

(19)



Europäisches Patentamt
European Patent Office
Office européen des brevets



(11)

EP 1 367 350 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
03.12.2003 Bulletin 2003/49

(51) Int Cl. 7: F28D 7/02, F25J 3/02

(21) Application number: 02011583.8

(22) Date of filing: 27.05.2002

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

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(54) Coil wound heat exchanger

(57) A coil wound tubing assembly for use in a coil wound heat exchanger. The tubing assembly may comprise a first coil wound tubing bundle and a second coil wound tubing bundle, wherein one or more groups of tubes in the first coil wound tubing bundle may be connected in direct fluid flow communication with one or more groups of tubes in the second coil wound tubing bundle, characterized in that 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, tube length, tube pitch, and tube winding angle.

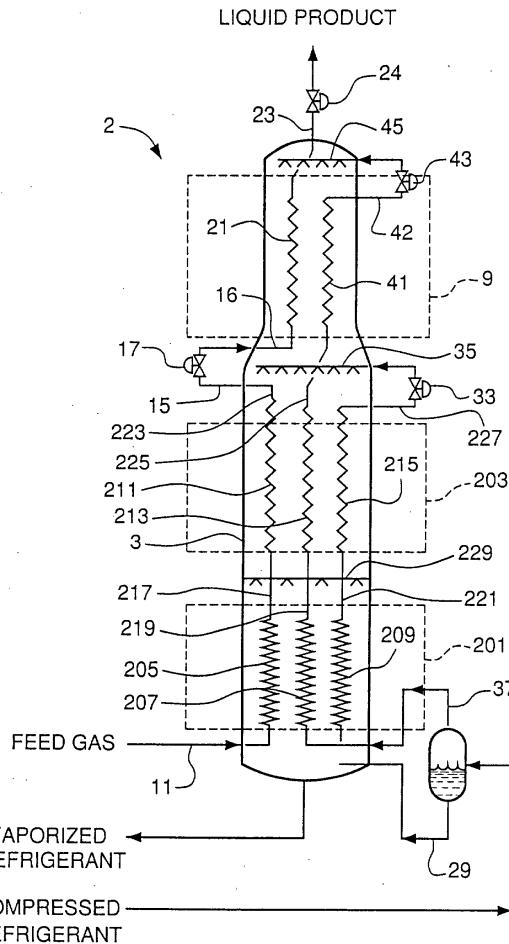


FIG. 2

Description

BACKGROUND OF THE INVENTION

5 [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-260°F. Coil wound heat exchangers are ideally suited for use in LNG process cycles at cryogenic conditions.

10 [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.

15 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.

20 [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 size.

BRIEF SUMMARY OF THE INVENTION

30 [0004] The invention relates to a coil wound tubing assembly for use in a coil wound heat exchanger, which tubing assembly comprises a first coil wound tubing bundle and a second 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, characterized in that 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, 35 number of spacers, number of tubes, tubing inner diameter, tubing outer diameter, tube length, tube pitch, and tube winding angle.

35 [0005] Each group of tubes in the first coil wound tubing bundle may be connected in direct fluid flow communication with a group of tubes in the second coil wound tubing bundle. The first and second coil wound tubing bundles may be vertically oriented and the second coil wound tubing bundle may be located above the first coil wound tubing bundle.

40 The first and second coil wound tubing bundles may be coaxial.

45 [0006] The invention also relates to a coil wound heat exchanger system which comprises a vertical cylindrical heat exchanger vessel comprising a first section having a first diameter; a first coil wound tubing bundle disposed axially in the first section of the heat exchanger vessel; and a second coil wound tubing bundle disposed axially in the first section of the heat exchanger vessel above the first coil wound tubing bundle,

50 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. The first and the second coil wound tubing bundles may 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.

55 [0007] 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;

5 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;

[0008] In this coil wound heat exchanger system, the second coil wound tubing bundle may include:

(c1) a second mandrel having a first end and a second end;

10 (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;

15 (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;

20 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.

[0009] The coil wound heat exchanger system may further comprise:

25 (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.

30 **[0010]** 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.

35 **[0011]** 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.

