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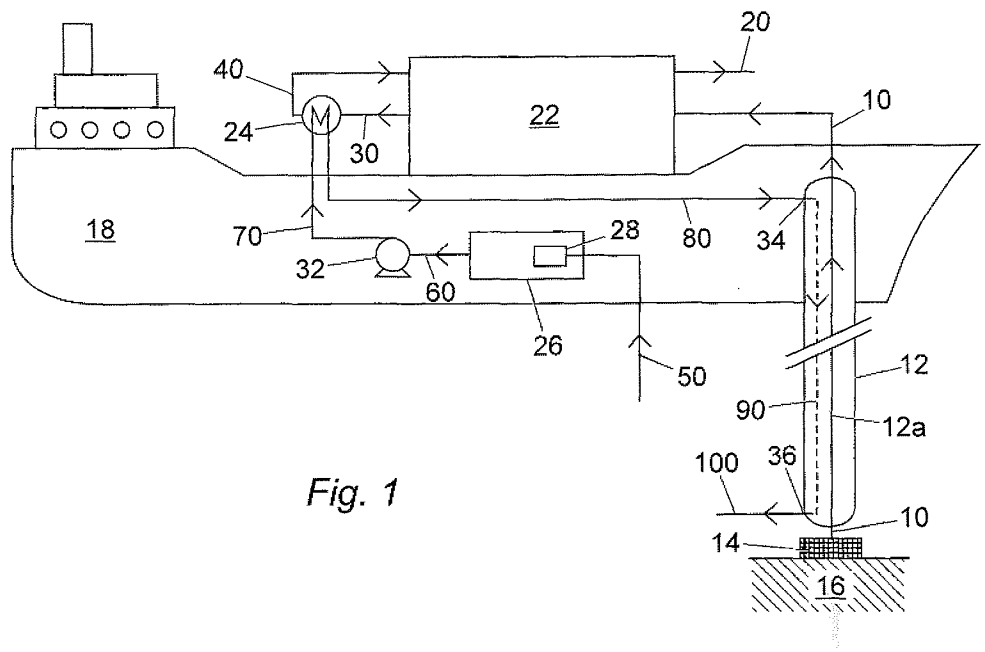

Fig. 1

(57) Abstract: A method of cooling a gaseous hydrocarbon stream (10) such as natural gas comprising at least the steps of : (a) sourcing the gaseous hydrocarbon stream (10) in an underwater pipeline (12) to a hydrocarbon facility at sea (18); (b) cooling the gaseous hydrocarbon stream (10) against one or more cooling streams (40) to remove heat from the gaseous hydrocarbon stream (10), and so provide a cooler hydrocarbon stream (20) and one or more warmer cooling streams (30); (c) using the heat of at least one warmer cooling stream (30) to heat the gaseous hydrocarbon stream (10) being sourced in the pipeline (12).

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METHOD AND APPARATUS FOR COOLING A GASEOUS HYDROCARBON STREAM

The present invention relates to a method and apparatus for cooling a gaseous hydrocarbon stream such as natural gas sourced from an underwater pipeline, in particular a subsea pipeline, more particularly extending from a subsea well.

Underwater or submarine hydrocarbon reservoirs such as natural gas reservoirs can be exploited through subsea wells which extract the hydrocarbons for transportation through submarine pipelines to above-surface hydrocarbon facilities at sea or on land. Such facilities can include processing, treating and/or liquefying the hydrocarbon stream, in particular to obtain liquefied natural gas (LNG).

A floating plant for liquefying natural gas comprising a barge provided with a liquefaction plant is described in WO 02/21060 A1. Cooling water is supplied to the liquefaction plant via an open-ended water intake conduit, and after it has been removed from a heat exchanger it is discharged directly into the sea through a discharge conduit into a chimney extending inside the hull of the vessel. There is often a maximum temperature specified at which the cooling water may be discharged into the environment like that, which in turn imposes limitations on the liquefaction process.

The present invention provides a method of cooling a gaseous hydrocarbon stream, such as a natural gas stream, comprising at least the steps of:

(a) sourcing the gaseous hydrocarbon stream in an underwater pipeline to hydrocarbon facility at sea;

(b) cooling the gaseous hydrocarbon stream against one or more cooling streams by removing heat from the gaseous hydrocarbon stream, and so to provide a cooler hydrocarbon stream and one or more warmer cooling streams;

(c) using the heat of at least one of the warmer cooling stream(s) to heat the gaseous hydrocarbon stream being sourced in the pipeline.

Since the heat of the warmer cooling stream is now used to heat the gaseous hydrocarbon stream being sourced in the pipeline, this heat is not added to the sea. Therefore, it becomes easier to meet any discharge specifications, which reduces constraints in the design and operation of the cooling process.

In another aspect, the present invention provides apparatus for cooling a gaseous hydrocarbon stream, such as natural gas stream, the apparatus at least comprising:

an underwater pipeline to a hydrocarbon facility at sea for sourcing the gaseous hydrocarbon stream to the hydrocarbon facility;

a cooling system to cool the gaseous hydrocarbon stream against one or more cooling streams, and so provide a cooler hydrocarbon stream and one or more warmer cooling streams; and

a heating line to pass the heat of at least one of the warmer cooling stream(s) to the gaseous hydrocarbon stream in the pipeline.

