a second mixed refrigerant system may be used to provide final gas cooling and liquefaction. In an alternative process, an ammonia absorption refrigeration system may be used to precool the feed gas and the mixed refrigerant. The present invention may be used with any natural gas liquefaction process which uses coil wound heat exchangers.

While the invention has been illustrated above for use in a natural gas liquefaction process, the split bundle concept may be used in any process which uses wound coil heat exchangers. This could include, for example, cryogenic processing of natural gas to recover light hydrocarbons as liquefied petroleum gas (LPG) and the recovery of helium from natural gas. The following Examples illustrate the present invention but do not limit the invention to any of the specific details described therein.

EXAMPLE 1

The use of the split bundle coil wound heat exchanger in a propane precooled mixed refrigerant LNG process is illustrated in the schematic flow diagram of Fig. 3. A natural gas feed stream is provided in line 301 at 9.75 MPa (1,431 psia) and has a composition (in vol%) of 93% methane, 4% ethane, 0.6% propane, 0.3% butane, 0.1% isobutane, 0.8% nitrogen, and trace amounts of higher hydrocarbons and water. The feed stream in line 301 is initially cooled to -36.7°C (-34°F), through a series of cascade heat exchangers 303, 305, and 307 which are cooled by a closed circuit precooling refrigeration system using propane as the refrigerant. Propane is the preferred refrigerant because it provides refrigeration duty at the desired operational temperature and pressure, and also because it is available from the separated natural gas liquids for initial charging of and makeup to the propane and mixed refrigerant systems.

The precooled high pressure feed is introduced via line 309 into expander turbine 311 where it is reduced in pressure to 5 MPa (725 psia) and has a composition (in vol%) of 93% methane, 4% ethane, 0.6% propane, 0.3% butane, 0.1% isobutane, 0.8% nitrogen, and trace amounts of higher hydrocarbons and water. The feed stream in line 301 is initially cooled to -36.7°C (-34°F), through a series of cascade heat exchangers 303, 305, and 307 which are cooled by a closed circuit precooling refrigeration system using propane as the refrigerant. Propane is the preferred refrigerant because it provides refrigeration duty at the desired operational temperature and pressure, and also because it is available from the separated natural gas liquids for initial charging of and makeup to the propane and mixed refrigerant systems.

The precooled high pressure feed is introduced via line 309 into expander turbine 311 where it is reduced in pressure to 5 MPa (725 psia) and has a composition (in vol%) of 93% methane, 4% ethane, 0.6% propane, 0.3% butane, 0.1% isobutane, 0.8% nitrogen, and trace amounts of higher hydrocarbons and water. The feed stream in line 301 is initially cooled to -36.7°C (-34°F), through a series of cascade heat exchangers 303, 305, and 307 which are cooled by a closed circuit precooling refrigeration system using propane as the refrigerant. Propane is the preferred refrigerant because it provides refrigeration duty at the desired operational temperature and pressure, and also because it is available from the separated natural gas liquids for initial charging of and makeup to the propane and mixed refrigerant systems.
Vapor phase methane which develops during storage of the LNG product is removed and compressed (not shown) for inclusion as plant fuel. Alternatively, the liquid in line 363 may be subcooled to a lower temperature such that no flash occurs when the liquid is flashed across valve 365.

[0058] The refrigeration for the liquefaction process described above is provided by a multicomponent refrigerant which vaporizes while flowing downward over the shell side of the three coil wound tubing bundles in heat exchange zones 337, 347, and 361 within exchanger vessel 367. A multicomponent refrigerant vapor stream is withdrawn from the bottom of exchanger vessel 367 via line 369 and has a composition (in vol%) of 47% ethane, 41% methane, 8.9% propane, and 2.9% nitrogen. Makeup multiple component refrigerant may be introduced into the liquefaction refrigeration loop as required via line 371.

[0059] The combined makeup refrigerant and recycle refrigerant in line 373 at 290kPA (40 psia) and -40°C (40°F) is compressed in compressor 375 and cooled by cooling water in heat exchanger 377. The refrigerant is further compressed in compressor 379 and cooled by cooling water in heat exchanger 381 to yield a compressed refrigerant stream in line 383 at 4.41 MPa (638 psia) and 12°C 54°F. This compressed, warm, multiple component refrigerant is vaporized and partially condensed in evaporative heat exchangers 385, 387, and 389 by indirect heat exchange with vaporizing propane refrigerant supplied via lines 391, 393, and 395. The multicomponent refrigerant exits heat exchanger 389 in line 397 at a pressure of 4.3MPa (620 psia) and a temperature of -34°C (30°F).