40 **[0012]** In another embodiment, a refrigerant distributor may be disposed above the second coil wound tubing bundle. In this embodiment, the coil wound heat exchanger system may also comprise means for placing the third group of tube outlets in the second coil wound tubing bundle in fluid flow communication with the refrigerant distributor above the second wound coil tubing bundle. Also, the coil wound heat exchanger system may further comprise:

(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

- 5 (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;
- 10 (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;

15 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.

[0013] 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.

[0014] 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.

[0015] 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.

[0016] The coil wound heat exchanger system also may utilize a refrigerant redistributor disposed below the second coil wound tubing bundle and above the first coil wound tubing bundle.

[0017] In another embodiment, the invention relates to a process for gas liquefaction which comprises

- 40 (a) introducing a feed gas into a first group of coil wound tubes in a first coil wound tubing bundle and cooling the feed gas by indirect heat exchange with a refrigerant to yield a cooled feed stream; and
- (b) introducing the cooled feed stream into a first group of coil wound tubes in a second coil wound tubing bundle and further cooling the cooled feed stream by indirect heat exchange with a refrigerant to yield a further cooled and partially liquefied feed stream;

45 characterized in that 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, tube length, tube pitch, and tube winding angle.

[0018] The process may further comprise introducing the further cooled and partially liquefied feed stream into a first group of coil wound tubes in a third coil wound tubing bundle and further cooling the cooled feed stream by indirect heat exchange with a refrigerant to yield a liquefied product. The first, second, and third coil wound tubing bundles may be vertically oriented, the second coil wound tubing bundle may be located above the first coil wound tubing bundle, and the third coil wound tubing bundle may located above the second coil wound tubing bundle.

[0019] The first, second, and third coil wound tubing bundles may be disposed coaxially in a vertical cylindrical heat exchanger vessel having a first section with a first diameter and a second section with a second diameter, wherein the first and second wound coil tubing bundles are disposed in the first section and the third wound coil tubing bundle is disposed in the second section, and 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, tube length, tube pitch, tube winding angle, and bundle diameter.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

[0020] Fig. 1 is a schematic illustration of a heat exchanger according to the prior art.

[0021] Fig. 2 is a schematic illustration of an exemplary heat exchanger according to the present invention.

[0022] Fig. 3 is a schematic flow diagram of an exemplary gas liquefaction process which uses the heat exchanger of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0023] 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.

[0024] 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.

[0025] 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 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.

[0026] 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.

[0027] 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 therein while 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).

[0028] 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 it is liquefied and optionally subcooled. This refrigerant is reduced in pressure across throttling valve 43 and distributed via distributor 45 in cold heat exchange zone 9. This refrigerant flows downward over the outer or shell side of the coil wound bundle and vaporizes to provide a portion of the refrigeration for cooling the feed gas in tube circuit 21 as earlier described. In addition, the vaporizing refrigerant provides some of the refrigeration to cool the refrigerant in tube circuit 41. Distributor 45 is shown schematically and may include means for phase separation and distribution of separate vapor and liquid refrigerant streams to heat exchange zone 9.

[0029] 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 pre-cooled to provide the two-phase cooled compressed refrigerant via line 25 as earlier described.

[0030] Tube 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.

[0031] 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.

[0032] 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.

[0033] 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.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] Each of the coil wound tubing bundles in heat exchange zones 201 and 203 may be 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 may 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.

[0039] 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.

[0040] 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.

[0041] 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.

[0042] 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.

[0043] 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, one or more tube sheets at the upper end of tube circuit 205 may be connected to feed transfer line 217, one or more tube sheets at the upper end of tube circuit 207 may be connected to refrigerant transfer line 219, and one or more tube sheets at the upper end of tube circuit 209 may be connected to refrigerant transfer line 221.

[0044] The connection of a tube sheet in one coil wound tubing bundle to a tube sheet in another wound 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.

[0045] Optionally, feed transfer line 217 may be extended through the wall of heat exchanger 3 to an external check valve (not shown) and then back through the wall of heat exchanger vessel 3 to connect with the lower end of tube circuit 211. In another option (not shown), feed transfer line 217 may be extended through the wall of heat exchanger vessel 3 to withdraw the cooled feed gas for an intermediate treatment step, after which the treated feed gas is returned in a line through the wall of heat exchanger 3 to connect with the lower end of tube circuit 211. Similarly, line 219 may be extended through the wall of heat exchanger 3 to an external check valve (not shown) and then back through the wall of heat exchanger vessel 3 to connect with the lower end of tube circuit 213.

