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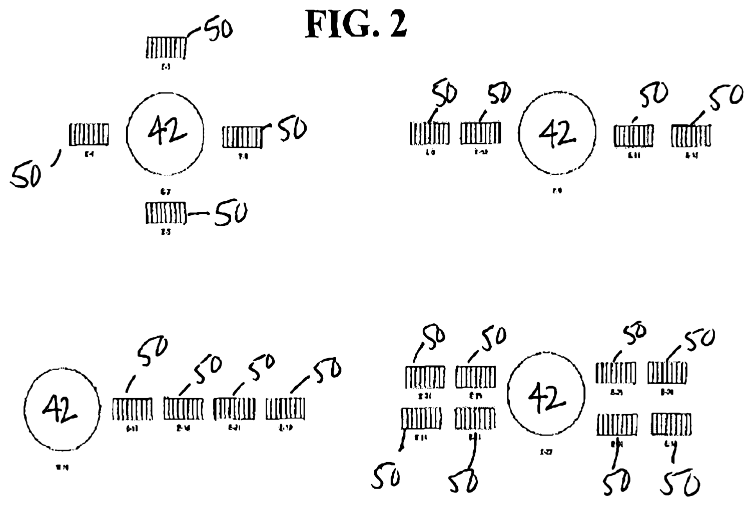
(54) **Title**: LIQUEFYING NATURAL GAS IN A MOTION ENVIRONMENT

FIG. 2



(57) **Abstract**: In an embodiment, a system for cooling or liquefying a process gas in a motion environment, includes: (a) a separation vessel, wherein the separation vessel includes motion suppressing baffles, wherein the separation vessel separates a high pressure refrigerant stream thereby producing a vapor refrigerant stream and a liquid refrigerant stream; (b) a vapor liquid refrigerant pipe for delivering the liquid refrigerant stream from the separation vessel to an external heat exchanger core; (c) at least one external heat exchanger core, wherein the external heat exchanger core is external to a kettle, wherein the liquid refrigerant stream and a warmer process stream undergo indirect heat exchange in the external heat exchanger core thereby producing a cooled process stream and a vaporized refrigerant stream.

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LIQUEFYING NATURAL GAS IN A MOTION ENVIRONMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority benefit under 35 U.S.C. Section 119(e) to U.S. Provisional Patent Serial No. 61/578,085 filed on December 20, 2011, the entire disclosure of which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates to a system and method for liquefying natural gas in a motion environment, utilizing a core-in-shell type heat exchanger.

BACKGROUND OF THE INVENTION

[0003] Natural gas in its native form must be concentrated before it can be transported economically. The use of natural gas has increased significantly in recent years due to its environmentally-friendly, clean burning characteristics. Burning natural gas produces less carbon dioxide than any other fossil fuel, which is important since carbon dioxide emissions have been recognized as a significant factor in causing the greenhouse effect. Liquefied Natural Gas (LNG) is likely to be used more and more in densely-populated urban areas with the increased concern over environmental issues.

[0004] Abundant natural gas reserves are located all over the world. Many of these gas reserves are located offshore in places that are inaccessible by land and are considered to be stranded gas reserves based on the application of existing technology. Existing technical reserves of gas are being replenished faster than oil reserves, making the use of LNG more important to meeting the demands of future energy consumption. In liquid form, LNG occupies 600 times less space than natural gas in its gaseous phase. Since many areas of the world cannot be reached by pipelines due to technical, economic, or political limits, locating the LNG processing plant offshore and utilizing a nautical vessels to directly transport the LNG offshore from the processing plant to the transportation vessel can reduce initial capital expenditure and release otherwise uneconomical offshore gas reserves.

[0005] Floating liquefaction plants provide an off-shore alternative to on-shore liquefaction plants and alternative to costly subsea pipeline for stranded offshore reserves. A floating liquefaction plant can be moored off the coast, or close to or at a gas field. It also represents a moveable asset, which can be relocated to a new site when the gas field is nearing the end of its production life, or when required by economic, environmental or political conditions.

