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(54) Title: PROCESS AND SYSTEM FOR REMOVING TOTAL HEAT FROM BASE LOAD LIQUEFIED NATURAL GAS FACILITY

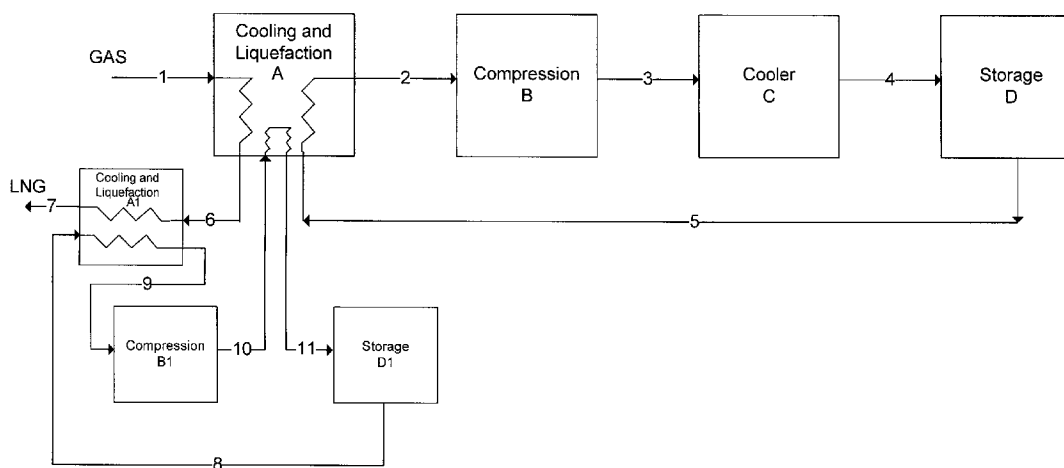


FIGURE 1

(57) Abstract: A process and system is provided for removing total heat from a base load LNG liquefaction facility by using a hybrid cooling process. After liquefying a gas such as natural gas with a refrigerant, the refrigerant is transferred to a compression unit. In order to condense the compressed refrigerant, the refrigerant first flows through process coil bundles. As the refrigerant flows through the process coil bundles, water is sprayed, via a spray distribution system and a water reservoir, onto the outer surface of the process coil bundles. Air is passed over the process coil bundles via a fan system to allow heat transfer to take place and to cool and condense the refrigerant.

PROCESS AND SYSTEM FOR REMOVING TOTAL HEAT FROM BASE LOAD LIQUEFIED NATURAL GAS FACILITY

Field of the Invention

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The present invention relates to a process and system for removing heat from a gas liquefaction facility. More particularly, the present invention relates to a process and system for removing total heat from a base load liquefied natural gas (LNG) facility by using hybrid cooling techniques.

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BACKGROUND OF THE INVENTION

Natural gas is a valuable, environmentally-friendly energy source. With gradually decreasing quantities of clean easily-refined crude oil, natural gas has become accepted as an alternative energy source. Natural gas may be recovered from natural gas reservoirs or as associated gas from a crude oil reservoir. Indeed, natural gas for use in the present process may be recovered from any process which generates light hydrocarbon gases.

Natural gas can be found all over the world. Much of the natural gas reserves found around the world are separate from oil and as new reserves are discovered and processed, growth in the LNG industry will continue. LNG comes from countries with large natural gas reservoirs including Algeria, Angola, Australia, Brunei, Indonesia, Libya, Malaysia, Nigeria, Oman, Qatar, Russia, Venezuela, Thailand and Trinidad and Tobago.

Most natural gas is handled in gaseous form. The most common means for transporting natural gas from the wellhead to gas processing plants and thence to the natural gas consumers is in high pressure gas transmission pipelines. In a number of circumstances, however, it has been found necessary and/or desirable to liquefy the natural gas either for transport or for use. In remote locations, for instance, there is often no pipeline infrastructure that would allow for convenient transportation of the natural gas to market. In such cases, the much lower specific volume of LNG relative to natural gas in the gaseous state can greatly reduce transportation costs by allowing delivery of the LNG using cargo ships and transport trucks.