The invention will be explained herein below with reference to embodiments by way of example only, and with reference to the accompanying non-limiting drawings, in which:

Figure 1 is a general scheme of a floating plant for cooling a hydrocarbon stream sourced from a subsea pipeline according to one embodiment of the present invention;

Figure 2 is a scheme of various embodiments of the present invention; and

Figure 3 is a more detailed scheme of Figure 1.

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. The same reference numbers refer to similar components.

An advantageous use is proposed of an underwater pipeline that sources a gaseous hydrocarbon stream to a hydrocarbon facility at sea, wherein heat of at least one warmer cooling stream of a hydrocarbon cooling process is added to the gaseous hydrocarbon stream in the pipeline.

The present invention is based on the insight that heat provided by the cooling of the gaseous hydrocarbon stream, which heat may otherwise be waste or excess heat that may be difficult to get rid of without disturbing the environment too much, instead can be used to directly or indirectly to heat the gaseous stream being sourced in the underwater, generally subsea, pipeline. This in turn may help to prevent formation of gas hydrates in the pipeline.

Using the gaseous hydrocarbon stream to remove at least part of the heat of the warmer cooling stream allows the heat of the warmer cooling stream to be removed at a temperature higher than possible when it would be added to the sea.

The present invention extends to providing heat to a gaseous hydrocarbon stream in an underwater pipeline passing to or from a land-based facility, another vessel or structure on or in the sea, or other wellheads on the seabed. The arrangement of such a pipeline and any other lines or conduits and insulation therewith, are as described herein.

Optionally, more than one pipeline may be provided from the same wellhead to the floating vessel, or from other wellheads. A suitable arrangement is to provide pairs of pipelines (or pairs of hydrocarbon carrying conduits 12a together in one single pipeline) that are U-looped to each other at the seabed such as to enable a pig to be moved in one direction from the surface to the seabed and back up to the surface.

The heat provided by cooling of the hydrocarbon stream and/or by any pre-treatment may be carried in the form of a heating fluid, preferably a heated water stream, to the underwater pipeline.

In another embodiment of the present invention, the heating fluid may be provided directly by the cooling and/or pre-treatment by heat exchange with a fluid, stream, unit, device or the like, and such heating fluid can be used directly, such as in a heating line, to provide heat to the gaseous hydrocarbon stream passing through the pipeline.

In an alternative embodiment, heat provided by the cooling of the hydrocarbon stream and/or any pre-treatment is heat exchanged with an intermediate fluid in a separate circuit or cycle, such as a separate water stream, and such intermediate fluid is then heat exchanged with a heating fluid or stream passing through the pipeline.

Any warmer cooling stream, heated stream, heating fluid and/or intermediate fluid involved in the present invention may also include one or more salt deposition inhibitors or corrosion inhibitors or the like.

The source of the gaseous hydrocarbon stream is usually extraction from one or more reservoirs on or in the seabed and through a well or wellhead located on or near the seabed. The hydrocarbon stream can then pass from the well or wellhead to a floating vessel along a suitable pipeline.

Figure 1 shows a method of cooling a gaseous hydrocarbon stream 10 such as natural gas, sourced from a pipeline 12 between a wellhead 14 on a sea bed 16 and an above-surface hydrocarbon facility at sea, here shown in the form of a floating vessel such as a ship 18. The pipeline does not have to be physically connected to the ship itself, nor does the gaseous hydrocarbon stream 10 have to be sourced directly from the pipeline 12 to the ship 18. The hydrocarbon facility may for instance comprise a turret, or the like, to which the ship 18 may be moored, whereby the gaseous hydrocarbon stream 10 is sourced to the ship 18 via the turret.

The gaseous hydrocarbon stream 10 may be any suitable hydrocarbon-containing gas stream to be cooled, but is usually a natural gas stream obtained from one or more natural gas or petroleum reservoirs. Usually, the natural gas stream is comprised substantially of methane. Preferably, the hydrocarbon stream comprises at least 60 mol% methane, more preferably at least 80 mol% methane.

Extraction of the gaseous hydrocarbon stream 10 such as natural gas from one or more seabed reservoirs is known in the art, as is the arrangement and operation of the wellhead 14.

The pipeline 12 may comprise one or more lines and conduits, as well as insulation, in any suitable arrangement known in the art. One example is a central conduit 12a for the gaseous hydrocarbon stream 10, and a heating line 90 comprising one or more conduits arranged alongside, such as around, the central gaseous hydrocarbon stream conduit 12a, each conduit embedded in one or more thermally insulating materials.

The length of the pipeline 12 may vary according to the depth of water and/or desired pathway for the pipeline, as is known in the art.

The pipeline 12 provides a source of a gaseous hydrocarbon stream 10 onto or into the ship 18, where the hydrocarbon stream 10 is discharged from the pipeline 12. In the embodiment as shown in Fig.1, it then passes to a cooling system 22.