[0006] One problem encountered in floating liquefaction vessels is the sloshing of vaporizing fluid inside heat exchangers. Sloshing in a heat exchanger may result in the production of forces that can affect stability and control of the heat exchanger. If the vaporizing fluid is allowed to slosh freely inside the shell of the heat exchanger, the moving fluid can have an adverse effect on the thermal function of the heat exchanger core. Furthermore, the cyclical nature of motion may result in cyclical behavior in heat transfer efficiency, and hence, process conditions in the LNG liquefaction plant may be impacted. These instabilities may result in poorer overall plant performance and may lead to narrower operating envelopes and limits to the available production capacity.

[0007] Therefore, a need exists for a system and method for liquefying natural gas in a motion environment.

SUMMARY OF THE INVENTION

[0008] In an embodiment, a system for cooling or liquefying a process gas in a motion environment, includes: (a) a separation vessel, wherein the separation vessel includes motion suppressing baffles, wherein the separation vessel separates a high pressure refrigerant stream thereby producing a vapor refrigerant stream and a liquid refrigerant stream; (b) a vapor liquid refrigerant pipe for delivering the liquid refrigerant stream from the separation vessel to an external heat exchanger core; (c) at least one external heat exchanger core, wherein the external heat exchanger core is external to a kettle, wherein the liquid refrigerant stream and a warmer process stream undergo indirect heat exchange in the external heat exchanger core thereby producing a cooled process stream and a vaporized refrigerant stream, wherein the cooled process stream is delivered to a location external to the external heat exchanger core; and (e) a partially vaporized refrigerant pipe for delivering the partially vaporized refrigerant from the external heat exchanger core to the separation vessel, wherein the partially vaporized refrigerant pipe provides minimal pressure drop, wherein the partially vaporized refrigerant pipe ensures the thermosiphon effect is maintained.

[0009] In another embodiment, a system for chilling or liquefying a process gas in a motion environment, includes: (a) a separation vessel, wherein the separation vessel separates a refrigerant stream thereby producing a vapor refrigerant stream and a liquid refrigerant stream; (b) a vapor liquid refrigerant pipe for delivering the liquid refrigerant stream from the separation vessel to an external heat exchanger core; (c) at least one external heat exchanger core, wherein the liquid refrigerant stream and a warmer process stream undergo indirect heat exchange in the external heat exchanger core thereby producing a cooled process stream and a vaporized refrigerant stream; and (d)a partially vaporized refrigerant pipe for delivering the partially vaporized refrigerant from the external heat exchanger core to the separation vessel.

[0010] In yet another embodiment, a method for liquefying natural gas in a motion environment, includes: (a) introducing a refrigeration into a separation vessel to thereby produce a vapor refrigerant stream and a liquid refrigerant stream, wherein the separation vessel includes motion suppressing baffles; (b) introducing the liquid refrigerant stream near the bottom of an external heat exchanger core; (c) introducing a warmer process stream into the external heat exchanger core at a location above the liquid refrigerant stream; (d) cooling the warmer process stream via indirect heat exchange with the liquid refrigerant stream to thereby produce a cooled process stream and a partially vaporized refrigerant stream; (e) removing the cooled process stream and the partially vaporized refrigerant stream from the external heat exchanger core; (f) delivering the partially vaporized refrigerant stream to the separation vessel; and (g) delivering the cooled process stream to a location external to the external heat exchanger core.

[0011] In a further embodiment, a method for liquefying natural gas in a motion environment, includes: (a) introducing a refrigeration into a separation vessel to thereby produce a vapor refrigerant stream and a liquid refrigerant stream; (b) introducing the liquid refrigerant stream near the bottom of an external heat exchanger core; (c) introducing a warmer process stream into the external heat exchanger core at a location above the liquid refrigerant stream; (d) cooling the warmer process stream via indirect heat exchange with the liquid refrigerant stream in the external heat exchanger core to thereby produce a cooled process stream and a partially vaporized refrigerant stream; and (e) removing the cooled process stream and the partially vaporized refrigerant stream from the external heat exchanger core.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention, together with further advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

[0013] FIG. 1 is a schematic of a separation vessel, according to one embodiment of the invention involving an external heat exchanger core.