[0046] The tubes in tube circuits 211, 213, and 215 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 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 211 may be connected to feed transfer line 217, one or more tube sheets at the lower end of tube circuit 213 may be connected to refrigerant transfer line 219, and one or more tube sheets at the lower end of tube circuit 215 may be connected to refrigerant transfer line 221. In like manner, one or more tube sheets at the upper end of tube circuit 211 may be connected to feed transfer line 223, one or more tube sheets at the upper end of tube circuit 213 may be connected to refrigerant transfer line 225, and one or more tube sheets at the upper end of tube circuit 215 may be connected to refrigerant transfer line 227. Refrigerant transfer line 227 may be connected to throttling valve 33 and refrigerant distributor 35. Reduced pressure refrigerant from throttling valve 33 is combined with downward-flowing partially-vaporized refrigerant from heat exchange zone 9 and the combined refrigerant is distributed by refrigerant distributor 35. 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 203.

[0047] 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.

[0048] Feed transfer line 223 optionally may be connected via line 15 to throttling valve 17, 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 211 and 211.

[0049] 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.

[0050] 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 16, and one or more tube sheets at the lower end of tube circuit 41 may be connected to refrigerant transfer line 225. In like manner, one or more tube sheets at the upper end of tube circuit 21 may be connected to feed product line 23, and one or more tube sheets at the upper 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 9. Liquefied product in line 23 may be reduced in pressure across throttling valve 24 to yield a final liquid product which is sent to storage and flash gas which may be used as fuel. If the liquid is at a sufficiently low temperature in line 23, it will remain as liquid after pressure reduction downstream of valve 24.

[0051] Downward-flowing refrigerant which reaches the bottom end of the coil wound tubing bundle in heat exchange zone 203 may be redistributed evenly over the top of the coil wound tubing bundle in heat exchanger zone 201 by redistributor 229 to ensure efficient heat transfer from tube circuits 205, 207, and 209 to the vaporizing refrigerant on the shell side. Redistributor 229 may utilize any type of cocurrent two-phase distributor known in the art. One type of redistributor which may be used in this service, for example, comprises a fan-shaped, enclosed, perforated plate which distributes the vapor and liquid refrigerant phases evenly over the top of the coil wound tubing bundle in heat exchanger zone 201. Redistributor 229 is shown schematically and may include means for phase separation and distribution of separate vapor and liquid refrigerant streams to heat exchange zone 201.

[0052] The coil wound tubing bundle which is made up of tube circuits 205, 207, and 209 in heat exchange zone 201 may be 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.

[0053] The coil wound tubing bundle which is made up of tube circuits 211, 213, and 215 in heat exchange zone 203 also may be 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 fabrication parameters in each of these coil wound tubing bundles may be selected to optimize the heat transfer process in each of heat transfer zones 201 and 203. Some of the parameters may be essentially the same in the two coil wound tubing bundles, while the others may be different. For example, the tube outer diameter, tube pitch, and tube winding angle may be the same in both coil wound tubing bundles, while the mandrel outer diameter, spacer thickness, bundle outer diameter, and bundle length may be different in each of the two coil wound tubing bundles. The proper selection of these parameters in the two coil wound tubing bundles will allow improved overall heat exchanger performance. For example, when the invention is applied to the main heat exchanger in the production of LNG, a higher production rate may be realized for a given overall main heat exchanger size. Alternatively, for a given production rate, a smaller main heat exchanger may be used.

[0054] As discussed above, 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. Heat transfer coefficient correlations which utilize the liquid fraction as an important design parameter can be individually tailored to a selected range of liquid fraction encountered in each of the bundles in heat transfer zones 201 and 203.

[0055] 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 used 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.

[0056] 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

[0057] 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 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 -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.

[0058] The precooled high pressure feed is introduced via line 309 into expander turbine 311 where it is reduced in pressure to 725 psia at -88°F, while producing mechanical energy. The expanded feed containing vapor and liquid in line 313 is introduced into the top of the scrub column 315. Fractionation column 315 operates at approximately 725 psia to separate a methane-rich fraction and a heavier hydrocarbon fraction from the feed gas. The heavier hydrocarbons are removed from the bottom of column 315 via line 317 and a portion of the stream is recycled through reboiling heat exchanger 319 in order to provide reboil vapor for the column. The remainder of the bottom stream in line 317 is removed as natural gas liquid (NGL) product stream 321 with a composition (in vol%) of 34.7% ethane, 17.8% propane, 13.5% butane, 4% isobutane, and residual amounts of methane, pentane, isopentane and heptane.

