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(54) **Coil wound heat exchanger and method of cooling a process stream**

(57) A coil wound heat exchanger has a shell enclosing a shell space. A tubing assembly is configured inside the shell space, and a refrigerant distributor is arranged inside the shell space gravitationally above the tubing assembly, for allowing a downward stream of liquid refrigerant inside the shell space. A liquid drain line is connected to the shell at a gravitational low level, for draining non-evaporated liquid refrigerant from the shell space. A vapour chamber is arranged inside the shell space, with a vapour chamber inlet. A vapour discharge line is in fluid communication with the shell space of the coil wound heat exchanger for discharging evaporated refrigerant from the shell space. The vapour discharge line and the vapour chamber inlet are separated from each other by gas/liquid separator internals. The gas/liquid separator internals prevent any liquid constituents from entering the vapour discharge line from the shell space.

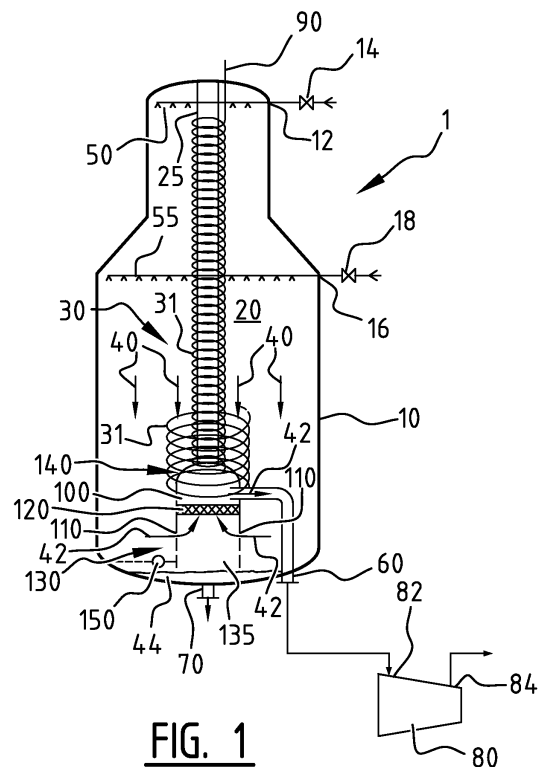


FIG. 1

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Description

[0001] In a first aspect, the present invention relates to a coil wound heat exchanger. In a further aspect, the present invention relates to a method of cooling a process stream in such a coil wound heat exchanger.

[0002] Coil wound heat exchangers, also known as coiled tubing heat exchangers, spiral wound heat exchangers or spool wound heat exchangers, are used in gas process industries for heating or cooling fluid streams at high heat transfer rates. This requires large heat transfer areas. This type of heat exchangers is particularly useful for cooling and condensing high pressure gas streams. In the production of liquefied natural gas (LNG), for example, large surface areas are beneficial for the high transfer rate of heat from the pressurized process stream to the refrigerant, during indirect heat exchanging.

[0003] Suitable coil wound heat exchangers are commercially available from a variety of vendors, including Air Products and Chemicals Inc (APCI), Pennsylvania (USA), and Linde AG (head quartered in Germany).

[0004] EP 1 367 350 A1 discloses examples of coil wound heat exchangers and a use of such coil wound heat exchangers in a gas liquefaction process. Each example comprises a pressure vessel, a coil wound tubing bundle, and a distributor disposed above the coil wound tubing bundle. A liquid mixed refrigerant stream streams into a heat exchange zone in the pressure vessel via the distributor. The refrigerant flows downward over the outer side, or shell side, of the coil wound bundle. Refrigeration typically is provided by vaporizing of the mixed refrigerant on the outer or shell side of the tubes. The refrigerant is typically totally vaporized upon reaching the bottom of the heat exchanger pressure vessel, and withdrawn from the heat exchanger as vapour via a vapour discharge line. This vapour is re-compressed in a refrigerant compression system. The liquefied process stream is discharged from the tubing bundle.

[0005] A problem associated with the arrangement of EP 1 367 350 A1 is that there is a risk of liquid constituents to reach the refrigerant compression system, for instance when the refrigerant has not totally vaporized when reaching the bottom of the heat exchanger pressure vessel. Entrained liquids in the vapour discharge line may cause severe damage to the compressor.

[0006] Process plant designers often include an MR suction drum (sometimes referred to as MR knock-out drum) in the vapour discharge line, such as shown in e.g. US Pat. 4,545,795 and US pre-grant publication 2010/326133, to protect the refrigerant compression system from entrained liquids. However, such MR suction drum incurs additional foot print of the plant, and a need for additional pressure-tight connectors, valves and piping.

[0007] In accordance with the first aspect of the present invention, there is provided a coil wound heat exchanger, comprising

- a shell with an elongate shape which during operation is vertically directed, said shell enclosing a shell space;
- a tubing assembly configured inside the shell space, said tubing assembly comprising a tube bundle for conveying a process stream through the shell in indirect heat exchange contact with a refrigerant available in the shell space;
- a refrigerant distributor arranged inside the shell space gravitationally above the tubing assembly;
- a vapour discharge line for discharging evaporated refrigerant from the shell space;
- a liquid drain line fluidly connected to the shell at a gravitational low level for draining non-evaporated liquid refrigerant from the shell space;
- a vapour chamber arranged inside the shell space, provided with a vapour chamber inlet, wherein the vapour discharge line is in fluid communication with the shell space via the vapour chamber and the vapour chamber inlet, wherein the vapour discharge line and the vapour chamber inlet are separated from each other by gas/liquid separator internals to avoid liquid constituents to flow from the shell space into the vapour discharge line.