[0014] FIG. 2 is a schematic of a separation vessel, according to one embodiment of the invention involving multiple external heat exchanger cores.

DETAILED DESCRIPTION OF THE INVENTION

[0015] Reference will now be made in detail to embodiments of the present invention, one or more examples of which are illustrated in the accompanying drawings. Each example is provided by way of explanation of the invention, not as a limitation of the invention. It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment can be used in another embodiment to yield a still further embodiment. Thus, it is intended that the present invention cover such modifications and variations that come within the scope of the appended claims and their equivalents.

[0016] A principle design of the core-in-shell heat exchanger provides cross exchange of a hot process feed stream against the colder vaporizing fluid. The vaporizing fluid resides in a pressure vessel where brazed aluminum compact exchanger cores are mounted and completely submerged in the vaporizing fluid which is at or near its boiling point. The liquid is drawn into the bottom face of the exchanger where it contacts the hotter surfaces within the core. The vaporizing fluid then transfers heat through the exchanger core channels. The majority of the heat transfer is from the latent heat of vaporization of the vaporizing fluid. The feed stream is cooled or condensed as it passes through the opposite side of the channels in the exchanger cores.

[0017] The thermal and hydraulic performance of the core-in-shell heat exchanger is dependent upon the liquid level in the exchanger. A predominant driving force for circulation of the vaporizing fluid into the exchanger cores is the thermosiphon effect. The thermosiphon effect is a passive fluid transfer phenomenon resulting from natural convective thermal forces. As the vaporization of the fluid occurs, the fluid is heated and the fluid density decreases. As it naturally flows upward in the channels, fresh liquid is drawn in. This results in a natural circulation of the vaporizing fluid into the core channels induced by the thermal gradient inside the core. Not all liquid in the channel is vaporized and a mixture of liquid and vapors typically are transported up through the exchanger core channels and expelled through the top of the core. Above the core, adequate space must be provided for the vapor and liquid to disengage so that only vapor leaves the overhead section of the shell side of the core. Liquid that separates in the upper section of the exchanger is then re-circulated to the bottom of the vessel where it is then vaporized in the core. The driving force for separation of the liquid and the gas in the upper section of the core-in-shell heat exchanger is gravity.

[0018] The thermosiphon circulation effect in the core is enhanced or impaired by the external hydraulic pressure (level differences) between the effective liquid level inside the core versus the liquid level outside the core. As the liquid level in the shell falls, the driving force for the transfer of the liquid into the exchanger core is decreased, and the effective heat transfer is reduced. When the liquid level falls below the core, the vaporizing fluid circulation stops due to the loss of the thermosiphon effect which results in the loss of heat transfer. If the heat exchanger is operated with a liquid level higher than the core, i.e., flooded, the heat transferred is impaired further as the vapor produced in the core has to overcome the additional head to escape from the core.

[0019] To mitigate concern with maintaining the necessary liquid level within the shell, the brazed aluminum compact heat exchanger core is removed from the shell. FIG. 1 depicts an exemplary configuration of an external heat exchanger core 50 connected to a kettle/separation vessel 42.

[0020] At least a portion of a high pressure liquid refrigerant stream exits an LNG facility via conduit 2 having been previously condensed and is transported to an expansion means (illustrated as expansion valve 40), wherein the stream is reduced in pressure to thereby produce an expanded refrigerant portion in conduit 4. The expansion valve 40 can be utilized as a control valve to control the level in the separation vessel 42. At least a portion of the expanded refrigerant stream is introduced to the separation vessel 42 to thereby produce a vapor refrigerant stream in conduit 6 and a liquid refrigerant stream. In an embodiment, the separation vessel includes motion suppressing baffles to reduce the liquid sloshing. The motion suppressing baffles 52 can be horizontally disposed, vertically disposed or combinations thereof. The liquid level within the separation vessel should be monitored and controlled. The vessel can also be fitted with a weir plate to ensure liquid is maintained at a minimum level in the vessel.