[0059] A methane-rich gas stream is withdrawn via line 323 as an overhead from fractionation column 315 at a temperature of -87°F and is compressed in compressor 325 which is driven by expander 311. The methane-rich gas is discharged from compressor 325 in line 327 at 1037 psia and a temperature of -47°F.

[0060] The methane-rich gas in line 327 is introduced into main heat exchanger 329 where it is cooled, liquefied, and subcooled to yield a LNG product as described below. Main heat exchanger 329 is similar to main heat exchanger 1 of Fig. 2 earlier described. The methane-rich feed stream is cooled initially in tube circuit 331, which forms a coil wound tubing bundle together with tube circuits 333 and 335 located in heat exchange zone 337. Refrigeration is provided by vaporizing multicomponent hydrocarbon refrigerant on the shell side of the exchanger as described later. Cooled methane-rich feed flows from tube circuit 331 via feed transfer line 339, which optionally may be extended through the wall of heat exchanger vessel 367 to an external check valve (not shown) and then back through the wall of heat exchanger vessel 367 to connect with the lower end of tube circuit 341.

[0061] The cooled methane-rich feed stream is further cooled and liquefied in tube circuit 341, which forms a coil wound tubing bundle together with tube circuits 343 and 345 located in heat exchange zone 347. Refrigeration is provided by vaporizing multicomponent hydrocarbon refrigerant on the shell side of the exchanger as described below. Cooled methane-rich feed flows from tube circuit 341 via feed transfer line 349 as high pressure liquid. The cooled stream is reduced in pressure to approximately 300 psia across throttling valve 351.

[0062] The cooled liquid methane-rich feed stream is further cooled in tube circuit 357, which forms together with tube circuit 359 a coil wound tubing bundle located in heat exchange zone 361. Refrigeration is provided by vaporizing multicomponent hydrocarbon refrigerant on the shell side of the exchanger as described below. Cooled methane-rich liquid product flows from tube circuit 359 via product transfer line 363 at approximately -250°F. and 270 psia. The liquid is reduced to near atmospheric pressure across throttling valve 365 and the small volume of vapor formed by this pressure reduction step is separated (not shown) from the final LNG product and used as plant fuel gas. The LNG product is pumped to storage (not shown) for eventual export.

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.

[0063] 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.

[0064] The combined makeup refrigerant and recycle refrigerant in line 373 at 40 psia and -40°F is compressed in compressor 375 and cooled by cooling water in heat exchanger 377. The refrigerant is further compressed in com-

pressor 379 and cooled by cooling water in heat exchanger 381 to yield a compressed refrigerant stream in line 383 at 638 psia and 54°F. This compressed, warm, multiple component refrigerant is cooled 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 620 psia and a temperature of -30°F.

[0065] 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 -200°F and 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.

[0066] 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 -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 redistributor 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.

[0067] 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 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.

[0068] 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.

[0069] 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.

[0070] 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

[0071] 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 1

Physical Design Parameters of Coil Wound Bundle for Example 2 (Heat Exchange Zone 5, Fig. 1)	
Bundle outer diameter, ft.	15
Bundle length, ft.	65
Tube length, ft	870
Tube outer diameter, in.	0.75
Mandrel outer diameter, in.	65
Spacer thickness, in.	0.23
Surface area, sq. ft.	314,000
Number of feed tubes	870
Number of vapor refrigerant tubes	350
Number of liquid refrigerant tubes	630
Total number of tubes	1,840

EXAMPLE 3

[0072] 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 2

Physical Design Parameters of Coil Wound Bundles for Example 3 (Heat Exchange Zones 201 and 203, Fig. 2)		
	Zone 201 (Warm bundle)	Zone 203 (Middle bundle)
Bundle outer diameter, ft.	14	11
Bundle length, ft.	49	12
Tube length, ft.	570	200
Tube outer diameter, in.	0.75	0.75
Mandrel outer diameter, in.	60	50
Spacer thickness, in.	0.25	0.16
Surface area, sq. ft.	224,000	38,000
Number of feed tubes	950	350
Number of vapor refrigerant tubes	390	126
Number of liquid refrigerant tubes	660	490
Total number of tubes	2,000	970

[0073] 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.