Liquefaction of natural gas in a base load LNG facility includes processes for liquefying hydrocarbons heavier than methane, such as natural gas liquids (NGL) composed of ethane, propane, butanes, and heavier hydrocarbon components; liquefied petroleum gas (LPG) composed of propane, butanes, and heavier hydrocarbon components; and condensate composed of butanes and heavier hydrocarbon components. Producing various liquid streams has two important benefits: the LNG produced has a high methane purity, and the other liquids provide a valuable product that may be used for many other purposes. A typical analysis of a natural gas stream that may be liquefied would be, in approximate mole percent, 85% methane, 7% ethane and other C₂ components, 5% propane and other C₃ components, 1% iso-butane, 1% normal butane, 1% pentanes plus, with the balance made up of nitrogen and carbon dioxide. Sulfur containing gases are also sometimes present.

Base load LNG facilities are categorized according to the general type of refrigeration cycle used. Examples of known refrigeration cycles include classical cascade, mixed refrigerant, and propane-precooled/mixed-refrigerant. Variations exist within each category, depending on the specific process requirements at a base load LNG facility.

The above mentioned refrigeration cycles generally include steps in which the natural gas is purified (by removing water and troublesome compounds such as mercury, butane plus, carbon dioxide and sulfur compounds), cooled, condensed, and expanded. Cooling and condensation of the natural gas can be accomplished in many different manners. "Cascade refrigeration" employs heat exchange of the natural gas with several refrigerants having successively lower boiling points, such as propane, ethylene, and methane. As an alternative, this heat exchange can be accomplished using a single refrigerant by evaporating the refrigerant at several different pressure levels. "Multi-component refrigeration" employs heat exchange of the natural gas with one or more refrigerant fluids composed of several refrigerant components in lieu of multiple single-component refrigerants. Expansion of the natural gas can be accomplished both isenthalpically (using Joule-Thomson expansion, for instance) and isentropically (using a work-expansion turbine, for instance).

Regardless of the method used to liquefy the natural gas stream, it is common to remove a significant fraction of the hydrocarbons heavier than methane before the methane-rich stream is liquefied. The reasons for this hydrocarbon removal step are

numerous, including the need to control the heating value of the LNG stream, prevent freezing, and the value of these heavier hydrocarbon components as products in their own right.

5 Presently, the majority of the existing base load LNG facilities use water coolers or air coolers to remove the total heat required to liquefy natural gas to make LNG. However, there are several problems with the use of these coolers as described below.

10 Typically, for a 5.0 MMTPA base load LNG facility, using a water cooler will require about 110,000 GPM of cooling water. Examples of water cooler systems include a once-through system (sea water or river water) and a cooling tower system (cooling tower). However, there are several problems with these water cooler systems. Firstly, in the once-through cooling water system, there are environmental issues which need to be addressed such as thermal pollution. Specifically, since once-through cooling water systems typically use sea water or river water, large volumes of cooling
15 water may require additional processing or handling, which will negatively impact the economics of the project. Also, in a cooling tower water system where cooling tower technology is utilized, loss of cooling water and availability of make-up water are of concern particularly given that the majority of base load LNG sites typically have limited cooling water resources available.

20 Since the majority of base load LNG liquefaction sites lack sufficient water supplies, most newly constructed LNG facilities install air coolers to liquefy natural gas. However, a complex compressor design and a higher compression horse power are required when using such air cooler systems.

25 The new methodology described below solves the above problems, reduces liquefaction equipment capital costs and operating expenses, and provides reliable and safe operations.

SUMMARY OF THE INVENTION

30 The present invention achieves the advantage of a process and system for removing the total heat from a gas liquefaction facility.