[0021] A portion of the liquid refrigerant stream is introduced into the bottom of the external heat exchanger core 50 via a liquid refrigerant pipe 8. A warmer process stream is also introduced into the external heat exchanger core 50 via conduit 12, whereby the warmer process feed stream is cooled via indirect heat exchange with the liquid refrigerant stream to thereby produce a cooled process stream and a partially vaporized liquid refrigerant stream.

[0022] The partially vaporized liquid refrigerant stream is re-circulated into the separation vessel via a pipe 16. The amount of vaporization is controlled to ensure adequate gas dispersion and the two phase flow regime is maintained in the dispersed region. Piping size and distances are controlled to ensure minimum pressure drop and thermosiphon effect is maintained. The higher the pressure drop in the pipe, the higher the liquid level has to be maintained in the separation vessel to ensure the flow to the external heat exchanger core is maintained. Adequate vapor disengaging space is provided above the partially vaporized liquid refrigerant transport pipe within the separation vessel to ensure that separation is maintained for re-circulated stream.

[0023] The remaining portion of the liquid refrigerant stream is transported to an expansion means (illustrated as expansion valve 48), wherein the stream is reduced in pressure to thereby produce an overflow refrigerant in conduit 18 which can be utilized in subsequent lower pressure stages of refrigeration.

[0024] The deign flexibility in positioning the external heat exchanger cores relative to other downstream processes and can handle multiple external heat exchanger cores for a single separation vessel. For example, FIG. 2 shows several configurations whereby the separation vessel is connected to multiple external heat exchanger cores.

[0025] Configuration of the exchangers external to the separation vessel also offers the advantage of eliminating downstream refrigerant compressor scrubbers as the pressure vessel can function as both a refrigerant separator and a compressor suction scrubber.

[0026] To minimize the sizing of the separation vessel 42 internals such as vane mist eliminators, mesh pads, or cyclonic vane mist eliminators could be installed to minimize the size of the separation vessel.

[0027] In closing, it should be noted that the discussion of any reference is not an admission that it is prior art to the present invention, especially any reference that may have a publication date after the priority date of this application. At the same time, each and every claim below is hereby incorporated into this detailed description or specification as a additional embodiments of the present invention.

[0028] Although the systems and processes described herein have been described in detail, it should be understood that various changes, substitutions, and alterations can be made without departing from the spirit and scope of the invention as defined by the following claims. Those skilled in the art may be able to study the preferred embodiments and identify other ways to practice the invention that are not exactly as described herein. It is the intent of the inventors that variations and equivalents of the invention are within the scope of the claims while the description, abstract and drawings are not to be used to limit the scope of the invention. The invention is specifically intended to be as broad as the claims below and their equivalents.

References

[0029] All of the references cited herein are expressly incorporated by reference. The discussion of any reference is not an admission that it is prior art to the present invention, especially any reference that may have a publication data after the priority date of this application. Incorporated references are listed again here for convenience:

1. US6543210 (Rostoucher; Peterschmitt; Vallat); “Cutting machine with improved cutting mechanism” (2001).
2. Lastname, F., et al., “Article title,” J. Abbr. 2:23-4 (2000).