Table 3

Comparison of Bundle Parameters for Examples 2 and 3		
Parameter	Example 2 (Single bundle)	Example 3 (Split bundle)
Maximum bundle outer diameter, ft	15	14

Table 3 (continued)

Comparison of Bundle Parameters for Examples 2 and 3		
Parameter	Example 2 (Single bundle)	Example 3 (Split bundle)
Total bundle length, ft	65	61
Total bundle surface area, sq ft	314,000	262,000
Total number of tubes	1,840	2,970
Total tube length, ft	870	770

[0074] 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

[0075] 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 4

Comparisons for Example 4			
	Process using main exchanger of Fig. 2	Case A	Case B
Parameter	Process using main exchanger of Fig. 1		
LNG Production rate	100	100	102
Total exchanger surface area	100	80	100

[0076] 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.

[0077] 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.

[0078] 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.

Claims

1. A coil wound tubing assembly for use in a coil wound heat exchanger, which tubing assembly comprises a first coil wound tubing bundle and a second 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, **characterized in that** 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, tube length, tube pitch, and tube winding angle.
2. The coil wound tubing assembly of Claim 1 wherein 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.
3. The coil wound tubing assembly of Claim 1 wherein the first and second coil wound tubing bundles are vertically oriented and the second coil wound tubing bundle is located above the first coil wound tubing bundle.
4. The coil wound tubing assembly of Claim 3 wherein the first and second coil wound tubing bundles are coaxial.
5. A coil wound heat exchanger system which comprises
 - (a) a vertical cylindrical heat exchanger vessel comprising a first section having a first diameter;
 - (b) a first coil wound tubing bundle disposed axially in the first section of the heat exchanger vessel; and
 - (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,**characterized in that** 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.
6. The coil wound heat exchanger system of Claim 5 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; 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.

7. The coil wound heat exchanger system of Claim 6 which further comprises 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.

8. The coil wound heat exchanger system of Claim 7 which further comprises 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.

9. The coil wound heat exchanger system of Claim 8 which further comprises 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.

10. The coil wound heat exchanger system of Claim 9 which further comprises 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.

11. The coil wound heat exchanger system of Claim 10 which further comprises 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.

12. The coil wound heat exchanger system of Claim 11 which further comprises 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.

13. The coil wound heat exchanger system of Claim 8 which further comprises a refrigerant distributor disposed above the second coil wound tubing bundle.

14. The coil wound heat exchanger system of Claim 13 which further comprises means for placing the third group of tube outlets in the second coil wound tubing bundle in fluid flow communication with the refrigerant distributor above the second wound coil tubing bundle.

15. The coil wound heat exchanger system of Claim 14 which further comprises

(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.

- 16. The coil wound heat exchanger system of Claim 15 which further comprises 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.
- 17. The coil wound heat exchanger system of Claim 16 which further comprises 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.
- 18. The coil wound heat exchanger system of Claim 17 which further comprises 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.
- 19. The coil wound heat exchanger system of Claim 18 which further comprises a refrigerant distributor disposed above the third coil wound tubing bundle.
- 20. The coil wound heat exchanger system of Claim 19 which further comprises 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.
- 21. The coil wound heat exchanger system of Claim 20 which further comprises piping means for withdrawing refrigerant vapor from the vertical heat exchanger vessel at a location below the first coil wound tubing bundle.
- 22. The coil wound heat exchanger system of Claim 21 which further comprises a refrigerant redistributor disposed below the second coil wound tubing bundle and above the first coil wound tubing bundle.
- 23. A process for gas liquefaction which comprises

- (a) introducing a feed gas into a first group of coil wound tubes in a first coil wound tubing bundle and cooling the feed gas by indirect heat exchange with a refrigerant to yield a cooled feed stream; and
- (b) introducing the cooled feed stream into a first group of coil wound tubes in a second coil wound tubing bundle and further cooling the cooled feed stream by indirect heat exchange with a refrigerant to yield a further cooled and partially liquefied feed stream;

characterized in that 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, tube length, tube pitch, and tube winding angle.