[0008] In accordance with a second aspect of the invention, there is provided a method of cooling a process stream in a coil wound heat exchanger as described herein, method of cooling a process stream in a coil wound heat exchanger, comprising:

- conveying a process stream through a tube bundle, which tube bundle is comprised in a tubing assembly that is configured inside a shell space, a shell space which is enclosed by a shell of a coil wound heat exchanger, said shell having an elongate which during operation is vertically directed;
- feeding a refrigerant in a liquid phase, through a refrigerant distributor arranged inside the shell space gravitationally above the tubing assembly, into the shell space in physical contact with the tube bundle;
- allowing the liquid phase of the refrigerant to run down an exterior surface of the tube bundle;
- allowing indirectly exchange of heat wherein heat from the process stream is extracted by the refrigerant whereby the liquid phase is caused to evaporate into vapour;
- collecting any non-evaporated liquid refrigerant in a gravitational low level in the shell space, in contact with a liquid drain line fluidly connected to the shell;
- discharging the vapour comprising evaporated refrigerant from the shell space through a vapour discharge line, wherein passing the vapour successively through a vapour chamber inlet, through gas/liquid separator internals into a vapour chamber, all configured inside the shell space whereby removing liquid constituents from the vapour, and from the vapour chamber into the vapour discharge line.

[0009] The invention will be further illustrated hereinafter by way of example only, and with reference to the nonlimiting drawing in which;

[0010] Fig. 1 shows a schematic inside view of a coil wound heat exchanger according to an embodiment of the invention;

[0011] Fig. 2 shows a schematic inside view of a coil wound heat exchanger according to another embodiment of the invention;

[0012] Fig. 3 shows a schematic process flow diagram illustrating an assembly for and a method of cooling a process stream.

[0013] For the purpose of this description, a single reference number will be assigned to a line as well as a stream carried in that line. Same reference numbers refer to similar components. The person skilled in the art will readily understand that, while the invention is illustrated making reference to one or more a specific combinations of features and measures, many of those features and measures are functionally independent from other features and measures such that they can be equally or similarly applied independently in other embodiments or combinations.

[0014] Described herein is a special adaptation of a coil wound heat exchanger. The coil wound heat exchanger has a shell, surrounding a shell space. A vapour discharge line is provided in fluid connection with the shell space for discharging evaporated refrigerant from the shell space. An external compressor can be connected to the vapour discharge line, for recompression of the evaporated refrigerant.

[0015] It is presently proposed to bring components of and/or functionality of a mixed refrigerant (MR) suction drum inside the shell space of the coil wound heat exchanger. More specifically, gas/liquid separator internals are configured inside the shell space of the coil wound heat exchanger, to prevent entrained liquids from entering a vapour discharge line. Furthermore, a liquid drain line may be connected to the shell at a gravitational low level, for draining non-evaporated liquid refrigerant from the shell space. Furthermore, a vapour chamber is arranged inside the shell space. The vapour chamber is provided with a vapour chamber inlet, and the vapour discharge line is in fluid communication with the shell space of the coil wound heat exchanger via the vapour chamber. The vapour discharge line and the vapour chamber inlet are separated from each other by the gas/liquid separator internals.

[0016] Liquid constituents that may be present in the shell space of the heat exchanger are prevented by the gas/liquid separator internals from entering the vapour discharge line. With these provisions, the coil wound heat exchanger can be used without the need for an external MR suction drum, or at least with a much smaller sized drum, as the expected liquid load in the discharged vapour refrigerant is lower than without these provisions.

[0017] Suitably, the gas/liquid separator internals comprise a mist extractor. Preferably, the mist extractor is an

impingement-type mist extractor, which is found to be more suitable for integration into the shell space of the coil wound heat exchanger than centrifugal mist-extraction devices. Regardless of the type, the mist extractor is functional to avoid liquid droplets entrained in the vapour refrigerant. Suitable examples of impingement-type mist extractors comprise: a mist mat, a wire mesh demister, a vane pack demister.

[0018] Preferably, the vapour chamber inlet is located gravitationally below the tubing assembly, and higher than said gravitational low level. This way the vaporized refrigerant does not have to undergo counter flow in order to reach the vapour chamber inlet, while at the same time liquid consisting of non-evaporated liquid refrigerant can be accumulated in the shell space 20 gravitationally lower than the vapour chamber inlet.

[0019] A high level liquid protection sensor is preferably arranged inside the shell space, at a level gravitationally lower than the gas/liquid separator internals. Here-with a warning signal can be produced, in an event of a liquid level exceeding a predetermined high liquid level. This allows for taking preventive action when the level of liquids that have accumulated in the shell space becomes so high that it jeopardizes further dry operation of the compressor.

[0020] Preventive action can take a variety of forms. For instance, upon producing of said warning signal, a drain flow rate of non-evaporated liquid refrigerant from the gravitational low level of the shell space into the liquid drain line could be increased. If this does not help to sufficiently lower the level of accumulated liquid, the flow rate of refrigerant into the shell space could be decreased. The ultimate action could be to cause the compressor to trip.

[0021] The coil wound heat exchanger may form part of an assembly for cooling a process stream. The assembly comprises a compressor arranged external to the shell of the coil wound heat exchanger. The vapour discharge line is in direct fluid communication with the compressor via a compressor stream intake opening of the compressor, without passing through any suction drum located external to the shell. The compressor stream discharge opening is in fluid connection with the refrigerant distributor via a refrigerant inlet opening in the shell, whereby bypassing the vapour chamber. The process stream is conveyed through the tube bundle, in indirect heat exchange contact with the refrigerant that is available in the shell space.

[0022] The process stream may comprise, or consist of, natural gas.