CLAIMS

1. A system for cooling or liquefying a process gas in a motion environment, comprising:
    a. a separation vessel, wherein the separation vessel includes motion suppressing baffles, wherein the separation vessel separates a high pressure refrigerant stream thereby producing a vapor refrigerant stream and a liquid refrigerant stream;
    b. a vapor liquid refrigerant pipe for delivering the liquid refrigerant stream from the separation vessel to an external heat exchanger core;
    c. at least one external heat exchanger core, wherein the external heat exchanger core is external to a kettle, wherein the liquid refrigerant stream and a warmer process stream undergo indirect heat exchange in the external heat exchanger core thereby producing a cooled process stream and a vaporized refrigerant stream, wherein the cooled process stream is delivered to a location external to the external heat exchanger core; and
    d. a partially vaporized refrigerant pipe for delivering the partially vaporized refrigerant from the external heat exchanger core to the separation vessel, wherein the partially vaporized refrigerant pipe provides minimal pressure drop, wherein the partially vaporized refrigerant pipe ensures the thermosiphon effect is maintained.
2. The system according to claim 1, wherein the motion suppressing baffles are horizontally disposed.
3. The system according to claim 1, wherein the motion suppressing baffles are vertically disposed.
4. The system according to claim 1, wherein the motion suppressing baffles are horizontally and vertically disposed.
5. A system for chilling or liquefying a process gas in a motion environment, comprising:
    a. a separation vessel, wherein the separation vessel separates a refrigerant stream thereby producing a vapor refrigerant stream and a liquid refrigerant stream;

b. a vapor liquid refrigerant pipe for delivering the liquid refrigerant stream from the separation vessel to an external heat exchanger core;
c. at least one external heat exchanger core, wherein the liquid refrigerant stream and a warmer process stream undergo indirect heat exchange in the external heat exchanger core thereby producing a cooled process stream and a vaporized refrigerant stream; and
d. a partially vaporized refrigerant pipe for delivering the partially vaporized refrigerant from the external heat exchanger core to the separation vessel.

6. The system according to claim 6, wherein the refrigerant stream is delivered to the separation vessel as a high pressure liquid refrigerant.
7. The system according to claim 6, wherein the separation vessel includes motion suppressing baffles.
8. The system according to claim 7, wherein the motion suppressing baffles are horizontally disposed.
9. The system according to claim 7, wherein the motion suppressing baffles are vertically disposed.
10. The system according to claim 7, wherein the motion suppressing baffles are horizontally and vertically disposed.
11. The system according to claim 6, wherein the partially vaporized refrigerant pipe provides minimal pressure drop.
12. The system according to claim 6, wherein the partially vaporized refrigerant pipe ensures the thermosiphon effect is maintained.
13. The system according to claim 6, wherein the cooled feed stream is delivered to a location external to the external heat exchanger core
14. A method for liquefying natural gas in a motion environment, comprising:
    a. introducing a refrigeration into a separation vessel to thereby produce a vapor refrigerant stream and a liquid refrigerant stream, wherein the separation vessel includes motion suppressing baffles;
    b. introducing the liquid refrigerant stream near the bottom of an external heat exchanger core;

c. introducing a warmer process stream into the external heat exchanger core at a location above the liquid refrigerant stream;
d. cooling the warmer process stream via indirect heat exchange with the liquid refrigerant stream to thereby produce a cooled process stream and a partially vaporized refrigerant stream;
e. removing the cooled process stream and the partially vaporized refrigerant stream from the external heat exchanger core;
f. delivering the partially vaporized refrigerant stream to the separation vessel; and
g. delivering the cooled process stream to a location external to the external heat exchanger core.

15. The method according to claim 14, wherein the motion suppressing baffles are horizontally disposed.
16. The method according to claim 14, wherein the motion suppressing baffles horizontally and vertically disposed.
17. A method for liquefying natural gas in a motion environment, comprising:
    a. introducing a refrigeration into a separation vessel to thereby produce a vapor refrigerant stream and a liquid refrigerant stream;
    b. introducing the liquid refrigerant stream near the bottom of an external heat exchanger core;
    c. introducing a warmer process stream into the external heat exchanger core at a location above the liquid refrigerant stream;
    d. cooling the warmer process stream via indirect heat exchange with the liquid refrigerant stream in the external heat exchanger core to thereby produce a cooled process stream and a partially vaporized refrigerant stream; and
    e. removing the cooled process stream and the partially vaporized refrigerant stream from the external heat exchanger core.
18. The method according to claim 17, further comprising (f) delivering the partially vaporized refrigerant stream to the separation vessel.
19. The method according to claim 17, further comprising (g) delivering the cooled feed stream to a location external to the external heat exchanger core.