- 24. The process of Claim 23 which further comprises

(c) introducing the further cooled and partially liquefied feed stream into a first group of coil wound tubes in a third coil wound tubing bundle and further cooling the cooled feed stream by indirect heat exchange with a refrigerant to yield a liquefied product.

5 **25.** The process of Claim 24 wherein the first, second, and third coil wound tubing bundles are vertically oriented, the second coil wound tubing bundle is located above the first coil wound tubing bundle, and the third coil wound tubing bundle is located above the second coil wound tubing bundle.

10 **26.** The process of Claim 25 wherein the first, second, and third coil wound tubing bundles are disposed coaxially in a vertical cylindrical heat exchanger vessel having a first section with a first diameter and a second section with a second diameter, wherein the first and second wound coil tubing bundles are disposed in the first section and the third wound coil tubing bundle is disposed in the second section, and 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, tube length, tube pitch, tube winding angle, and bundle diameter.

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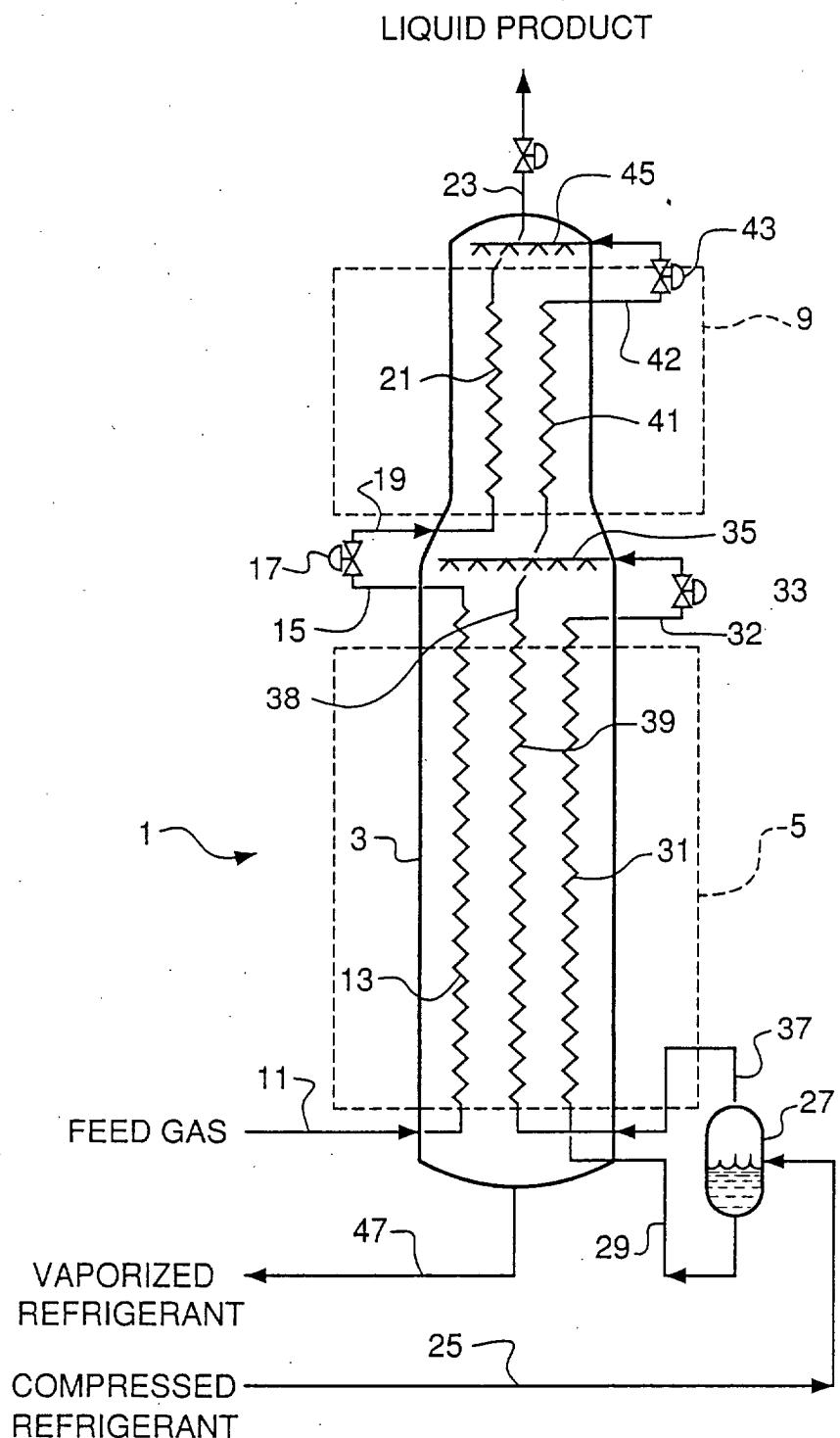