In an aspect of the invention, a process for removing the total heat from a gas liquefaction facility includes: cross heat exchanging a natural gas with a refrigerant; compressing the refrigerant; and hybrid-cooling and condensing the refrigerant.

5 Optionally, in the above process, the refrigerant is one or a mixture of two or more selected from the group consisting of methane, ethane, ethylene, propane, butane and nitrogen.

Optionally, in the above process, the step of hybrid-cooling includes: de-superheating the refrigerant in a first stage hybrid cooler; and condensing the refrigerant in a second stage hybrid cooler.

10 Optionally, in the above process, the step of hybrid-cooling includes: flowing the refrigerant through at least one process coil; spraying water onto an outer surface of the at least one process coil; and flowing air over the outer surface of the at least one process coil.

Optionally, in the above process, the air and the water flow over the exterior surface of the at least one process coil in a co-current direction and at the same time.

15 Optionally, in the above process, the step of hybrid-cooling is conducted in a wet surface air cooler.

Optionally, in the above process, the refrigerant is propane, and wherein the refrigerant is compressed to a pressure in the range of about 540 to 2060 kPa.

20 Optionally, in the above process, the refrigerant is propane, and wherein the refrigerant is hybrid-cooled to a temperature in the range of about 0 to 60 °C.

Optionally, in the above process, the step of compressing is conducted in one or multi-stage steam/gas turbine or motor driven compressors.

25 Optionally, in the above process, the step of cross heat exchanging is conducted in at least one selected from the group consisting of a spool wound heat exchanger, shell and tube heat exchanger and a plate-fin heat exchanger.

In another aspect of the invention, a gas liquefaction system includes: a cooling and liquefaction unit; a compression unit; a hybrid-cooler unit; and a storage unit, wherein a refrigerant is transferred to the compression unit and the hybrid-cooler unit after being cross heat exchanged with a natural gas in the cooling and liquefaction unit.

30 Optionally, in the above system, the refrigerant is one or a mixture of two or more selected from the group consisting of methane, ethane, ethylene, propane, butane and nitrogen.

Optionally, in the above system, the hybrid-cooler unit includes: a de-superheating first stage hybrid-cooler; and a condensing second stage hybrid-cooler, wherein a refrigerant is cooled to a dew point temperature in the de-superheating first stage hybrid-cooler before being condensed in the condensing second stage hybrid
5 cooler.

Optionally, in the above system, the hybrid-cooler unit includes: at least one process coil; a spray distribution system; and a fan system, wherein the refrigerant flows through the at least one process coil while water is sprayed onto an outer surface of the at least one process coil via the spray distribution system, and wherein air is
10 passed over the at least one process coil via the fan system.

Optionally, in the above system, the hybrid-cooler unit includes a wet surface air cooler.

Optionally, in the above system, the refrigerant is propane, and wherein the refrigerant is compressed to a pressure in the range of about 540 to 2060 kPa in the
15 compression unit.

Optionally, in the above system, the refrigerant is propane, and wherein the refrigerant is hybrid-cooled to a temperature in the range of about 0 to 60 °C in the hybrid-cooler unit.

Optionally, the above system further includes: a storage unit, wherein the
20 refrigerant is transferred to the storage unit after being cooled in the hybrid-cooler unit.

Optionally, in the above system, the compression unit comprises one or multi-stage steam/gas turbine or motor driven compressors.

Optionally, in the above system, the liquefaction unit comprises at least one selected from the group consisting of a spool wound heat exchanger, shell and tube heat
25 exchanger and a plate-fin heat exchanger.

DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a process flow diagram of an embodiment of the invention.
30 Fig. 2 illustrates an embodiment of a hybrid cooler of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Reference is made to Figures 1 and 2. The base load facility for liquefying natural gas according to the present invention includes a cooling and liquefaction unit (A), a compression unit (B), a cooler unit (C), and a storage unit (D).