[0023] Figure 1 shows in a very schematic way an inside view of coil wound heat exchanger 1 according to an embodiment of the invention. It has a shell 10 with an elongate shape. Apart from instrumentation connections and flange connections and the like, the shape has a generally circular cylindrical contour. The diameter can vary as a function of the height along the shell 10. During operation the shell 10 is vertically directed. The shell gen-

erally encloses a shell space 20, that can be pressurized above atmospheric pressure. With the shell 10 being vertically directed in its operational orientation, the shell space 20 generally has a bottom side and a top side, the top side being gravitationally above the bottom side.

[0024] A tubing assembly 30 is configured inside the shell space 20. The tubing assembly 30 comprises one or more tube bundles, amongst which at least a process tube bundle 31 for conveying a process stream through the shell 10 in indirect heat exchange contact with a refrigerant 40 that is available in the shell space 20. The process tube bundle 31 extends from a warm end of the coil wound heat exchanger 1 to a cold end of the coil wound heat exchanger 1. The cold end is gravitationally higher than the warm end. The cold end is generally at the top side of the shell space 20 and the warm end at the bottom side of the shell space 20.

[0025] As in any coil wound heat exchanger, one or more tube bundles can be installed in one shell 10. Each tube bundle is constructed of a plurality of tubes, typically a large number of long tubes. Appropriate headers and piping (not shown) are configured for introducing one or more streams to be cooled, amongst which the process stream, into the tubes, and for withdrawing cooled liquefied streams from the tubes. The process tube bundle 31, optionally together with any other tube bundle in the shell space 20, is helically wound with a plurality of windings about an axial, vertically extending, central core. These windings circumvent the vertically extending core in the shell space 20, and leave a vertically extending annular space between the plurality of windings and the shell 10. Numerous tube layers may be thus formed in a radial (horizontal) direction. Each layer may be separated from adjacent layers by axial spacers or spacer wires. The vertically extending core may consist of void space and/or contain structural support elements such as a mandrel 25.

[0026] The mandrel 25 may suitably be provided in the vertically extending core. The mandrel may mechanically support the entire tubing assembly 30, whereby the process tube bundle may be suspended from the mandrel 25. The mandrel may be formed of a hollow support pipe, welded to or otherwise supported in, the shell 10.

[0027] A refrigerant distributor 50 is also arranged inside the shell space 20. The refrigerant distributor is configured at the cold end, gravitationally above the tubing assembly 30.

[0028] One or more auxiliary refrigerant distributors 55 may optionally be arranged inside the shell space 20 in addition to the refrigerant distributor 50. The auxiliary refrigerant distributors 55 are not required to be configured at the cold end gravitationally above the entire tubing assembly 30: they can be configured at one or more mid-points, gravitationally above one or more lower segments of the tubing assembly 30 but below one or more upper segments of the tubing assembly 30.

[0029] Typically, a coil wound heat exchanger designed for the purpose of liquefying and sub-cooling a

process stream consisting of a methane-rich stream, such as a natural gas stream, comprises at least three tube bundles, each for conveying a separate stream in indirect heat exchange relationship with the refrigerant 40 available in the shell space 20 through the shell 10: one tube bundle, the process tube bundle 31, is for the process stream. One is for a heavy refrigerant fraction, and one for a light refrigerant fraction. This is further explained in EP 1 367 350 A1, which is incorporated herein by reference for this purpose. Further details will also be discussed herein with reference to Figure 3.

[0030] A vapour discharge line 60 is in fluid communication with the shell space 20 for discharging evaporated refrigerant from the shell space 20. The vapour discharge line 60 is typically in fluid communication with, and discharges into, a compressor 80 via a compressor stream intake opening 82. The compressor 80 is suitably configured external to the shell 10. Furthermore, a liquid drain line 70 is fluidly connected to the shell 10, at a gravitational low level, for draining non-evaporated liquid refrigerant from the shell space 20. The gravitational low level may be at the warm end of the coil wound heat exchanger 1.

[0031] A vapour chamber 100 is arranged inside the shell space 20. The vapour chamber 100 is provided with a vapour chamber inlet 110, which is preferably located gravitationally below the tubing assembly 30. The vapour chamber inlet 110 may suitably have a vertically aligned slot shape. The vapour chamber inlet 110 may comprise of a plurality of openings distributed over an area.

[0032] The vapour discharge line 60 is also connected to the vapour chamber 100. The vapour discharge line 60 and the vapour chamber inlet 110 are separated from each other by gas/liquid separator internals 120. The vapour discharge line 60 is in fluid communication with the shell space 20 via the vapour chamber 100 and the vapour chamber inlet 110. During operation, vaporous refrigerant 42 can pass from the shell space 20 through the vapour inlet 110 and the gas/liquid separator internals 120 into the vapour chamber 100 and from there be discharged from the coil wound heat exchanger 1 through the vapour discharge line 60. Any liquid constituents, such as small droplets and/or mist, are impeded from flowing from the shell space 20 into the vapour discharge line 60 as a result of the gas/liquid separator internals 120.

[0033] The compressor 80 further comprises a compressor stream discharge opening 84, which is in fluid connection with the refrigerant distributor 50 via a refrigerant inlet opening 12 in the shell 10. The liquid distributor 50 can be reached without passing through the vapour chamber 100. Typically, a pressure reduction device 14 is provided between the compressor stream discharge opening 84 and the refrigerant distributor 50. The compressor stream discharge opening 84 may further be in fluid connecting with one or more of the optional auxiliary refrigerant distributors 55, if provided. In such cases, the shell 10 may comprise an auxiliary refrigerant inlet open-

ing 16, and an auxiliary pressure reduction device 18 may be provided between the compressor stream discharge opening 84 and the auxiliary refrigerant distributor 55. A more detailed embodiment of the compressor configuration will be discussed below with reference to a schematic process flow diagram illustrating an assembly for and a method of cooling a process stream as illustrated in Figure 3.