Cooling systems and/or liquefying systems are known in the art, and usually comprise one or more cooling stages, each cooling stage involving one or more heat exchangers. A cooling system and/or liquefaction system may comprise one or more refrigerant circuits, having dedicated and/or shared refrigerant compressors and downstream heat exchangers e.g. for removing heat of compression. The cooling system may include a cooling stage followed by a liquefaction stage for liquefying the gaseous hydrocarbon stream, such as in an LNG production facility. A common method of cooling a gaseous hydrocarbon stream is to heat exchange it with one or more cooling fluids such as a refrigerants in one or more heat exchangers.

Cooling fluids or refrigerants are known in the art, and can comprise single component refrigerants such as propane or nitrogen, or a mixed refrigerant, usually comprising two or more selected from the group comprising: nitrogen, methane, ethane, ethylene, propane, propylene, butanes, pentanes and C_6+ hydrocarbons.

The cooling may include at least one compressor and at least one downstream heat exchanger, which may be part of one or more refrigerant circuits for cooling the hydrocarbon stream. A refrigerant usually passes around a refrigerant circuit, which refrigerant circuit usually includes at least one refrigerant compressor and at least one downstream heat exchanger to cool the compressed stream.

A cooling system and/or liquefaction system may have one or more other providers or generators of heat such as boilers, turbines, condensers, heat from which can be used for the heating line. Such heat can be from the unit itself, or an exhaust or waste stream. For example, a turbine exhaust can include a heat exchanger to provide a warmed or heated stream.

Thus, referring again to Fig. 1, the cooling system 22 may be any arrangement, apparatus, unit or device or combination thereof adapted to cool the gaseous hydrocarbon stream 10 and so provide a cooled hydrocarbon stream 20. The cooled hydrocarbon stream 20 may be a purified and/or liquefied natural gas stream as described hereinafter.

In one embodiment of the present invention, the cooling of the hydrocarbon stream is to below 0 °C. Preferably, the cooling includes liquefying the hydrocarbon stream such as natural gas, to provide the cooled hydrocarbon stream 20 in the form of a liquefied hydrocarbon stream such as liquefied natural gas.

One or more parts, units, items or streams of the cooling system 22 provides a warmer cooling stream 30 which passes through a heat exchanger 24, and whose return cooling stream 40 passes back into the cooling system 22.

The warmer cooling stream 30 may comprise a compressed refrigerant. Alternatively, the warmer cooling stream may comprise water and optionally one or more other thermal components. Alternatively, line 30 may carry a heat transfer fluid which carries at least a fraction of the heat removed from the warmer cooling stream, instead of the warmer cooling stream itself.

The stream in line 30, such as the water and the optional one or more thermal components, may have a temperature greater than >20 °C, preferably >30 °C, >40 °C or >50 °C, or even greater than for example 100 °C, such as 150 °C or 200 °C.

Figure 1 also shows a water intake conduit 50, generally being from the seawater surrounding the ship 18, which passes into a receptacle 26 which includes a filter system 28. The filter system 28 can comprise filter equipment suitable for continuously clarifying water, such as a rotating drum or a cyclone.

The filter system 28 provides a filtered water stream 60, which passes through a pump 32 to provide a pumped water stream 70, which stream 70 also passes through the heat exchanger 24. In this way, heat is exchanged from the warmer cooling stream 30 to the pumped stream 70 in the heat exchanger 24 to provide a heated water stream 80.

Preferably, the pipeline includes at least one hydrocarbon conduit 12a for the gaseous hydrocarbon stream 10, and at least one heating line 90 along which the heat from the warmer cooling stream passes. The heated water stream 80 can then be passed directly into the heating line 90 through inlet 34 in the pipeline 12, so that the heat in the heated water stream 80 provides heat to the conduit 12a in the pipeline 12 carrying the gaseous hydrocarbon stream 10.

The heating line 90 may extend partially along the pipeline 12, but preferably extends through the pipeline 12 between the ship 18 to a location adjacent to or neighbouring the end of the pipeline 12 at or near the wellhead 14. The skilled person may vary the precise configuration of the pipeline 12 and its conduits.

Near the wellhead 14, the heating line 90 can pass its stream 90 through an outlet 36 in the pipeline 12 and along a release line 100 (and back into the sea), whose length may be any suitable length in the art. Preferably, the temperature of the stream 90 through the outlet 36 is greater than the ambient sea temperature, for example +30 °C. The temperature of the heated water stream 80 passing through inlet 34 may exceed the temperature that would be allowed if this heated water stream would be discharged directly into the ambient sea not via heating line 90. Thus, the flow rate of cooling water which needs to be taken in via intake conduit 50 is lowered by discharging it via heating line 90.

The stream of the heating line 90 provides heat to the gaseous hydrocarbon stream 10 carried in the pipeline 12 to reduce, preferably prevent, hydrate formation that may occur in the pipeline 12, in particular in the hydrocarbon conduit 12a.