[0060] The multicomponent refrigerant is separated in separator 399, vapor is withdrawn via line 401 (about 25% of the total molar refrigerant flow) and liquid is withdrawn via line 403 (about 75% of the total molar refrigerant flow). The liquid refrigerant enters via line 403 and is subcooled by flow through tube circuit 335 of the coil wound bundle in heat exchange zone 337 and tube circuit 345 of the coil wound bundle in heat exchange zone 347. Subcooled refrigerant at -129°C (-200°F) and 3.6 MPa (517 psia) in line 405 is reduced in pressure across throttling valve 407, and the reduced pressure refrigerant is combined with refrigerant from the shell side of heat exchange zone 361. The combined refrigerant is distributed onto the coil wound bundle in heat exchange zone 347 through distributor 409.

[0061] The vapor from separator 399 is removed via line 401 and flows through tube circuits 333, 343, and 359 wherein it is cooled and liquefied. Liquid refrigerant at -157°C (250°F) is withdrawn via line 411, reduced in pressure across throttling valve 413, and distributed via distributor 415 over the coil wound bundle in heat exchange zone 361. Vaporizing refrigerant flows downward through heat exchange zone 361, is combined with the refrigerant from valve 407 as described above, and the combined vaporizing refrigerant is distributed through distributor 409 and flows downward over the coil wound bundle in heat exchange zone 347. The downward-flowing refrigerant is redistributed by distributor 416, after which the refrigerant continues in downward flow over the coil wound bundle in heat exchange zone 337. Vaporized refrigerant is withdrawn via line 369 and is recycled to compression as described earlier.

[0062] The propane refrigeration cycle mentioned earlier for feed precooling and mixed refrigerant cooling will now be described. Propane vapor streams in lines 417, 419, and 421 are compressed to 1.4 MPa (200 psia) in multistage compressor 423. The compressed propane is aftercooled and totally condensed in water-cooled heat exchangers 425 and 427, and the resulting compressed liquid propane is delivered to liquid reservoir 429. The liquid refrigerant is further subcooled in water-cooled heat exchanger 431 before being passed to refrigeration duty through line 433. The refrigerant is expanded through valve 435 and delivered to supply suction drum 437.

[0063] The refrigerant vapor from drum 437, which vapor is formed due to flash across valve 435 and evaporation in exchangers 303 and 385, flows to recompression via line 421. The liquid refrigerant from drum 437 is removed in line 439 and split into lines 441 and 443. The refrigerant in line 443 is expanded across valve 445 and introduced into supply suction drum 447. The refrigerant in line 441 is divided to flow into lines 449 and 391, which provide propane refrigerant respectively to be vaporized in feed cooling heat exchanger 303 and multicomponent refrigerant cooling exchanger 385 earlier described. Vaporized propane from exchangers 303 and 385 is returned via line 450 to supply suction drum 437.

[0064] The single component refrigerant in supply suction drum 447 is separated into a vapor and a liquid phase. This vapor phase formed by flash across valve 445 and evaporation in exchangers 305 and 387 is removed from supply suction drum 447 via line 419 for recompression in compressor 423. The liquid phase is removed in line 451 which splits into lines 453 and 455. The refrigerant in line 455 is expanded across valve 457 and introduced into supply suction drum 459. The liquid refrigerant stream in line 453 is further split into lines 461 and 393, which provide propane refrigerant to be vaporized respectively in feed cooling heat exchanger 305 and multicomponent refrigerant cooling exchanger 387 earlier described. Vaporized propane from exchangers 305 and 387 is returned via line 463 to supply suction drum 447.