[0034] Suitably, the gas/liquid separator internals 120 comprise a mist extractor. The mist extractor may be of any suitable type, but it has been found that an impingement-type mist extractor is more suitable for integration into the shell space 20 of the coil wound heat exchanger 1 than known centrifugal mist-extraction devices. Regardless of the type, the mist extractor is functional to stop liquid droplets entrained in the vapour refrigerant, typically those liquid droplets that are smaller than about 150 μm in cross section, from entering into the vapour chamber 100. Liquid droplets of 150-300 μm are typically large enough to settle and form a liquid layer 44 at the bottom of the shell space 20, but to the extent they don't settle by gravity these droplets may also be caught by the mist extractor.

[0035] Suitable examples of impingement-type mist extractors comprise: a mist mat, a wire mesh demister, a vane pack demister. The mist extractor preferably consists of more than 92%, preferably more than 95%, of void space, whereby liquid particles are primarily collected by impingement, whereby the vapour flowing through the mist extractor is forced to change direction a number of times. Herewith, a relatively low pressure drop over the gas/liquid separator internals 120 is established.

[0036] In one contemplated example, a wire mesh is proposed having a void volume of between 97 and 98%, a bulk density of about 190 kg/m^3 , a surface area of between 330 and 410 m^2/m^3 , with a wire diameter of 0.28 mm. A pad of this wire mesh may be held in and supported by a support grid. The support grid preferably has at least 90% free area to facilitate effective liquid drainage from the pad. A pad thickness of between 10 and 50 cm may be employed, depending on liquid load and refrigerant flow rate. These numbers and dimensions are an example and variations are contemplated which can be adapted to the governing specifics of an embodiment.

[0037] It may be contemplated to provide a wire mesh and a vane pack in series, whereby the vane pack is installed on the vapour chamber side of the wire mesh. A vane pack can have a higher liquid removal capacity than a wire mesh at liquid removal rates where the wire mesh floods. Under usual operations, the wire mesh will be virtually fully effective at removing a sufficient amount of the liquids from the refrigerant stream. In a rare case wherein the wire mesh floods, the wire mesh in flooded mode acts as a coalescer for the vane pack whereby improving the efficiency of the vane pack in removing liquids. At lower rates the wire mesh becomes the primary mist eliminator device. This configuration has a higher operational range (turndown) than a configuration based

on a single type of mist extractor.

[0038] Considering in more detail, the vapour chamber 100 and the gas/liquid separator internals 120 are located inside a shielded area within the shell space 20. The shielded area is shielded by at least a wall section 130 and a fluid cap 140 provided at an upper end of the wall section 130. The wall section 130 and the fluid cap 140 together may form a bell-shaped shield. The fluid cap 140 may have a dome shape, for instance spherical in which case in vertical cross section it has a contour of a circle segment, or elliptical. However, as the vapour chamber 100 is fully embedded in the shell space 20, it does not have to be a pressure vessel. Hence, the fluid cap 140 could be flat, having a contour of a straight line piece when seen in the vertical cross section.

[0039] The wall section 130 and the fluid cap 140 prevent refrigerant 40 from entering into the vapour chamber 100 via any other path than through the gas/liquid separator internals 120. The wall section 130 suitably has an open end 135 facing downward, through which the shielded area is in open fluid communication with the shell space. This open end 135 functions to exempt liquid from being contained within the shielded area. Instead, the liquid can spread over the entire surface area available in the bottom part of the shell space 20, so that the liquid level builds up less fast than would be the case in an external suction drum. This makes it possible to achieve a similar gas/liquid separation efficiency as in an external suction drum, while needing a smaller shielded area volume than external suction drum volume. The vapour chamber inlet 110 is preferably provided in the wall section 130 above the open end 135, to assure vapour can continue to flow from the shell space 20 through the gas/liquid separator internals 120 into the vapour chamber 100 even if the liquid level accumulated inside the shell space 20 is so high that the open end 135 is submerged in the liquid layer 44.

[0040] Moreover, a high level liquid protection sensor 150 may suitably be arranged inside the shell space 20, at a level gravitationally lower than the gas/liquid separator internals 120. Preferably high level liquid protection sensor 150 is arranged at a level gravitationally lower than the vapour chamber inlet 110. The high level liquid protection sensor 150 is configured to produce a warning signal in an event of the liquid level of the liquid layer 44 exceeds the predetermined high liquid level.

[0041] In a group of embodiments, to which Figure 1 also belongs, an upper part of the wall section 130, together with the fluid cap 140, projects upward into the vertically extending core. The vapour chamber 100, the fluid cap 140 and the gas/liquid separation internals 120 may for instance be integrally provided inside the mandrel 25. Specifically, the mandrel 25 may be vertically supported on the fluid cap 140. If the mandrel 25 does not have enough space on its inside to house the gas/liquid separator internals, the in cross sectional diameter of the mandrel 25 may be configured with an increasing profile when comparing cross sections at decreasing

heights along the mandrel 24. An example is shown in Figure 1.

[0042] Alternatively, and this is schematically illustrated in Figure 2, the vapour chamber 100 may be constructed ex-centrally. In such a case, the mandrel 25 may be constructed separately from the vapour chamber 100 of the present invention. Possibly the vapour chamber 100 may be accommodated in the form of an annular space either fully or at least partially extending along the entire inner circumference of the shell 10. At least an upper part of the wall section 130, together with the fluid cap 140, may project upward into the vertically extending annular space left between the plurality of windings and the shell 10. Nonetheless, the vapour chamber inlet 110 is preferably located gravitationally below the tubing assembly 30. In other aspects, the group of alternative embodiments of which Figure 2 is an example, the coil wound heat exchanger resembles the example as shown in Figure 1 both in terms of structure and operation in use, and reference is made to the description of Figure 1 for further details.