The present process can be employed with a natural gas feed stream (1) over the full range of typical compositions. In one embodiment, an example of the typical natural gas feed stream (1) that may be liquefied may be, in approximate mole percent, 85% methane, 7% ethane and other C2 components, 5% propane and other C3 components, 1% iso-butane, 1% normal butane, 1% pentanes plus, with the balance made up of nitrogen and carbon dioxide. Sulfur containing gases may also be present. In this example, the natural gas feed stream (1) has a pressure in the range of about 1000 to about 6200 kPa, and a temperature in the range of about -5 to about 45 °C. However, the temperature and pressure of the natural gas to be liquefied may be outside of these stated ranges.

Typically, prior to liquefaction, the natural gas feed stream (1) is also pretreated via an inlet scrubber, amine treater, chiller, dehydrator and carbon filtration before being further processed.

During the process of the present invention, as illustrated in Figures 1 and 2, the natural gas feed stream (1) is first fed to the cooling and liquefaction unit (A). Here, the natural gas feed stream (1) is cooled and liquefied using, for example, a liquefaction heat exchanger. In order to cool and liquefy the natural gas, a propane refrigerant (5) is cross heat exchanged with the natural gas feed stream (1). Although the refrigerant (5) is described to be propane in this embodiment, the invention is not limited thereto. The present invention may also use a refrigerant including methane, ethane, ethylene, propane, butane and nitrogen or mixtures thereof.

Exemplary liquefaction heat exchangers include any heat exchangers of suitable design for the liquefaction of gases, such as a spiral wound heat exchanger, shell and tube heat exchanger or a plate-fin heat exchanger. Additionally, the liquefaction heat exchangers may suitably include a set of two or more heat exchangers arranged in series or parallel, wherein the propane refrigerant (5) is allowed to evaporate at one or more pressure levels. The natural gas flowing through the cooling and liquefaction unit (A) cools and liquefies to a temperature of about -161 °C at about 112 kPa. The

propane refrigerant (5) flowing through the cooling and liquefaction unit (A) vaporizes and changes in temperature and pressure in the range of about 10 to about -35°C and of about 700 to about 40 kPa, respectively. It should also be understood that these temperatures and pressures are dependent on the composition of the refrigerant and will vary if a different refrigerant composition is selected.

The vaporized propane stream (2) is transferred from the cooling and liquefaction unit (A) to the compression unit (B). Here, the vaporized propane stream (2) is compressed to a pressure in the range of about 540 to 2060 kPa at about 40 to 85°C via at least one compressor. Exemplary compressors include one or multi-stage steam/gas turbine or motor driven compressors with inter-cooling, or a combination of compressors in series with inter-cooling in between two compressors, or a combination of compressors in parallel. Instead of turbines, electric motors can be used to drive the compressors.

Next, the compressed propane gas stream (3) is transferred from the compression unit (B) to the cooler unit (C). Here, the compressed propane stream (3) is hybrid-cooled and liquefied (condensed) to a temperature in the range of about 0 to about 60 °C at a pressure in the range of about 480 to about 2000 kPa.

The cooler unit (C) includes a hybrid cooler, more specifically, a wet surface air hybrid cooler. As illustrated in the embodiment shown in Figure 2, the hybrid cooler further includes a water reservoir (E), process coil bundles (F), spray distribution system (G), a fan system (H) and a hybrid cooler box (I). As also illustrated in Figure 2, the water reservoir (E), the process coil bundles (F), the spray distribution system (G) and the fan system (H) are all housed within the hybrid cooler box (I).

In order to liquefy the compressed propane stream (3), the compressed propane stream (3) flows through the process coil bundles (F). As the compressed propane (3) flows through the process coil bundles (F), the water is sprayed, via the spray distribution system (G) and the water reservoir (E), onto the outer surfaces of the process coil bundles (F). Air is then passed over outer surfaces of the process coil bundles (F) via the fan system (H) to allow heat transfer to take place and to cool and liquefy the compressed propane stream (3).