[0065] The single component refrigerant delivered to supply suction drum 459 through line 455 and valve 457 is separated into a vapor phase and a liquid phase. The vapor phase along with vapor from line 469 is removed via line 417 for recompression in compressor 423. The liquid phase is removed in line 465 which splits into lines 467 and 395, which provide propane refrigerant to be vaporized respectively in feed cooling heat exchanger 307 and multicomponent refrigerant cooling exchanger 389 earlier described. Vaporized propane from exchangers 307 and 389 is returned via line 469 to supply suction drum 459. The vapor is supplied to the compressor 423 for recompression via line 417.
EXAMPLE 2

[0066] A two-bundle main heat exchanger as illustrated in Fig. 1 is operated for the production of liquefied natural gas using a propane precooled mixed refrigerant cycle similar to that of Example 1 above. The physical design parameters of the coil wound bundle in heat exchange zone 5 are given in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Physical Design Parameters of Coil Wound Bundle for Example 2 (Heat Exchange Zone 5, Fig. 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bundle outer diameter, (ft.) m</td>
<td>15 4.95</td>
</tr>
<tr>
<td>Bundle length, (ft.) m</td>
<td>65 21.45</td>
</tr>
<tr>
<td>Tube length, (ft) m</td>
<td>870 28.71</td>
</tr>
<tr>
<td>Tube outer diameter, (in.) cm</td>
<td>0.75 1.91</td>
</tr>
<tr>
<td>Mandrel outer diameter, (in.) cm</td>
<td>65 165.1</td>
</tr>
<tr>
<td>Spacer thickness, (in.) cm</td>
<td>0.23 0.58</td>
</tr>
<tr>
<td>Surface area, (sq. ft.) m²</td>
<td>314,000 29.18</td>
</tr>
<tr>
<td>Number of feed tubes</td>
<td>870</td>
</tr>
<tr>
<td>Number of vapor refrigerant tubes</td>
<td>350</td>
</tr>
<tr>
<td>Number of liquid refrigerant tubes</td>
<td>630</td>
</tr>
<tr>
<td>Total number of tubes</td>
<td>1,840</td>
</tr>
</tbody>
</table>

EXAMPLE 3

[0067] A split bundle main heat exchanger as illustrated in Fig. 2 is operated for the production of liquefied natural gas at the same production rate as Example 1 using a propane precooled mixed refrigerant cycle similar to that of Example 1. The physical design parameters of the coil wound bundles in heat exchange zones 201 and 203 are given in Table 2. The pressure drop characteristics of the combined coil wound bundles in heat exchanger zones 201 and 203 (Fig. 2) are approximately the same as those of heat exchange zone 3 (Fig. 1).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Physical Design Parameters of Coil Wound Bundles for Example 3 (Heat Exchange Zones 201 and 203, Fig. 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 201 (Warm bundle)</td>
<td>Zone 203 (Middle bundle)</td>
</tr>
<tr>
<td>Bundle outer diameter, (ft.) m</td>
<td>(14) 4.62</td>
</tr>
<tr>
<td>Bundle length, (ft.) m</td>
<td>(49) 16.17</td>
</tr>
<tr>
<td>Tube length, (ft. m)</td>
<td>(570) 18.8</td>
</tr>
<tr>
<td>Tube outer diameter, (in.) cm</td>
<td>(0.75) 1.9</td>
</tr>
<tr>
<td>Mandrel outer diameter, (in.) cm</td>
<td>(60) 152</td>
</tr>
<tr>
<td>Spacer thickness, (in.) cm</td>
<td>(0.25) 0.64</td>
</tr>
<tr>
<td>Surface area, (sq. ft.) m²</td>
<td>(224,000) 20.82</td>
</tr>
<tr>
<td>Number of feed tubes</td>
<td>950</td>
</tr>
<tr>
<td>Number of vapor refrigerant tubes</td>
<td>390</td>
</tr>
<tr>
<td>Number of liquid refrigerant tubes</td>
<td>660</td>
</tr>
<tr>
<td>Total number of tubes</td>
<td>2,000</td>
</tr>
</tbody>
</table>

[0068] A comparison of the key bundle parameters for the single bundle of Example 2 and the split bundle of Example 3 is given in Table 3 below.
It is seen from the comparison in Table 5 that the split bundle process requires significantly less heat exchange surface area than the single bundle process.

EXAMPLE 4

Information from Examples 1-3 were used with additional process calculations to compare the process of Fig. 3, which uses the split bundle main heat exchanger configuration of Fig. 2, with the same process using the conventional main heat exchanger configuration of Fig. 1. Comparisons were made of relative production at a given exchanger total surface area and of relative total surface area required for a given production rate. Total surface area includes the surface areas of both the warm and the cold bundles. The results are summarized in Table 4.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Comparison of Bundle Parameters for Examples 2 and 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Example 2 (Single bundle)</td>
</tr>
<tr>
<td>Maximum bundle outer diameter, (ft) m</td>
<td>(15) 4.95</td>
</tr>
<tr>
<td>Total bundle length, (ft) m</td>
<td>(65) 21.45</td>
</tr>
<tr>
<td>Total bundle surface area, (sq ft) m²</td>
<td>(314,000) 29.18</td>
</tr>
<tr>
<td>Total number of tubes</td>
<td>1,840</td>
</tr>
<tr>
<td>Total tube length, (ft) m</td>
<td>(870) 287</td>
</tr>
</tbody>
</table>