For most if not all hydrocarbon fluids, it is desired to maintain the temperature of the flow of the hydrocarbon stream from the subsea wellhead above 25 °C or even 30 °C to prevent hydrate formation. Where the sea is or is likely to be colder than that, one or more glycol compounds are often added to the hydrocarbon stream in an amount that is a function of temperature of seawater and water content in the hydrocarbon stream.

The amount of glycol compounds required may be high or very high, especially in non-tropical waters, e.g. 20-30 vol.%. A number of methods of insulating or heating a subsea pipeline have been described in the art, including the use of various solid and liquid insulating materials to reduce the amount of glycol compounds that needs to be added. However, the source of heat in the prior art has only been described as being from separate heating facilities.

The arrangement shown in Figure 1 is able to use heat provided by the cooling system 22 of the gaseous hydrocarbon stream 10, thereby increasing the efficiency of the combined operation. This efficiency includes reducing the capital and/or running costs of providing a separate heating apparatus, unit or facility for any fluid passing down the heating line 90, as well as using heat created by the cooling system 22 which may otherwise be wasted or vented to atmosphere.

The present invention may thus simplify and/or reduce the capital and/or running costs of a liquefaction plant and heating of the subsea pipeline.

The present invention is not limited by any arrangement of any hydrocarbon conduit and any heating line in the pipeline. The pipeline may optionally also include one or more other lines and/or any static insulation known in the art.

In this respect, it is remarked that subsea pipelines *per se* are known in the art, and there have been many arrangements used and suggested for such pipelines. Many include insulation and/or the passage of other fluids either concurrently and/or counter-currently with the gaseous hydrocarbon stream flow. Such arrangements include co-axial passages, conduits, lines, etc, and/or parallel lines, etc. Such arrangements also include 'bundling' a number of lines or conduits within one pipeline casing; see for example WO 02/053869 A1.

US 2004/0040716 A1 describes a method of actively heating hydrocarbon liquids contained in a hydrocarbon-transporting pipe-in-pipe flow line whose annulus contains thermally insulated material and/or a partial vacuum, by also passing hot water along the annulus. The hot water can be supplied from an above-surface hydrocarbon process facility. However, US 2004/0040716 does not involve a method of cooling a hydrocarbon stream, nor address the problem of handling excess process heat from a hydrocarbon cooling process.

Preferably, the or each heating line 90 is 'alongside' the or each hydrocarbon conduit by being near to, neighbouring, within, or in any other proximal, preferably close proximal, relationship to the hydrocarbon conduit of the pipeline, as long as heat from the heating line(s) has a thermal path to the hydrocarbon conduit(s).

The heating line 90 may comprise one or more lines, adapted to carry the heat equally or non-equally, in the pipeline.

The hydrocarbon conduit 12a may comprise one or more conduits, adapted to carry the gaseous hydrocarbon stream equally or non-equally in the pipeline.

If necessary or desired, one or more hydrate inhibiting fluids such as alcohol compounds, for example methanol, or glycol compounds, examples of which are MEG, PEG and TEG, could still be added to the pipeline at the seabed to assist the prevention of hydrate formation, although any such addition is done at a significantly reduced amount or rate compared with prior art methods relying solely on the use of glycol compounds to prevent hydrate formation.

At the surface end of the pipeline 12, a gas/liquid separator, for instance a slug catcher, may be provided to receive the gaseous hydrocarbon stream from conduit 12a and separate the gaseous hydrocarbons which may be fed into line 10 from any entrained condensate hydrocarbons, water phases (possibly containing hydrate inhibitors) and/or solids. Likewise, equipment known to the skilled person may be provided to pre-treat the gaseous hydrocarbon stream in line 10, which pre-treatment may comprise one or more of dehydration, acid component removal, notably CO_2 and H_2S, and mercury removal as needed and as known to the person skilled in the art.

In one embodiment of the present invention, heat for the gaseous hydrocarbon stream 10 flowing in pipeline 12 is at least partly provided by at least one downstream heat exchanger of a refrigerant circuit. A refrigerant circuit may comprise more than one downstream heat exchanger, from which heat could be provided for the present invention.

Figure 2 shows two possible sources of heat from the cooling system 22 for use to heat gaseous hydrocarbon stream 10 in the pipeline 12. Both arrangements involve a cooling stream 40 passing through an accumulator 38, an expander such as a valve 39, prior to passage through the cooling system 22 and outflow as a fully vapourised warmer cooling stream 30. The warmer cooling stream 30 passes through a compressor 36, which may be one or more compressors in series, parallel or a combination of same, prior to passage of its outflow stream through a downstream heat exchanger here represented as compressor cooler 24a, which may comprise one or more coolers in series, parallel or a combination of same.

In one arrangement, a first water stream 70b passes through one or more of the compressor coolers 24a, to take heat away from the compressed cooling stream and so provide a heated water stream 80b, whose heat could then be passed to the heating line 90 in the pipeline 12.

In a second alternative and/or additional arrangement, there is a driver 35 to drive the compressor 36. The driver 35 has an exhaust 37 for a hot exhaust stream therefrom, and in the path of the exhaust stream could be a second water stream 70a which is heated thereby, possibly to a temperature above 100°C, and so provide a second heated water stream 80a, which can be passed to the heating line 90 in the pipeline 12.