In an alternative embodiment, the cooler unit (C) may include staged cooling such as a first stage hybrid cooler (de-superheater) and a second stage hybrid cooler (condenser). The de-superheater would be capable of cooling the compressed

refrigerant to its dew point, while the condenser would liquefy the compressed refrigerant. Additionally, the cooler unit (C) may include a hybrid cooler to subcool the refrigerant.

As the hybrid cooler's basic principle of operation (See Figure 2), heat is rejected by means of latent (evaporative) heat transfer. The compressed propane (3) is condensed as it flows through the process coil bundles (F) as part of a closed-loop system. The water from the water reservoir (E) (unit basin) is sprayed via the spray distribution system (G) in large quantities over the process coil bundle's (F) outer surfaces. Air is induced by the fan system (H), and latent heat transfer through evaporation takes place at the fluid film on the surface of the process coil bundles (F). In the embodiment illustrated in Figure 2, the saturated air stream makes two 90° turns in the hybrid cooler box (I) at a lower velocity, dropping almost all of the large water droplets back into the water reservoir (E) (unit basin). The air then is discharged out of the hybrid cooler box (I) through fan stacks.

Because of the large quantity of water sprayed over the process coil bundle (F), the exterior of the process coil (F) surface does not dry during operation. The air and water flow over the exterior surface of the process coil bundles (F) in the same direction (co-current flow), preventing dry areas on the underside of the process coils (F). Because the air passes over the spray system water before and during contact with the process coil bundle (F), the mixed water temperature remains above freezing. This protects the hybrid cooler from freezing even when the ambient air temperature is below freezing.

Water use and disposal have become increasingly important in base load LNG facility site and design selection. The hybrid cooler (wet-surface air cooler) can use poor quality water such as that from blowdown, reverse osmosis (RO) discharge, condensate, sea water, pond water, gray water or sewage effluent for spray water makeup. Because the water does not evaporate directly off the process coil bundles (F), higher cycles of concentration can be achieved. The fan system (H) can run high cycles of concentration because the spray water only is used to wet the exterior process coil (F) surface, and the process coil (F) spacing is very wide.

The liquefied propane stream (4) is then transferred from the cooler unit (C) to the storage unit (D), such as a propane accumulator, and fed back to the cooling and

liquefaction unit (A) or to other downstream process applications requiring a propane liquid.

Although the above embodiment mainly describes a propane refrigerant loop, it should also be understood that other refrigerant loops may be incorporated into the
5 above described hybrid-cooling process.

As shown in Figure 1, in another refrigerant loop, a cooled natural gas stream (6) is output from the cooling and liquefaction unit (A) and input into another cooling and liquefaction unit (A1). The cooled natural gas (6) is further cooled and condensed by cross-heat exchanging with another refrigerant (8), and output as liquefied natural
10 gas (7). A warmed refrigerant (9) is output from the cooling and liquefaction unit (A1) and input into a compression unit (B1). A compressed refrigerant (10) is output from the compression unit (B1) and input into the cooling and liquefaction unit (A). After the compressed refrigerant is cross-heat exchanged in the cooling and liquefaction unit (A), a cooled refrigerant (11) is output into a storage unit (D1) and output as the other
15 refrigerant (8).

The other refrigerant (8) includes methane, ethane, ethylene, propane, butane and nitrogen or mixtures thereof.

Also, the above units and processes of the other refrigerant loop are similar to the above described propane refrigerant loop.