It is seen from Table 6 that for a given LNG production rate, the present invention requires 80% of the exchanger surface area used in the conventional main exchanger of Fig. 1. Conversely, for a given exchanger surface area, the present invention yields a 2% increase in LNG production rate over that achieved using the conventional main exchanger of Fig. 1.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Comparisons for Example 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Process using main exchanger of Fig. 1</td>
</tr>
<tr>
<td>LNG Production rate</td>
<td>100</td>
</tr>
<tr>
<td>Total exchanger surface area</td>
<td>100</td>
</tr>
</tbody>
</table>

The invention is illustrated in the Examples above for use in the main heat exchanger of the propane-precooled natural gas liquefaction process of Fig. 3. The invention also may be applied to coil wound heat exchangers used in other natural gas liquefaction processes. For example, coil wound heat exchangers used in the well-known dual mixed refrigerant (MR) natural gas liquefaction process can be modified according to the present invention. Examples of the dual MR natural gas liquefaction process are disclosed in U.S. Patents 4,504,296 and 6,119,479. In the dual MR process, natural gas is cooled in a first coil wound heat exchanger by a first recirculating mixed refrigerant system and is further cooled and liquefied in a second coil wound heat exchanger by a second recirculating mixed refrigerant system. The split bundle concept of the present invention may be used in either or both of the first and second coil wound heat exchangers in the dual MR process.

Thus the present invention offers improved heat exchanger performance and size characteristics compared with conventional heat exchanger design. Splitting a single bundle into two or more separate bundles with different design parameters offers the potential for improved production for a given exchanger surface area or, alternatively, offers the potential for using a smaller heat exchanger surface area for a given production rate. In addition, it is possible to redistribute the downward-flowing refrigerant between the split bundles on the shell side of the exchanger, which may improve heat transfer efficiency in the lower bundle. Splitting a bundle also may allow the design of an exchanger with more heat exchanger surface area for a given exchanger. Another advantage of the split bundle configuration is that the axial expansion and contraction in each of two shorter bundles during startup and shutdown will be less than the corresponding expansion and contraction of a single bundle. This reduces mechanical stresses in the shorter bundles compared to the stresses in a single longer bundle.
1. A coil wound heat exchanger system for the liquefaction of natural gas against a vaporizing refrigerant which comprises

(a) a vertical cylindrical heat exchanger vessel comprising a first section having a first diameter and a second section having a second diameter,
(b) a first coil wound tubing bundle disposed axially in the first section of the heat exchanger vessel,
(c) a second coil wound tubing bundle disposed axially in the first section of the heat exchanger vessel above the first coil wound tubing bundle, wherein one or more groups of tubes in the first coil wound tubing bundle are connected in direct fluid flow communication with one or more groups of tubes in the second coil wound tubing bundle,
(d) a third coil wound tubing bundle disposed axially in the second section of the heat exchanger vessel above the second wound tubing bundle,
(e) wherein the first and the second coil wound tubing bundles differ in one or more parameters selected from a group including mandrel outer diameter, spacer thickness, number of spacers, number of tubes, tubing inner diameter, tubing outer diameter, bundle outer diameter, tube length, tube pitch, and tube winding angle, characterized in that
(f) each group of tubes in the first coil wound tubing bundle is connected in direct fluid flow communication with a group of tubes in the second coil wound tubing bundle,
(g) a refrigerant distributor (229) is disposed between the first and second coil wound tubing bundles,
(h) and the second section has a diameter which is different than the first diameter.