FIG. 1 PRIOR ART

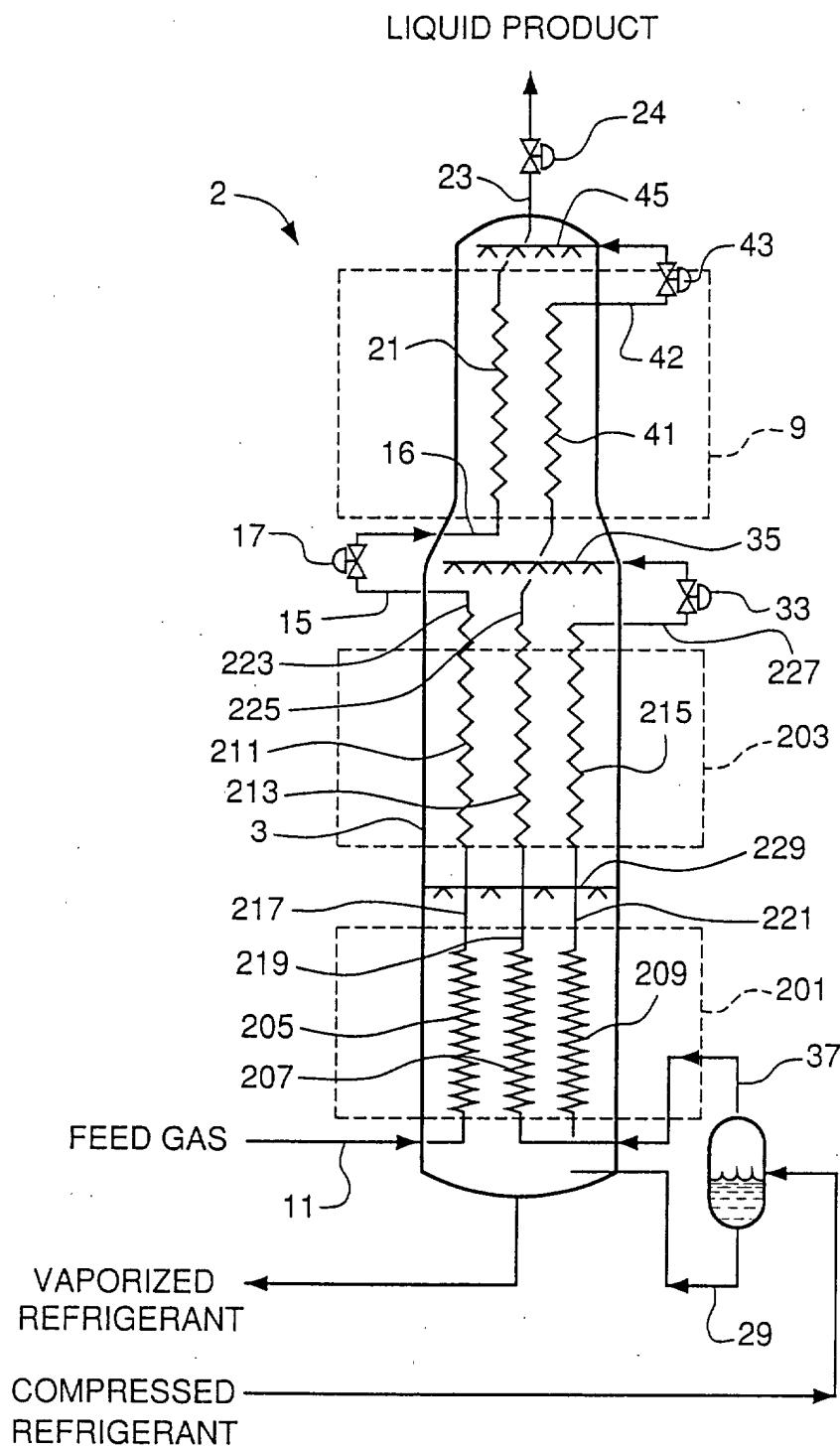
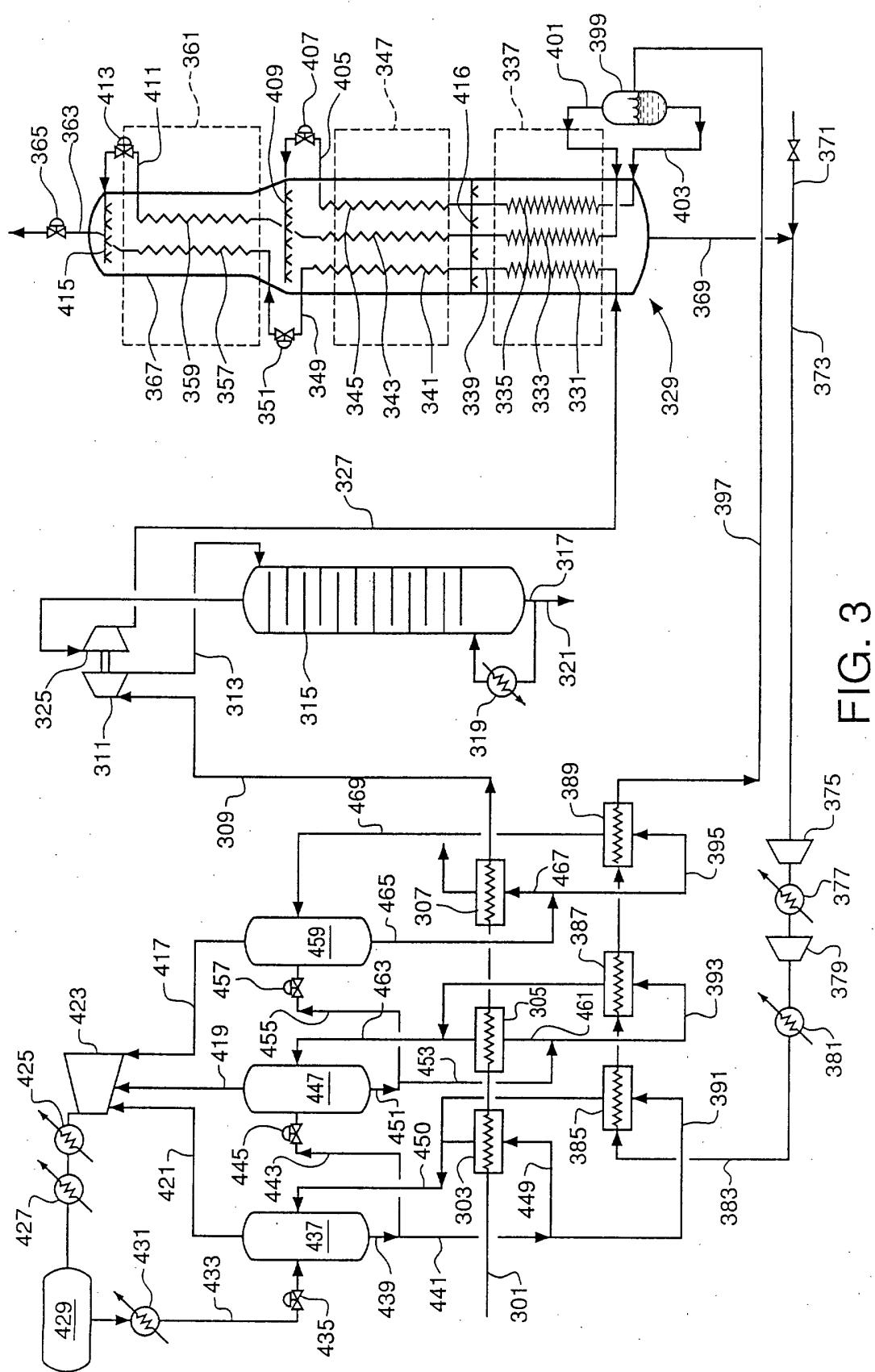


FIG. 2





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number

EP 02 01 1583

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X	GB 1 578 505 A (GULDAGER CONSULT) 5 November 1980 (1980-11-05) * page 2, line 15 - line 43 *	1-5	F28D7/02 F25J3/02
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