What is claimed is:

- 1) A process for removing the total heat from a gas liquefaction facility, comprising:
cross heat exchanging a natural gas with a refrigerant;
compressing the refrigerant; and
hybrid-cooling and condensing the refrigerant.
- 2) The process according to claim 1, wherein the refrigerant is one or a mixture of two or more selected from the group consisting of methane, ethane, ethylene, propane, butane and nitrogen.
- 3) The process according to claim 1, wherein the step of hybrid-cooling comprises:
de-superheating the refrigerant in a first stage hybrid cooler; and
condensing the refrigerant in a second stage hybrid cooler.
- 4) The process according to claim 1, wherein the step of hybrid-cooling comprises:
flowing the refrigerant through at least one process coil;
spraying water onto an outer surface of the at least one process coil; and
flowing air over the outer surface of the at least one process coil.
- 5) The process according to claim 4, wherein the air and the water flow over the exterior surface of the at least one process coil in a co-current direction and at the same time.
- 6) The process according to claim 1, wherein the step of hybrid-cooling is conducted in a wet surface air cooler.
- 7) The process according to claim 1, wherein the refrigerant is propane, and wherein the refrigerant is compressed to a pressure in the range of about 540 to 2060 kPa.
- 8) The process according to claim 1, wherein the refrigerant is propane, and wherein the refrigerant is hybrid-cooled to a temperature in the range of about 0 to 60 °C.

- 9) The process according to claim 1, wherein the step of compressing is conducted in one or multi-stage steam/gas turbine or motor driven compressors.
- 10) The process according to claim 1, wherein the step of cross heat exchanging is conducted in at least one selected from the group consisting of a spool wound heat exchanger, shell and tube heat exchanger and a plate-fin heat exchanger.
- 11) A gas liquefaction system comprising:
a cooling and liquefaction unit;
a compression unit;
a hybrid-cooler unit; and
a storage unit,
wherein a refrigerant is first transferred to the compression unit, the hybrid-cooler unit and then to the storage unit after being cross heat exchanged with a gas in the cooling and liquefaction unit.
- 12) The system according to claim 11, wherein the refrigerant is one or a mixture of two or more selected from the group consisting of methane, ethane, ethylene, propane, butane and nitrogen.
- 13) The system according to claim 11, wherein the hybrid-cooler unit comprises:
a de-superheating first stage hybrid-cooler; and
a condensing second stage hybrid-cooler,
wherein a refrigerant is cooled to a dew point temperature in the de-superheating first stage hybrid-cooler before being condensed in the condensing second stage hybrid-cooler.
- 14) The system according to claim 11, wherein the hybrid-cooler unit comprises:
at least one process coil;
a spray distribution system; and
a fan system,
wherein the refrigerant flows through the at least one process coil while water is sprayed onto an outer surface of the at least one process coil via the spray

distribution system, and wherein air is passed over the at least one process coil via the fan system.

- 15) The system according to claim 11, wherein the hybrid-cooler unit comprises a wet surface air cooler.
- 16) The system according to claim 11, wherein the refrigerant is propane, and wherein the refrigerant is compressed to a pressure in the range of about 540 to 2060 kPa in the compression unit.
- 17) The system according to claim 11, wherein the refrigerant is propane, and wherein the refrigerant is hybrid-cooled to a temperature in the range of about 0 to 60 °C in the hybrid-cooler unit.
- 18) The system according to claim 11, further comprising:
a storage unit,
wherein the refrigerant is transferred to the storage unit after being cooled in the hybrid-cooler unit.
- 19) The system according to claim 11, wherein the compression unit comprises one or multi-stage steam/gas turbine or motor driven compressors.
- 20) The system according to claim 11, wherein the liquefaction unit comprises at least one selected from the group consisting of a spool wound heat exchanger, shell and tube heat exchanger and a plate-fin heat exchanger.