Thus, the arrangement shown in Figure 2 is able to use heat provided by warmer cooling stream 30 and/or the driver 35 hot exhaust stream, thereby increasing the efficiency of the combined operation and using heat which may otherwise be wasted or vented to atmosphere.

Figure 3 shows a more detailed scheme of Figure 1. In the same way, a gaseous hydrocarbon stream 10 from a wellhead 14 on a seabed 16 is provided through a central conduit 12a in a pipeline 12 to a ship 18. Similarly, a water intake stream 50 is provided through a receptacle 26, filter system 28, and pump 32 to provide a pumped stream 70.

Figure 3 shows three units on or in the ship 18, each one of which, or any combination of which, can be used for cooling and optionally pre-treating the hydrocarbon stream 10. Thus, the arrangement shown in Figure 3 is not limited to the combination of the units shown, or to the heat arrangements provided by each unit and discussed after herein.

Depending on the source, the gaseous hydrocarbon stream may contain varying amounts of hydrocarbons heavier than methane, such as ethane, propane, butanes and pentanes, as well as some aromatic hydrocarbons. The gaseous hydrocarbon stream may also contain non-hydrocarbons such as H_2O, N_2, CO_2, H_2S and other sulphur compounds, and the like.

The gaseous hydrocarbon stream may be pre-treated prior to cooling. This could be for example for the removal of carbon dioxide and optionally hydrogen sulphide and/or COS, such as by an acid gas removal system or unit. Many processes, methods and systems for reducing carbon dioxide/acid gas from a gaseous hydrocarbon stream are known in the art, including the use of organic solvents or aqueous solutions of organic solvents, and usually including chemical solvents and physical solvents. WO 03/057348 A1 describes a process for the removal of carbon dioxide and optionally hydrogen sulphide and/or COS from a gas stream containing these compounds by washing the gas with an aqueous washing solution of water, sulfolane and a secondary or tertiary amine derived from ethanol amine.

In such acid gas removal processes, systems and methods, heat can be generated either by one or more generators used to provide power to a device or unit of the system, or by the provision or creation of a heated stream, such as a carbon dioxide or acid gas exhaust stream at an above ambient temperature.

Such heat can be used to provide heat either directly or indirectly to the hydrocarbon stream in the pipeline.

Thus, in another aspect, the present invention provides a method of pre-treating a gaseous hydrocarbon stream such as natural gas in preparation for its cooling and/or liquefaction, the method at least comprising the steps of:

(a) providing a hydrocarbon stream from an underwater pipeline, optionally from a sea bed, to a hydrocarbon facility at sea, for instance in the form of a floating vessel;

(b) treating the hydrocarbon stream to reduce and/or remove one or more components from the gaseous hydrocarbon stream, and to provide a treated hydrocarbon stream and a heated stream;

(c) using the heat of the heated stream to heat the hydrocarbon stream in the underwater pipeline.

The treating may be provided by a treatment system, and may include any physical and/or chemical process or combination of processes to affect the nature or constituency of the gaseous hydrocarbon stream, including but not limited reducing and/or removing one or more components of the gaseous hydrocarbon stream.

A treatment system may also include one or more heat exchangers to exchange heat with the gaseous hydrocarbon stream, or to exchange heat with another stream.

Cooling of the hydrocarbon stream and/or any pre-treatment may also comprise or involve one or more units, apparatus or devices either producing heat, or requiring energy, including power generated by a generator. Such generators include electrical, turbine and other generators known in the art, which include motors and drivers. Such generators can act on compressors, pumps, separators, and the like, and their operation generally creates heat. Cooling and/or pre-treating may also create or provide a separate stream with heat desired to be extracted. Any or all of these sources of heat can be used directly or indirectly in the heating of the present invention.

In Figure 3, the gaseous hydrocarbon stream 10 first undergoes acid gas removal by passing through an acid gas removal (AGR) unit or system 52, which may be a separate or dedicated unit, or integrated with one or more other units or apparatus. The AGR system 52 provides a process for the removal of carbon dioxide and hydrogen sulphide and/or COS in a manner known in the art, for example one or more of the methods described in WO 03/057348 A1.

The AGR system 52 provides a treated stream 110, whilst one or more units, devices or heat exchangers in the AGR system 52 provides heat which can be passed by a heat transfer stream 120 into a first secondary heat exchanger 54, wherein its heat can be passed to the or a first fraction of the pumped stream 703 of clarified seawater, thus providing a first hotter water stream 70c which can be part or whole of the heated water stream 80 which can pass through an inlet 34 in the pipeline 12 and down a heating line 90 in a manner described hereinabove.

The treated hydrocarbon stream 110 can then pass into a first cooling stage 62 which may comprise part of a cooling system and/or liquefaction system. The first cooling stage 62 may comprise one or more heat exchangers in parallel and/or series, and is able to reduce the temperature of the treated hydrocarbon stream 110, preferably below 0 °C, and more preferably in the range -10 °C to -70 °C, and provide a cooled hydrocarbon stream 130.