20. The method according to claim 19, wherein the separation vessel includes motion suppressing baffles.
21. The method according to claim 19, wherein the motion suppressing baffles are vertically disposed.
22. The method according to claim 19, wherein the motion suppressing baffles are horizontally disposed.
23. The method according to claim 19, wherein the motion suppressing baffles horizontally and vertically disposed.

FIG. 1

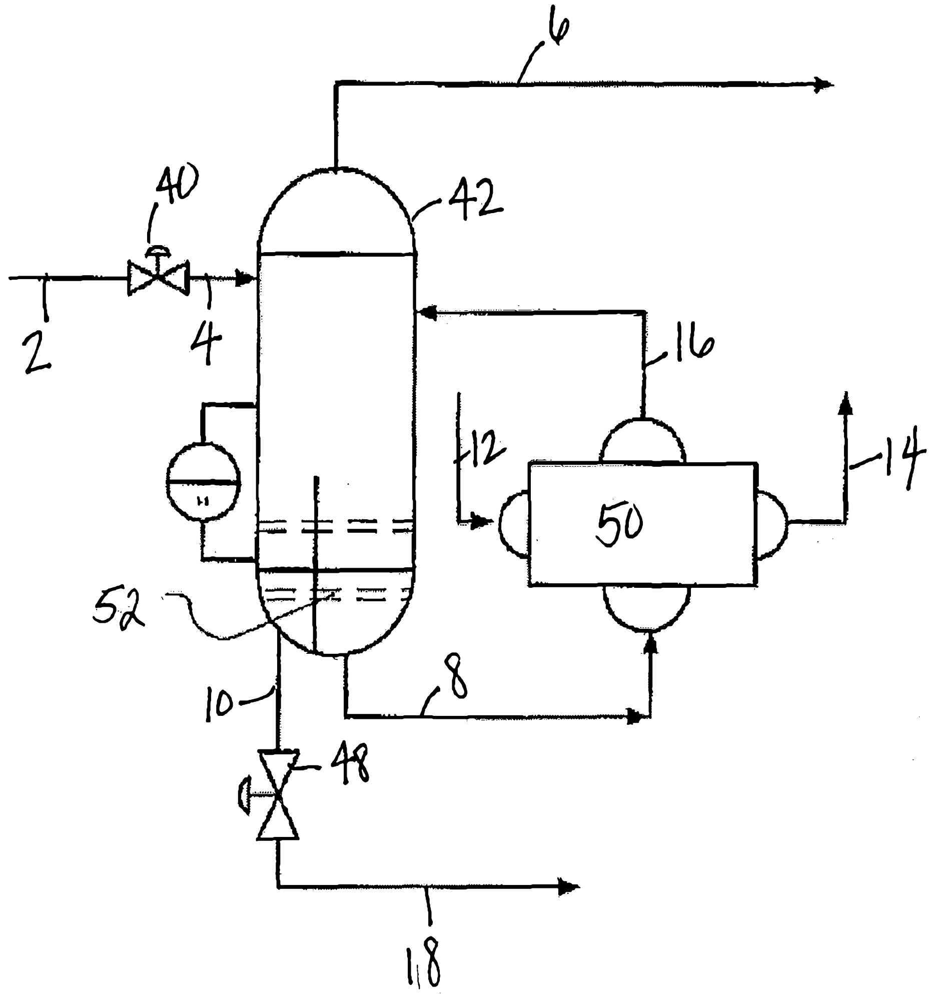

FIG. 2