[0043] Regardless of the precise construction of the coil wound heat exchanger 1, in operation it can be used for cooling a process stream in the coil wound heat exchanger 1. The process stream is conveyed through the process tube bundle 31. The process stream flows in an upward direction, from the warm end to the cold end of the coil wound heat exchanger 1. As the process stream flows through the coil wound heat exchanger 1 it is cooled by transferring heat to a refrigerant 40 by indirect heat exchanging. It may be cooled sufficiently to produce a liquefied and subcooled process stream.

[0044] The refrigerant 40 is fed into the shell space 20 through the refrigerant distributor 50. The refrigerant 40 comprises a liquid phase as it passes through the distributor 50. The liquid phase of the refrigerant is allowed to run down along an exterior surface of the process tube bundle 31. To this end, the refrigerant 40 is brought in physical contact with the process tube bundle 31. Typically, the liquid trickles down, in other words it flows in a generally downward direction, under the influence of gravity. Heat from the process stream is extracted by the refrigerant 40 as a result of indirect heat exchange taking place, whereby the liquid phase of the refrigerant is caused to evaporate into vapour phase. Thus, as the refrigerant 40 trickles down, it continuously evaporates leaving less and less liquid phase on the process tube bundle 31.

[0045] In normal operation all the liquid is vaporized and only super-heated vapour is discharged from the shell space 20 via the vapour discharge line 60. Nonetheless, any non-evaporated liquid refrigerant is collected in a gravitational low level in the shell space 20. The collected liquid is in contact with the liquid drain line 70.

[0046] Regardless of the presence of any such liquid refrigerant below the process tube bundle 31, the vapour comprising the evaporated refrigerant is discharged from the shell space 30 through the vapour discharge line 60.

To this end, the vapour passes successively through the vapour chamber inlet 110, through the gas/liquid separator internals 120 and subsequently into the vapour chamber 100. From the vapour chamber 100 the vapour passes into the vapour discharge line 60. Preferably, the vapour passes into the vapour discharge line 60 exclusively from the vapour chamber 100.

[0047] As all of the vapour being discharged from the coil wound heat exchanger 1 through the vapour discharge line 60 has been demisted by passing the gas/liquid separator internals 120, the discharged vapour can be conveyed directly to the compressor stream intake opening 82 of the compressor 80, without passing through any further suction drum arranged external to the shell 10. The vapour can be compressed in the compressor 80, and the vapour being discharged from the compressor 80 can be condensed, before re-feeding through the refrigerant distributor 50.

[0048] The high level liquid protection sensor 150 is continuously guarded. The high level liquid protection sensor 150 produces a warning signal in an event of a liquid level of liquid refrigerant that has accumulated inside the shell space 20 exceeds the predetermined high liquid level. Corrective action can then be taken to avoid the liquid level to raise even more, thereby possibly submerging and blocking the vapour chamber inlet 110 and/or the gas/liquid separator internals 120. Upon producing of the warning signal, a drain flow rate of non-evaporated liquid refrigerant from the gravitational low level of the shell space 20 into the liquid drain line 70 may be increased. In addition, it can be contemplated to lower the feed rate of the refrigerant 40 into the shell space 20 via the refrigerant distributor 50 and/or any auxiliary refrigerant distributor 55. An extreme measure could include causing the compressor 80 to trip or to cause the compressor 80 to run in full recycle mode.

[0049] The coil wound heat exchanger as described above is particularly suitable for use in processes that produce liquefied natural gas (LNG). Suitable processes for producing liquefied natural gas (LNG) wherein the coil wound heat exchanger can be suitably employed generally make use of a mixed refrigerant for cooling the natural gas. The natural gas is deeply cooled in the coil wound heat exchanger, to reach a temperature of typically below $-135\text{ }^{\circ}\text{C}$, and often below $-145\text{ }^{\circ}\text{C}$. The temperature is selected such as to fully liquefy the process stream with all its constituents. The final liquefied product stream, the LNG, is at a temperature of $-160\text{ }^{\circ}\text{C}$ or below to allow for its storage and transportation at a pressure of between 1 and 2 bara, or even at a pressure of between 1 and 1.2 bara.

[0050] One suitable group of processes include single refrigerant cycle processes, also known as single mixed refrigerant - SMR - processes, such those described in US Patents 3,593,535 (APCI) and 5,832,745 (Shell SMR). Other suitable processes include double refrigerant cycle processes. Examples include the much applied Propane-Mixed-Refrigerant process, often abbreviated

C3MR, such as described in for instance US Patent 4,404,008, or for instance double mixed refrigerant - DMR - processes of which examples are described in US Patent 6,658,891 and in US Pat. 6,370,910 (Shell DMR). Still another suitable group of processes are based on three or more compressor trains for three or more refrigeration cycles. Examples of such three-cycle processes are described in WO 2008/020044; DE3521060A1; and Mark J. Roberts et al "Large capacity single train AP-X(TM) Hybrid LNG Process", Gastech 2002, Doha, Qatar (13-16 October 2002).

[0051] Figure 3 shows a schematic process flow diagram generically illustrating an example embodiment of an assembly for and a method of cooling a process stream.

[0052] The assembly comprises the coil wound heat exchanger 1 in accordance with the present invention. As explained above, the shell 10 of the coil wound exchanger 1 defines the shell space 20. Configured within the shell space 20 are the process tube bundle 31, extending from the warm end of the coil wound heat exchanger 1 to the cold end of the coil wound heat exchanger 1, an HMR tube bundle 32 extending from the warm end to a mid-point, and an LMR tube bundle 33 also extending from the warm end to the cold end.