The first cooling stage 62 may have any configuration known in the art, and generally includes one or more refrigerant circuits passing one or more refrigerants to provide cold or cold energy to the treated hydrocarbon stream 110. An example refrigerant circuit is a propane refrigerant circuit known in the art.

Figure 3 shows a first refrigerant circuit 140 passing through the first cooling stage 62, from which the refrigerant stream, expanded after providing its cooling to treated hydrocarbon stream 110, passes into a first stage compressor 66 for recompression. The first stage compressor 66 may comprise one or more compressors in series or parallel in a manner known in the art. Compression of the refrigerant usually increases the refrigerant temperature, such that it is commonly cooled by one or more downstream heat exchangers downstream of the first stage compressor 66, represented in Figure 2 by a second secondary heat exchanger 64. The downstream heat exchanger(s) may comprise one or more ambient water and/or air coolers known in the art.

In the arrangement shown in Figure 3, the pumped stream or a second fraction thereof 702 also passes through the second secondary heat exchanger 64 so as to receive heat from the compressed stream from the first stage compressor 66, and therefore be at least partly heated thereby and provide a second hotter water stream 70b, which can be part or whole of the heated water stream 80 for the heating line 90. The refrigerant from the heat exchanger 64 can pass through a valve prior to re-entry into the first cooling stage 62.

Figure 3 also shows the cooled hydrocarbon stream 130 passing through a second cooling stage 72, again comprising one or more heat exchangers in parallel and/or series and designed to further cool and/or liquefy the cooled hydrocarbon stream 130, to provide a further cooled hydrocarbon stream 150, which is preferably a liquefied hydrocarbon stream such as liquefied natural gas. The further cooled hydrocarbon stream 150 such as LNG can be passed into storage such as to one or more storage tanks (not shown) in the ship 18, or be passed through a further pipeline or conduit (not shown) to one or more storage tanks located elsewhere, such as on a land-based facility or other floating vessel.

As with the first cooling stage 62, the second cooling stage 72 may involve one or more refrigerant circuits having a refrigerant adapted to provide the further cooling to the cooled hydrocarbon stream 130. An example refrigerant circuit is a mixed refrigerant, and the second cooling stage could reduce the temperature of the cooled hydrocarbon stream 130 to below -100 °C, preferably below -150 °C.

Figure 3 shows a second refrigerant circuit 160, wherein expanded refrigerant from the second cooling stage 72 can pass through a second stage compressor 76 (which may comprise one or more compressors in parallel and/or series), and which compressed stream is usually then cooled by one or more downstream heat exchangers, for example ambient water and/or air coolers, represented in Figure 3 as a third secondary heat exchanger 74. The refrigerant stream in the second refrigerant circuit 160 then passes through the first cooling stage 62 in a manner known in the art, optionally a first passage through the second cooling stage for further cooling (not shown), prior to reaching a valve for expansion and reuse in the second cooling stage 72 in a manner known in the art.

The third secondary heat exchanger 74 may receive the pumped stream 70 or a third fraction thereof 701 so as to accept heat from the refrigerant stream (in the third secondary heat exchanger 74) of the second refrigerant circuit 160 after its compression, and provide a third hotter cooling stream 70a.

Heat to be provided to the pumped stream 70 to create the heated stream 80 may be provided by one or more, or any combination of, the AGR system 52 and the first and second cooling stages 62 and 72, and is not limited to the arrangement shown in Figure 3.

Thus, the final heated stream 80 can be provided by one or more of the hotter streams 70a, 70b, and 70c.

One or more of the AGR system 52 and the first and second cooling stages 62, 72 may include one or more generators such as gas turbines, to drive one or more devices, units or separators therein, such as, by way of example only, the first and second compressors 66, 76. Such generators may also provide at least some of the heat to the pumped stream 70 or a fraction thereof, either directly or indirectly.

Again, in Figure 3, the heated water stream 80 can then be passed directly into a heating line 90 through inlet 34 in the pipeline 12, so that the heat in the heated water stream 80 provides heat to the conduit 12a in the pipeline 12 carrying the gaseous hydrocarbon stream 10 from the wellhead 14. The arrangement shown in Figure 3 is able to use heat provided by one or more of the AGR system 52 and the first and second cooling stages 62, 72, thereby increasing the efficiency of the combined operation and using heat which may otherwise be wasted or vented to atmosphere.

The person skilled in the art will understand that the new invention can be carried out in many various ways without departing from the scope of the appended claims.

C L A I M S

1. A method of cooling a gaseous hydrocarbon stream, such as a natural gas stream, comprising at least the steps of:

(a) sourcing the gaseous hydrocarbon stream in an underwater pipeline to hydrocarbon facility at sea;

(b) cooling the gaseous hydrocarbon stream against one or more cooling streams by removing heat from the gaseous hydrocarbon stream, and so to provide a cooler hydrocarbon stream and one or more warmer cooling streams;

(c) using the heat of at least one of the warmer cooling stream(s) to heat the gaseous hydrocarbon stream being sourced in the pipeline.