2. The coil wound heat exchanger system of Claim 2 wherein:

- the first coil wound tubing bundle includes
  (b1) a first mandrel having a first end and a second end;
  (b2) a first set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the mandrel to form a first tube layer;
  (b3) a first plurality of spacers disposed in contact with the first tube layer, each spacer having a thickness defined in a radial direction;
  (b4) a second set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the first tube layer to form a second tube layer, wherein the second tube layer is in contact with the first plurality of spacers; and
  (b5) a plurality of additional successive layers of spacers and tubes similar to the spacers and tubes of (b3) and (b4), wherein the plurality of additional successive spacers and layers of tubes are disposed radially;

wherein the inlets and outlets of the tubes of (b2) through (b5) are proximate the first end and the second end respectively of the first mandrel;

- the second coil wound tubing bundle includes
  (c1) a second mandrel having a first end and a second end;
  (c2) a first set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the mandrel to form a first tube layer;
  (c3) a first plurality of spacers disposed in contact with the first tube layer, each spacer having a thickness defined in a radial direction;
  (c4) a second set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the first tube layer to form a second tube layer, wherein the second tube layer is in contact with the first plurality of spacers; and
  (c5) a plurality of additional successive layers of spacers and tubes similar to the spacers and tubes of (c3) and (c4), wherein the plurality of additional successive spacers and layers of tubes are disposed radially;

wherein the inlets and outlets of the tubes of (c2) through (c5) are proximate the first end and the second end respectively of the second mandrel;

- and wherein the coil wound heat exchanger system further comprises

(d) means for aggregating the outlet ends of two or more sets of tubes in the first coil wound tubing bundle
to form a first group of tube outlets;
(e) means for aggregating the inlet ends of two or more sets of tubes in the second coil wound tubing bundle to form a first group of tube inlets;
(f) means for placing the first group of tube outlets in the first coil wound tubing bundle in fluid flow communication with the first group of tube inlets in the second coil wound tubing bundle; and
(g) a third coil wound tubing bundle disposed axially in a second section of the heat exchanger vessel above the second wound tubing bundle, wherein the second section has a diameter which is different than the first diameter, and

wherein the third coil wound tubing bundle includes

(g1) a third mandrel having a first end and a second end;
(g2) a first set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the mandrel to form a first tube layer;
(g3) a first plurality of spacers disposed in contact with the first tube layer, each spacer having a thickness defined in a radial direction;
(g4) a second set of tubes, each tube having an inlet end and an outlet end, which tubes are helically wound about the first tube layer to form a second tube layer, wherein the second tube layer is in contact with the first plurality of spacers;
(g5) a plurality of additional successive layers of spacers and tubes similar to the spacers and tubes of (g3) and (g4), wherein the plurality of additional successive spacers and layers of tubes are disposed radially;

wherein the inlets and outlets of the tubes of (g2) through (g5) are proximate the first end and the second end respectively of the third mandrel.

Patentansprüche

1. Wärmetauschersystem aus gewickelten Rohrschlangen zur Verflüssigung von Erdgas gegen ein verdampfendes Kältemittel, welches umfasst:

(a) ein vertikales zylindrisches Wärmetauschergefäß, umfassend einen ersten Abschnitt mit einem ersten Durchmesser und einen zweiten Abschnitt mit einem zweiten Durchmesser;
(b) ein erstes Röhrenbündel aus gewickelten Rohrschlangen, das axial im ersten Abschnitt des Wärmetauschergefäßes angeordnet ist;
(c) ein zweites Röhrenbündel aus gewickelten Rohrschlangen, das axial im ersten Abschnitt des Wärmetauschergefäßes über dem ersten Röhrenbündel aus gewickelten Rohrschlangen angeordnet ist, wobei eine oder mehrere Röhrengruppen im ersten Röhrenbündel aus gewickelten Rohrschlangen in direkter Strömungsverbindung mit einer oder mehreren Röhrengruppen im zweiten Röhrenbündel aus gewickelten Rohrschlangen stehen;
(d) ein drittes Röhrenbündel aus gewickelten Rohrschlangen, das axial im zweiten Bereich des Wärmetauschergefäßes über dem zweiten Röhrenbündel aus gewickelten Rohrschlangen angeordnet ist;
(e) wobei das erste und das zweite Röhrenbündel aus gewickelten Rohrschlangen sich in einem oder mehreren Parametern unterscheiden, ausgewählt aus einer Gruppe, umfassend den Außendurchmesser des Doms, die Dicke des Abstandshalter, die Anzahl der Abstandshalter, die Anzahl der Röhren, den Innendurchmesser der Röhren, den Außendurchmesser der Röhren, den Außendurchmesser des Bündels, die Röhrenlänge, den Gangabstand der Röhren, den Windungswinkel der Röhren,
dadurch gekennzeichnet, dass
(f) jede Gruppe von Röhren im ersten Röhrenbündel aus gewickelten Rohrschlangen in direkter Fluidströmungsverbindung mit einer Gruppe von Röhren im zweiten Röhrenbündel aus gewickelten Rohrschlangen steht,
(g) ein Kälteteilverteiler (229) zwischen dem ersten und dem zweiten Röhrenbündel aus gewickelten Rohrschlangen angeordnet ist,
(h) und der zweite Abschnitt einen Durchmesser hat, der anders als der erste Durchmesser ist.