[0053] During normal operation, a gaseous, methane-rich feed is supplied at elevated pressure through a supply conduit 210 to the process tube bundle 31 of the coil wound heat exchanger 1 at its warm end. The feed, which passes through the process tube bundle 31, is cooled, liquefied and sub-cooled against refrigerant evaporating in the shell space 20. The resulting liquefied stream is removed from the process tube bundle 31 at the cold end of the coil wound heat exchanger 1 through process stream discharge conduit 90. The liquefied process stream is passed to storage (not shown) where it is stored as liquefied at atmospheric pressure.

[0054] Evaporated refrigerant is removed from the shell space 20 of the coil wound heat exchanger 1 at its warm end as vapour through vapour discharge line 60. The refrigerant is a mixed refrigerant, also known as multicomponent refrigerant.

[0055] The evaporated refrigerant is compressed in compressor 80 to get high-pressure refrigerant that is removed through compressor discharge line 85. The compressor 80 is driven by a suitable driver 35, for example a gas turbine (industrial frame or aero-derivative) and/or a steam turbine and/or an electric motor. The pressure of the high-pressure refrigerant is higher than the refrigerant available in the shell space 20.

[0056] The high-pressure refrigerant in compressor discharge line 85 is cooled against the ambient in ambient cooler 185, by indirect heat exchanging the high-pressure refrigerant against an ambient stream such as air or water. The intention is to obtain a partly-condensed refrigerant. If the resulting ambient-cooled high-pressure refrigerant in compressor discharge line 85 is not condensed at all or insufficiently condensed, the resulting

ambient cooled high-pressure refrigerant is subsequently passed through a pre-cooling heat exchanger 190 where it is chilled to a pre-cooling temperature below the temperature of the ambient against which high-pressure refrigerant was cooled in the ambient heat cooler 185. In that case, the partly-condensed refrigerant partly is discharged from the pre-cooling heat exchanger.

[0057] The partly-condensed refrigerant is introduced into a gas/liquid separator 195 through inlet device 196. In the separator vessel 195, the partly-condensed refrigerant is separated into a liquid heavy refrigerant fraction and a gaseous light refrigerant fraction. The liquid heavy refrigerant fraction is removed from the bottom of the separator vessel 195 through conduit 220, and the gaseous light refrigerant fraction is removed through conduit 230.

[0058] Refrigerant can be selectively removed from and/or supplemented to the refrigerant circuit, to adjust the amount of refrigerant and/or the bulk composition of the refrigerant. A portion of the liquid heavy refrigerant fraction may suitably be drained through conduit 222 provided with valve 224. A portion of the gaseous light refrigerant fraction may suitably be vented through conduit 232 provided with valve 234. To adjust the bulk composition of the refrigerant, individual components, such as nitrogen, methane, ethane and propane can be added to the refrigerant in line 60 through one or more optional make-up conduits 66. The make-up conduits 66 through may be provided with suitable valves (not shown) controlling the flow of the components into the vapour discharge line 60. The bulk composition may be adjusted such as to avoid non-evaporated liquid refrigerant to accumulate in the gravitational low level of the shell space 20.

[0059] The remaining gaseous light refrigerant fraction removed through conduit 220 is passed to the LMR tube bundle 33 in the coil wound heat exchanger 1, where it is cooled, liquefied and sub-cooled to get a sub-cooled light refrigerant stream. The sub-cooled light refrigerant stream is removed from the coil wound heat exchanger 1 through conduit 52, and allowed to expand over the pressure reduction device 14. The pressure reduction device 14 may typically be provided in the form of an expansion valve and/or an expansion turbine. At reduced pressure it is introduced through the refrigerant inlet opening 12 and refrigerant distributor 50 into the shell space 20 of the coil wound heat exchanger 1. The light refrigerant stream is allowed to evaporate in the shell space 20 at reduced pressure, in indirect heat exchange with respective fluids in the tube bundles 31, 32, and 33 whereby extracting heat from, and thereby cooling, the respective fluids in the tube bundles 31, 32, and 33.

[0060] The remaining heavy refrigerant fraction is sub-cooled in the HMR tube bundle 32 of the coil wound heat exchanger 1 to get a sub-cooled heavy refrigerant stream. The sub-cooled heavy refrigerant stream is removed from the coil wound exchanger 1 through an auxiliary conduit 56, and allowed to expand over the auxiliary

pressure reduction device 18, typically in the form of an expansion valve and/or an expansion turbine. At reduced pressure it is passed through the auxiliary refrigerant inlet opening 16 and auxiliary distributor 55 into the shell space 20 of the coil wound heat exchanger 1. The heavy refrigerant stream is allowed to evaporate in the shell space 20 at reduced pressure, thereby cooling the respective fluids in the tube bundles 31, 32, and 33.

[0061] Amongst these fluids is the process stream. The process stream is cooled, liquefied and subcooled, and the resulting liquefied stream is removed from the coil wound heat exchanger 1 through the process stream discharge conduit 90. The subcooled stream is optionally passed to a depressurization system 240, order to allow reduction of the pressure so that the resulting final product stream is at a reduced pressure. The reduced pressure is suitably between 1.0 and 2 bar absolute (bara), preferably between 1 and 1.5 bara, more preferably between 1 and 1.2 bara, which is substantially equal to atmospheric pressure. The depressurization system 240 also regulates the total flow rate of the process stream through the coil wound heat exchanger 1. The depressurization system 240 may comprise a turbine expander and/or one or more expansion valves.

[0062] A suitable separation system may optionally be configured to separate volatile components from the product stream. The separation system may be selected depending on specific requirements and conditions such as product specification, feed specification, fuel gas requirements, etc.. The invention is not limited to any particular choice. As an example a simple flash vessel 260 is shown in Fig. 3 in which the liquefied stream together with the volatile components is introduced via inlet device 262 at the reduced pressure. From the top of the flash vessel 260 an off-gas is removed through off-gas discharge conduit 270. The off-gas can be compressed in an end-flash compressor (not shown), for instance to get high-pressure fuel gas. From the bottom of the flash vessel 260 the liquefied product stream is removed through rundown conduit 250, and passed to storage (not shown).