2. A method as claimed in claim 1, wherein the cooling in step (b) includes a cooling stage to cool the hydrocarbon stream to below 0 °C.

3. A method as claimed in claim 1 or claim 2, wherein the cooling in step (b) includes a liquefaction stage to liquefy the hydrocarbon stream, and to provide a liquefied hydrocarbon stream, such as a liquefied natural gas stream.

4. A method as claimed in one or more of the preceding claims, wherein the cooling includes compressing the one or more cooling streams in at least one compressor and removing heat from the one or more cooling streams in at least one downstream heat exchanger.

5. A method as claimed in claim 4, wherein the heat in step (c) for the gaseous hydrocarbon stream being sourced in the pipeline is at least partly provided by at least one of the downstream heat exchanger(s).

6. A method as claimed in one or more of the preceding claims, wherein the gaseous hydrocarbon stream is pre-treated downstream of step (a) and prior to step (b), which treatment includes acid gas removal, and wherein the heat for the gaseous hydrocarbon stream being sourced in the pipeline is at least partly provided by the acid gas removal process.

7. A method as claimed in one or more of the preceding claims, wherein the heat for the gaseous hydrocarbon stream being sourced in the pipeline is supplied to the pipeline in the form of a heated water stream.

8. A method as claimed in claim 7, wherein at least part of the heated water stream is provided by heat exchange of a water stream or a fraction thereof with at least one of the warmer cooling stream(s).

9. A method as claimed in claim 7, wherein at least part of the heated water stream is provided by heat exchange between a water stream or a fraction thereof and a heat transfer fluid, the heat transfer fluid carrying at least a fraction of the heat removed from the at least one of the warmer cooling stream(s).

10. A method as claimed in one or more of the preceding claims, wherein the pipeline extends between one or more wellheads on a seabed and the hydrocarbon facility at sea.

11. The method as claimed in one or more of the preceding claims, wherein the hydrocarbon facility at sea is a floating vessel.

12. Apparatus for cooling a gaseous hydrocarbon stream, such as natural gas stream, the apparatus at least comprising:

an underwater pipeline to a hydrocarbon facility at sea for sourcing the gaseous hydrocarbon stream to the hydrocarbon facility;

a cooling system to cool the gaseous hydrocarbon stream against one or more cooling streams, and so provide a cooler hydrocarbon stream and one or more warmer cooling streams; and

a heating line to pass the heat of at least one of the warmer cooling stream(s) to the gaseous hydrocarbon stream in the pipeline.

13. Apparatus as claimed in claim 12, wherein the cooling system includes a cooling stage and a liquefaction stage for liquefying the gaseous hydrocarbon stream.