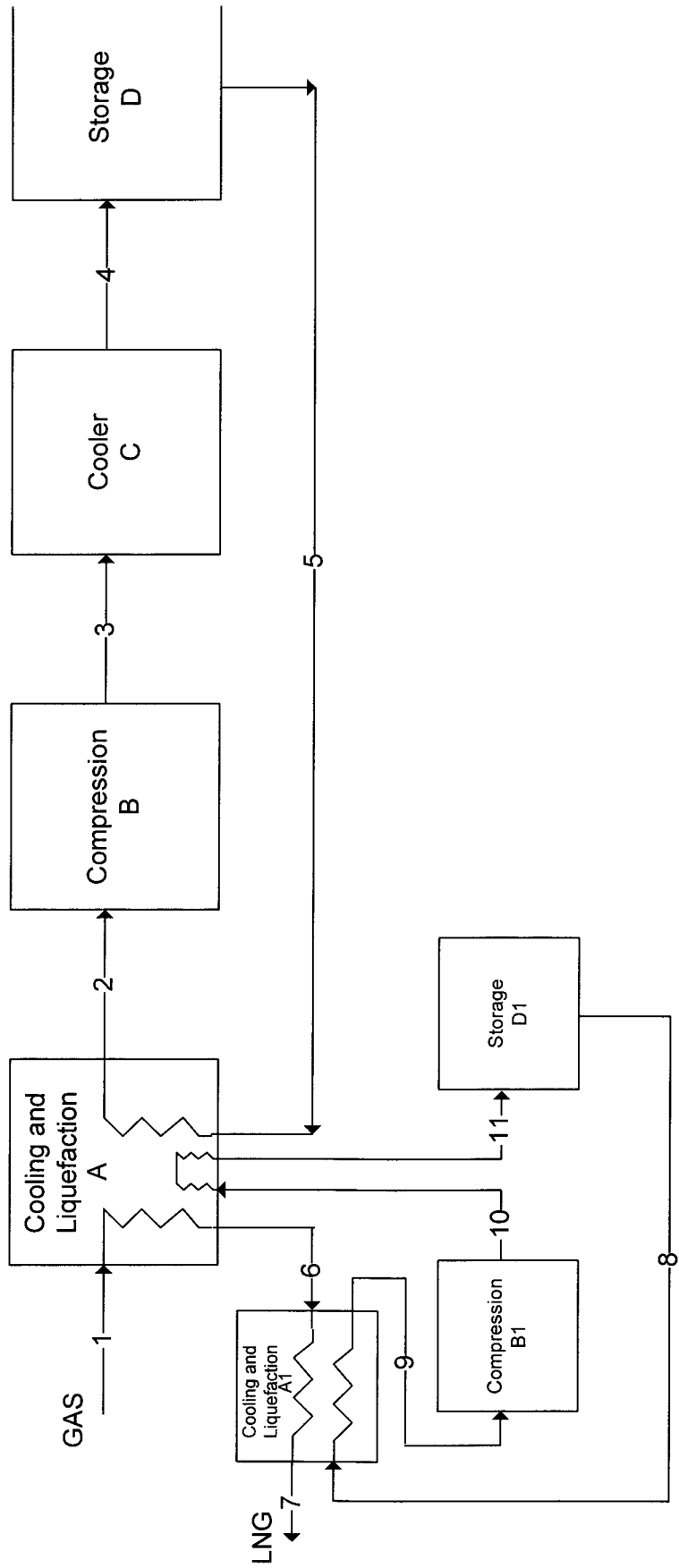


FIGURE 1

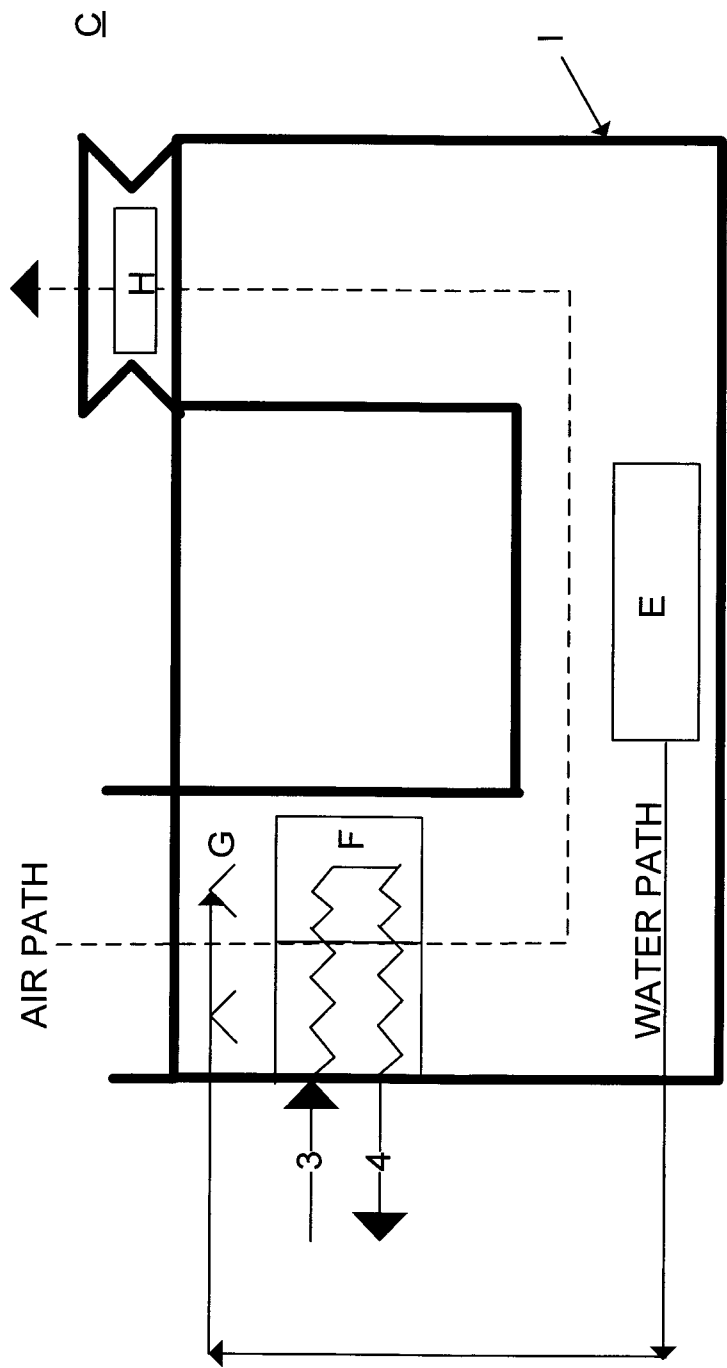


FIGURE 2

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 08/79071

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F25J 1/00 (2008.04)

USPC - 62/611, 612

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC - 62/611, 612Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 62/613, 614, 606
IPC(8) - F25J 1/00 (2008.04)Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST (USPT, PGPB, USOC, EPAB, JPAB) and Google: LNG, liquid natural gas, base load, cool, refrigerant, hybrid, fan, spray, water, coil, shell, tube, spool, plate, fin, pressure, kPa, methane, ethane, ethylene, propane, butane, nitrogen, chevron, kuo, demakos

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---	US 5,979,177 A (Sumner et al.) 9 November 1999 (09.11.1999) Entire document, particularly col 1, ln 37-42; col 2, ln 22-26, 33-34; col 3, ln 1-26; col 5, ln 35-46; col 6, ln 2-12.	1-3, 6, 7, 9, 11-13, 15, 16, 18, 19
Y		4, 5, 8, 10, 14, 17, 20
Y	US 2007/0214806 A1 (Faka) 20 September 2007 (20.09.2007) Para [0032]; Fig 3.	4, 5, 14
Y	US 5,365,740 A (Kikkawa et al.) 22 November 1994 (22.11.1994) col 2, ln 23-35.	8, 10, 17, 20
A	US 4,526,596 A (Baggio et al.) 2 July 1985 (02.07.1985) col 4, ln 21-42.	1-20

☐ Further documents are listed in the continuation of Box C.

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"&" document member of the same patent family

Date of the actual completion of the international search

21 November 2008 (21.11.2008)

Date of mailing of the international search report

04 DEC 2008

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