[0063] The flash vessel 260 of Fig. 3 is only a simple example, and depending on specific circumstances and specifications a more complex end flash system may be implemented instead. Examples have been published in US patents: 5,421,165; 5,893,274; 6,014,869; and in patent application publications: US2008/0066492; US2011/0296871; US2012/0167617; WO 2006/120127; WO2009/07436; WO2013/076185; WO2013/087571. These examples are not intended to be a complete list of options.

[0064] In any of the examples, the process stream to be cooled in the coil wound heat exchanger, and ultimately preferably liquefied and sub-cooled, as will be described in embodiments below, may be derived from any suitable methane containing gas stream to be refrigerated and optionally liquefied. An often used example is a natural gas stream, for instance obtained from natural gas or petroleum reservoirs, shale, or coal beds. As an

alternative the process stream may also be obtained from another source, including as an example a synthetic source such as a Fischer-Tropsch process.

[0065] When the process stream is a natural gas stream, it is usually comprised substantially of methane. Such process stream may for at least 50 mol% methane, preferably at least 80 mol%, consist of methane.

[0066] Depending on the source, natural gas may contain varying amounts of hydrocarbons heavier than methane such as in particular ethane, propane and the butanes (together indicated by the abbreviation C2-C4), and possibly lesser amounts of pentanes and aromatic hydrocarbons (C5+ hydrocarbons). The composition varies depending upon the type and location of the gas.

[0067] If the ultimate goal is liquefaction of the process stream, the level C5+ hydrocarbons must preferably be below 0.1 mol.%. If the process stream has a higher content of C5+ hydrocarbons, any excess above 0.1 mol.% can be extracted using scrubbing techniques or (distillative) natural gas liquids extraction techniques.

[0068] The natural gas may also contain non-hydrocarbons such as H₂O, N₂, CO₂, Hg, H₂S and other sulphur compounds, and the like. The natural gas may be submitted to perform pre-treatment steps comprising one or more of reduction and/or removal of undesired components such as CO₂ and H₂S or other steps such as early cooling, pre-pressurizing or the like. As such steps are well known to the person skilled in the art, their mechanisms are not further discussed here.

[0069] The person skilled in the art will understand that the present invention can be applied and/or carried out in many various ways without departing from the scope of the appended claims.

Claims

1. A coil wound heat exchanger, comprising

- a shell with an elongate shape which during operation is vertically directed, said shell enclosing a shell space;
- a tubing assembly configured inside the shell space, said tubing assembly comprising a tube bundle for conveying a process stream through the shell in indirect heat exchange contact with a refrigerant available in the shell space;
- a refrigerant distributor arranged inside the shell space gravitationally above the tubing assembly;
- a vapour discharge line for discharging evaporated refrigerant from the shell space;
- a liquid drain line fluidly connected to the shell at a gravitational low level for draining non-evaporated liquid refrigerant from the shell space;
- a vapour chamber arranged inside the shell space, provided with a vapour chamber inlet, wherein the vapour discharge line is in fluid com-

- munication with the shell space via the vapour chamber and the vapour chamber inlet, wherein the vapour discharge line and the vapour chamber inlet are separated from each other by gas/liquid separator internals to avoid liquid constituents to flow from the shell space into the vapour discharge line.
2. The coil wound heat exchanger of claim 1, wherein a compressor is arranged external to the shell, and wherein the vapour discharge line is in direct fluid communication with the compressor via a compressor stream intake opening without passing through any suction drum, and wherein a compressor stream discharge opening is in fluid connection with the refrigerant distributor via a refrigerant inlet opening in the shell whereby bypassing the vapour chamber.
 3. The coil wound heat exchanger of claim 1 or 2, wherein the vapour chamber inlet is located gravitationally below the tubing assembly and higher than said gravitational low level.
 4. The coil wound heat exchanger of any one of claims 1 to 3, wherein the gas/liquid separator internals comprise a mist extractor.
 5. The coil wound heat exchanger of claim 4, wherein the mist extractor comprises at least one from the group consisting of: a mist mat, a wire mesh demister, a vane pack demister.
 6. The coil wound heat exchanger of any one of the preceding claims, further comprising a high level liquid protection sensor arranged inside the shell space at a level gravitationally lower than the gas/liquid separator internals.
 7. The coil wound heat exchanger of any one of the preceding claims, wherein the vapour chamber and the gas/liquid separator internals are located inside a shielded area that is shielded by at least a wall section and a fluid cap provided at an upper end of the wall section, to prevent refrigerant from entering into the vapour chamber via any other path than through the gas/liquid separator internals.
 8. The coil wound heat exchanger of claim 7, wherein said wall section has an open end facing downward, through which the shielded area is in open fluid communication with the shell space.
 9. The coil wound heat exchanger of claim 8, wherein the vapour chamber inlet is provided in the wall section above the open end.
 10. The coil wound heat exchanger of any one of claims 7 to 9, wherein the tube bundle is helically wound with a plurality of windings, said windings circumventing a vertically extending core in the shell space and leaving a vertically extending annular space between the plurality of windings and the shell, and wherein at least an upper part of the wall section with the fluid cap projects upward into the vertically extending core.
 11. The coil wound heat exchanger of any one of claims 1 to 9, wherein the tube bundle is helically wound with a plurality of windings, said windings circumventing a vertically extending core in the shell space and leaving a vertically extending annular space between the plurality of windings and the shell.
 12. A method of cooling a process stream in a coil wound heat exchanger, comprising:
 - conveying a process stream through a tube bundle, which tube bundle is comprised in a tubing assembly that is configured inside a shell space, a shell space which is enclosed by a shell of a coil wound heat exchanger, said shell having an elongate which during operation is vertically directed;
 - feeding a refrigerant in a liquid phase, through a refrigerant distributor arranged inside the shell space gravitationally above the tubing assembly, into the shell space in physical contact with the tube bundle;
 - allowing the liquid phase of the refrigerant to run down an exterior surface of the tube bundle;
 - allowing indirectly exchange of heat wherein heat from the process stream is extracted by the refrigerant whereby the liquid phase is caused to evaporate into vapour;
 - collecting any non-evaporated liquid refrigerant in a gravitational low level in the shell space, in contact with a liquid drain line fluidly connected to the shell;
 - discharging the vapour comprising evaporated refrigerant from the shell space through a vapour discharge line, wherein passing the vapour successively through a vapour chamber inlet, through gas/liquid separator internals into a vapour chamber, all configured inside the shell space whereby removing liquid constituents from the vapour, and from the vapour chamber into the vapour discharge line.
 13. The method of cooling of claim 12, further comprising directly conveying the vapour in the vapour discharge line to a compressor stream intake opening, without passing through any suction drum, of a compressor which is arranged external to the shell, compressing the vapour in the compressor and condensing the vapour being discharged from the compressor, before re-feeding through the refrigerant distrib-