2. Wärmetauschersystem aus gewickelten Rohrschlangen nach Anspruch 1, wobei das erste Rohrbündel aus gewickelten Rohrschlangen umfasst:

(b1) einen ersten Dorn mit einem ersten Ende und einem zweiten Ende;
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(b2) einen ersten Röhrensatz, wobei jede Röhre ein Einlassende und ein Auslassende hat und wobei die Röhren helixförmig um den Dorn gewickelt sind, um eine erste Röhrenschicht zu bilden;
(b3) eine erste Vielzahl von Abstandshaltern, die in Kontakt mit der ersten Röhrenschicht angeordnet sind, wobei jeder Abstandhalter eine in radialer Richtung definierte Dicke aufweist;
(b4) einen zweiten Röhrensatz, wobei jede Röhre ein Einlassende und ein Auslassende hat und wobei die Röhren helixförmig um die erste Röhrenschicht gewickelt sind, um eine zweite Röhrenschicht zu bilden, wobei die zweite Röhrenschicht in Kontakt mit der ersten Vielzahl von Abstandshaltern ist; und
(b5) eine Vielzahl zusätzlicher aufeinanderfolgender Schichten von Abstandshaltern und Röhren ähnlich den Abstandshaltern und Röhren von (b3) und (b4), wobei die Vielzahl zusätzlicher aufeinanderfolgender Abstandshalter und Röhrensichten radial angeordnet sind;

wobei die Einlässe und Auslässe der Röhren von (b2) bis (b5) in der Nähe des ersten Endes bzw. des zweiten Endes des ersten Dorns sind;

- wobei das zweite Röhrenbündel aus gewundenen Rohrschlangen umfasst:

(c1) einen zweiten Dorn mit einem ersten Ende und einem zweiten Ende;
(c2) einen ersten Röhrensatz, wobei jede Röhre ein Einlassende und ein Auslassende hat und wobei die Röhren helixförmig um den Dom gewickelt sind, um eine erste Röhrenschicht zu bilden;
(c3) eine erste Vielzahl von Abstandshaltern, die in Kontakt mit der ersten Röhrenschicht angeordnet sind, wobei jeder Abstandhalter eine in radialer Richtung definierte Dicke aufweist;
(c4) einen zweiten Röhrensatz, wobei jede Röhre ein Einlassende und ein Auslassende hat und wobei die Röhren helixförmig um die erste Röhrenschicht gewickelt sind, um eine zweite Röhrenschicht zu bilden, wobei die zweite Röhrenschicht in Kontakt mit der ersten Vielzahl von Abstandshaltern ist; und
(c5) eine Vielzahl zusätzlicher aufeinanderfolgender Schichten von Abstandshaltern und Röhren ähnlich den Abstandshaltern und Röhren von (c3) und (c4), wobei die Vielzahl zusätzlicher aufeinanderfolgender Abstandshalter und Röhrensichten radial angeordnet sind;

wobei die Einlässe und Auslässe der Röhren von (c2) bis (c5) in der Nähe des ersten Endes bzw. des zweiten Endes des zweiten Dorns sind;

- und wobei das Wärmetauschersystem aus gewundenen Rohrschlangen außerdem umfasst:

(d) Mittel zum Zusammenfassen der Auslassenden von zwei oder mehreren Röhrensätzen im zweiten Röhrenbündel aus gewickelten Rohrschlangen, um eine erste Gruppe von Röhrenauslässen zu bilden;
(e) Mittel zum Zusammenfassen der Einlassenden von zwei oder mehreren Röhrensätzen im ersten Röhrenbündel aus gewickelten Rohrschlangen, um eine erste Gruppe von Röhreneinlässen zu bilden;
(f) Mittel zum Versetzen der ersten Gruppe von Röhrenauslässen im ersten Röhrenbündel aus gewundenen Rohrschlangen in Fluidströmungsverbindung mit der ersten Gruppe von Röhreneinlässen im zweiten Röhrenbündel aus gewickelten Rohrschlangen; und
(g) ein drittes Röhrenbündel aus gewickelten Rohrschlangen, das axial in einem zweiten Abschnitt des Wärmetauschergefässes über dem zweiten Bündel aus gewickelten Rohrschlangen angeordnet ist, wobei der zweite Abschnitt einen Durchmesser hat, der anders als der erste Durchmesser ist; und
wobei das dritte Röhrenbündel aus gewickelten Rohrschlangen umfasst:

(g1) einen dritten Dorn mit einem ersten Ende und einem zweiten Ende;
(g2) einen ersten Röhrensatz, wobei jede Röhre ein Einlassende und ein Auslassende hat und wobei die Röhren helixförmig um den Dom gewickelt sind, um eine erste Röhrenschicht zu bilden;
(g3) eine erste Vielzahl von Abstandshaltern, die in Kontakt mit der ersten Röhrenschicht angeordnet sind, wobei jeder Abstandhalter eine in radialer Richtung definierte Dicke aufweist;
(g4) einen zweiten Röhrensatz, wobei jede Röhre ein Einlassende und ein Auslassende hat und wobei die Röhren helixförmig um die erste Röhrenschicht gewickelt sind, um eine zweite Röhrenschicht zu bilden, wobei die zweite Röhrenschicht in Kontakt mit der ersten Vielzahl von Abstandshaltern ist; und
(g5) eine Vielzahl zusätzlicher aufeinanderfolgender Schichten von Abstandshaltern und Röhren ähnlich den Abstandshaltern und Röhren von (g3) und (g4), wobei die Vielzahl zusätzlicher aufeinanderfolgender Abstandshalter und Röhrensichten radial angeordnet sind;

wobei die Einlässe und Auslässe der Röhren von (g2) bis (g5) in der Nähe des ersten Endes bzw. des zweiten Endes des dritten Dorns sind.
Revendications

1. Système échangeur de chaleur à serpents pour la liquéfaction de gaz naturel contre un réfrigérant se vaporisant, qui comprend :

   (a) un récipient vertical cylindrique d’échangeur de chaleur comprenant une première section possédant un premier diamètre et une seconde section possédant un second diamètre,
   (b) un premier faisceau de tubes en serpents disposé axialement dans la première section du récipient d’échangeur de chaleur,
   (c) un deuxième faisceau de tubes en serpents disposé axialement dans la première section du récipient d’échangeur de chaleur au-dessus du premier faisceau de tubes en serpents, dans lequel un ou plusieurs groupes de tubes parmi le premier faisceau de tubes en serpents sont raccordés en communication directe d’écoulement de fluide avec un ou plusieurs groupes de tubes parmi le deuxième faisceau de tubes en serpents,
   (d) un troisième faisceau de tubes en serpents disposé axialement dans la seconde section du récipient d’échangeur de chaleur au-dessus du deuxième faisceau de tubes en serpents,
   (e) dans lequel les premier et deuxième faisceaux de tubes en serpents diffèrent par un ou plusieurs paramètres sélectionnés parmi un groupe comprenant le diamètre extérieur de mandrin, l’épaisseur de pièce d’espacement, le nombre de pièces d’espacement, le nombre de tubes, le diamètre intérieur de tube, le diamètre extérieur de tube, le diamètre extérieur de faisceau, la longueur de tube, le pas de tube, et l’angle d’enroulement de tube, caractérisé en ce que
   (f) chaque groupe de tubes dans le premier faisceau de tubes en serpents est raccordé en communication directe d’écoulement de fluide avec un groupe de tubes dans le deuxième faisceau de tubes en serpents,
   (g) un distributeur de réfrigérant (229) est disposé entre les premier et deuxième faisceaux de tubes en serpents,
   (h) et la seconde section possède un diamètre qui est différent du premier diamètre.

2. Système échangeur de chaleur à serpents de tubes selon la revendication 2, dans lequel :

   - le premier faisceau de tubes en serpents comprend :
     (b1) un premier mandrin possédant une première extrémité et une seconde extrémité ;
     (b2) un premier ensemble de tubes, chaque tube possédant une extrémité d’entrée et une extrémité de sortie, lesquels tubes sont enroulés de façon hélicoïdale autour du mandrin pour former une première couche de tubes ;
     (b3) une première pluralité de pièces d’espacement disposées en contact avec la première couche de tubes, chaque pièce d’espacement possédant une épaisseur définie dans une direction radiale ;
     (b4) un second ensemble de tubes, chaque tube possédant une extrémité d’entrée et une extrémité de sortie, lesquels tubes sont enroulés de façon hélicoïdale autour de la première couche de tubes pour former une deuxième couche de tubes, dans lequel la deuxième couche de tubes est en contact avec la première pluralité de pièces d’espacement ; et
     (b5) une pluralité de couches successives supplémentaires de pièces d’espacement et de tubes similaires aux pièces d’espacement et tubes de (b3) et (b4), dans lequel la pluralité de pièces d’espacement et couches de tubes successives supplémentaires sont disposées radialement ;