utor in the form of said refrigerant in said liquid phase.

- 14. The method of cooling of claim 12 or 13, wherein guarding a high level liquid protection sensor arranged inside the shell space at a level gravitationally lower than the gas/liquid separator internals, and producing a warning signal in an event of a liquid level exceeding a predetermined high liquid level.

- 15. The method of cooling of claim 14, further comprising, upon producing of said warning signal, increasing a drain flow rate of non-evaporated liquid refrigerant from the gravitational low level of the shell space into the liquid drain line.

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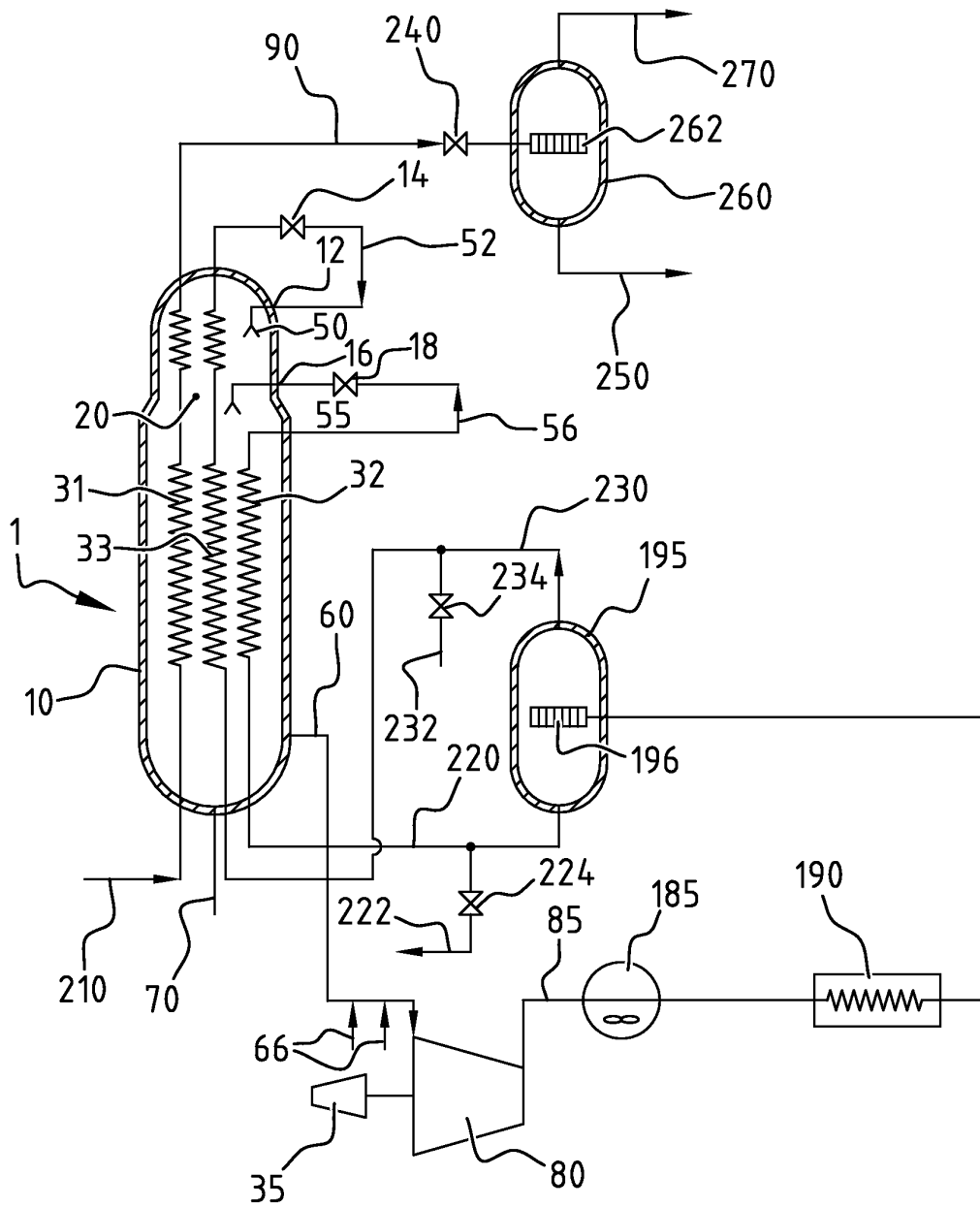


FIG. 3



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Munich		23 April 2014	Martínez Rico, Celia
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