dans lequel les entrées et sorties des tubes de (b2) à (b5) sont à proximité de la première extrémité et la seconde extrémité, respectivement, du premier mandrin ;

   - le deuxième faisceau de tubes en serpents comprend :
     (c1) un second mandrin possédant une première extrémité et une seconde extrémité ;
     (c2) un premier ensemble de tubes, chaque tube possédant une extrémité d’entrée et une extrémité de sortie, lesquels tubes sont enroulés de façon hélicoïdale autour du mandrin pour former une première couche de tubes ;
     (c3) une première pluralité de pièces d’espacement disposées en contact avec la première couche de tubes, chaque pièce d’espacement possédant une épaisseur définie dans une direction radiale ;
     (c4) un second ensemble de tubes, chaque tube possédant une extrémité d’entrée et une extrémité de sortie, lesquels tubes sont enroulés de façon hélicoïdale autour de la première couche de tubes pour former une deuxième couche de tubes, dans lequel la deuxième couche de tubes est en contact avec la première pluralité de pièces d’espacement ; et
(c5) une pluralité de couches successives supplémentaires de pièces d’espacement et de tubes similaires aux pièces d’espacement et tubes de (c3) et (c4), dans lequel la pluralité de pièces d’espacement et couches de tubes successives supplémentaires sont disposées radialement ;

dans lequel les entrées et sorties des tubes de (c2) à (c5) sont à proximité de la première extrémité et la seconde extrémité, respectivement, du second mandrin ;

- et dans lequel le système échangeur de chaleur à serpentin comprend en outre :

(d) des moyens pour regrouper les extrémités de sortie de deux, ou plus, ensembles de tubes dans le premier faisceau de tubes en serpentin pour former un premier groupe de sorties de tubes ;
(e) des moyens pour regrouper les extrémités d’entrée de deux, ou plus, ensembles de tubes dans le deuxième faisceau de tubes en serpentin pour former un premier groupe d’entrées de tubes ;
(f) des moyens pour placer le premier groupe de sorties de tubes dans le premier faisceau de tubes en serpentin en communication d’écoulement de fluide avec le premier groupe d’entrées de tubes dans le deuxième faisceau de tubes en serpentin ; et

(g) un troisième faisceau de tubes en serpentin disposé axialement dans une seconde section du récipient d’échangeur de chaleur au-dessus du deuxième faisceau de tubes en serpentin, dans lequel la seconde section possède un diamètre qui est différent du premier diamètre, et

dans lequel le troisième faisceau de tubes en serpentin comprend :

(g1) un troisième mandrin possédant une première extrémité et une seconde extrémité ;
(g2) un premier ensemble de tubes, chaque tube possédant une extrémité d’entrée et une extrémité de sortie, lesquels tubes sont enroulés de façon hélicoïdale autour du mandrin pour former une première couche de tubes ;
(g3) une première pluralité de pièces d’espacement disposées en contact avec la première couche de tubes, chaque pièce d’espacement possédant une épaisseur définie dans une direction radiale ;
(g4) un second ensemble de tubes, chaque tube possédant une extrémité d’entrée et une sortie et, lesquels tubes sont enroulés de façon hélicoïdale autour de la première couche de tubes pour former une deuxième couche de tubes, dans lequel la deuxième couche de tubes est en contact avec la première pluralité de pièces d’espacement ;
(g5) une pluralité de couches successives supplémentaires de pièces d’espacement et de tubes similaires aux pièces d’espacement et tubes de (g3) et (g4), dans lequel la pluralité de pièces d’espacement et couches de tubes successives supplémentaires sont disposées radialement ;

dans lequel les entrées et sorties des tubes de (g2) à (g5) sont à proximité de la première extrémité et la seconde extrémité, respectivement, du troisième mandrin.
FIG. 2
REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 6347532 B [0004]
- US 4504296 A [0072]
- US 6119479 A [0072]