14. Apparatus as claimed in claim 12 or claim 12, wherein the hydrocarbon facility at sea is a floating vessel.

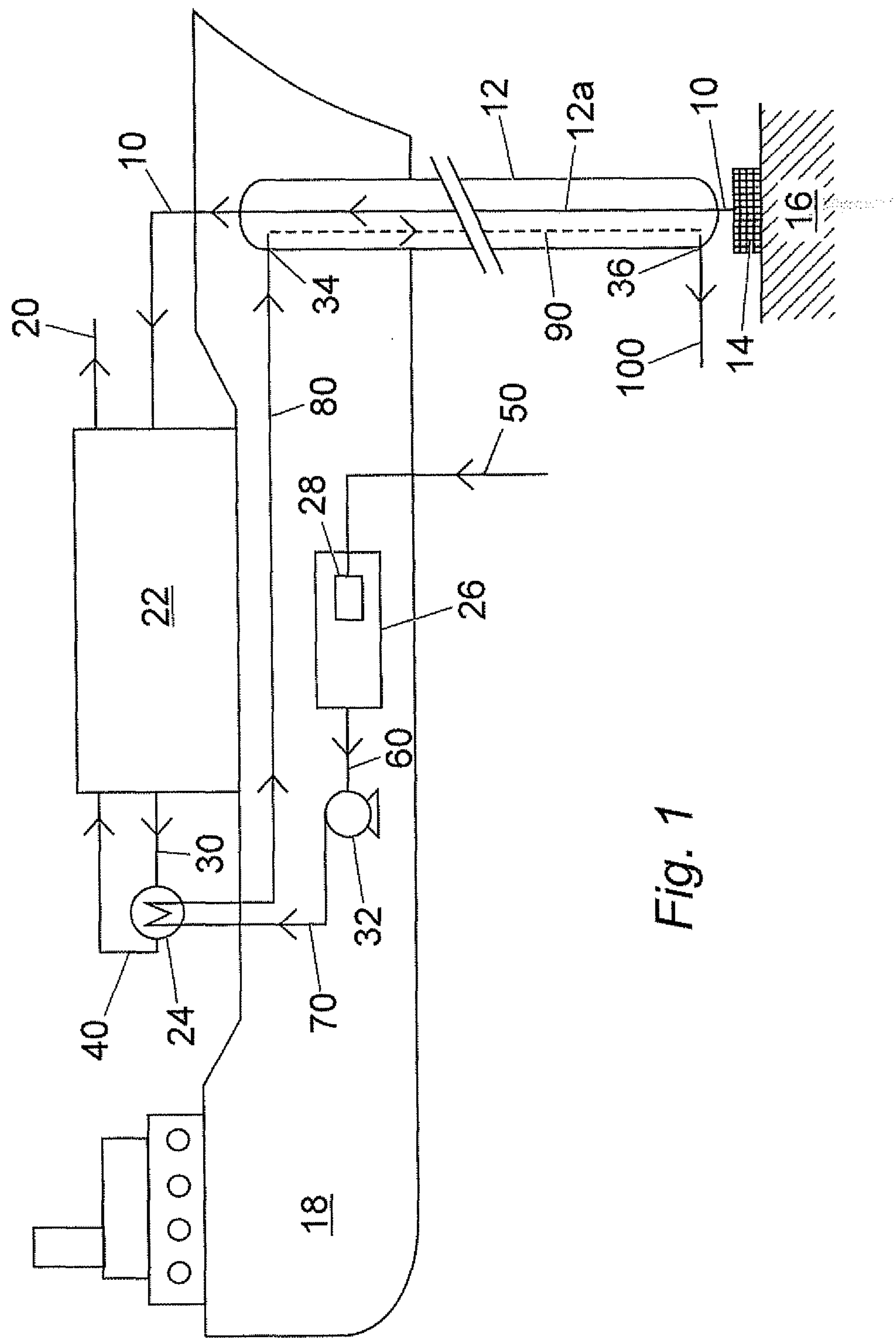

Fig. 1

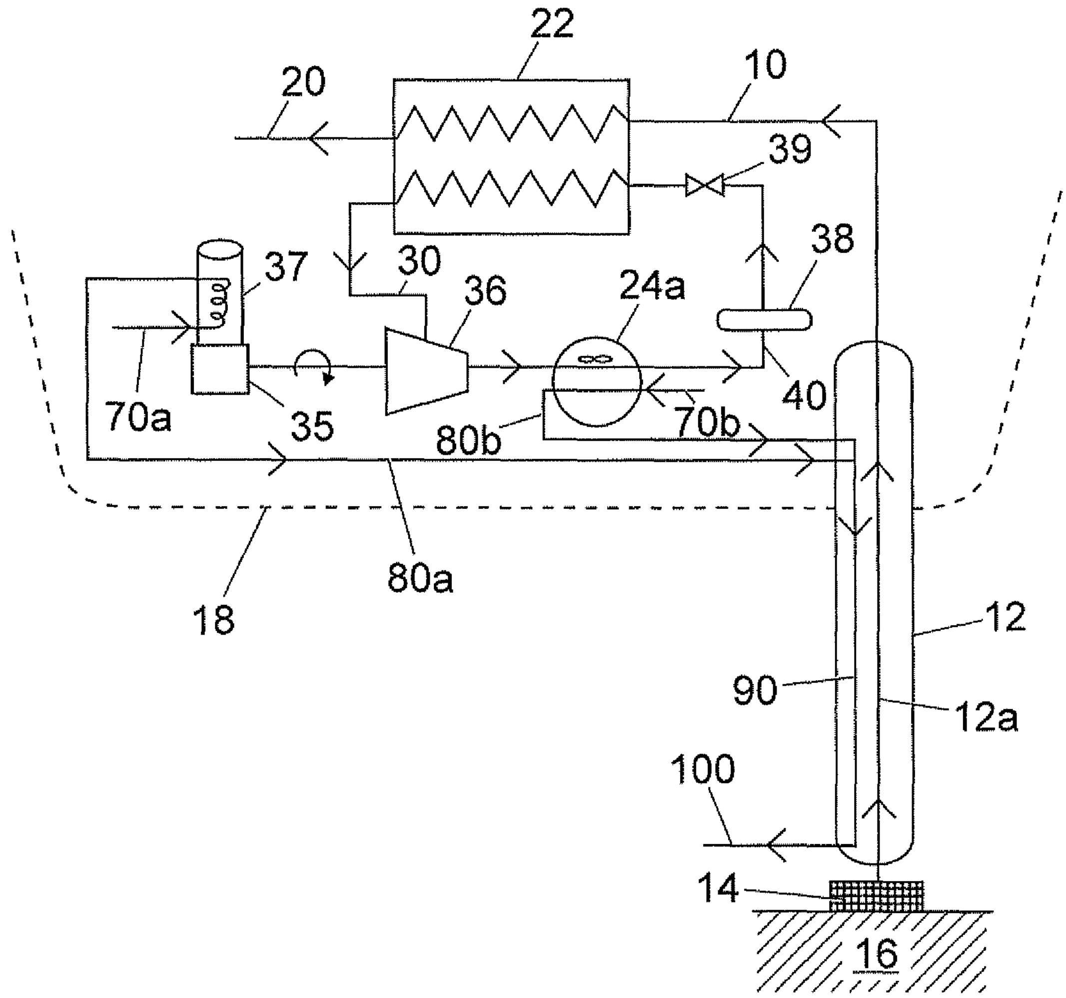
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Fig. 2

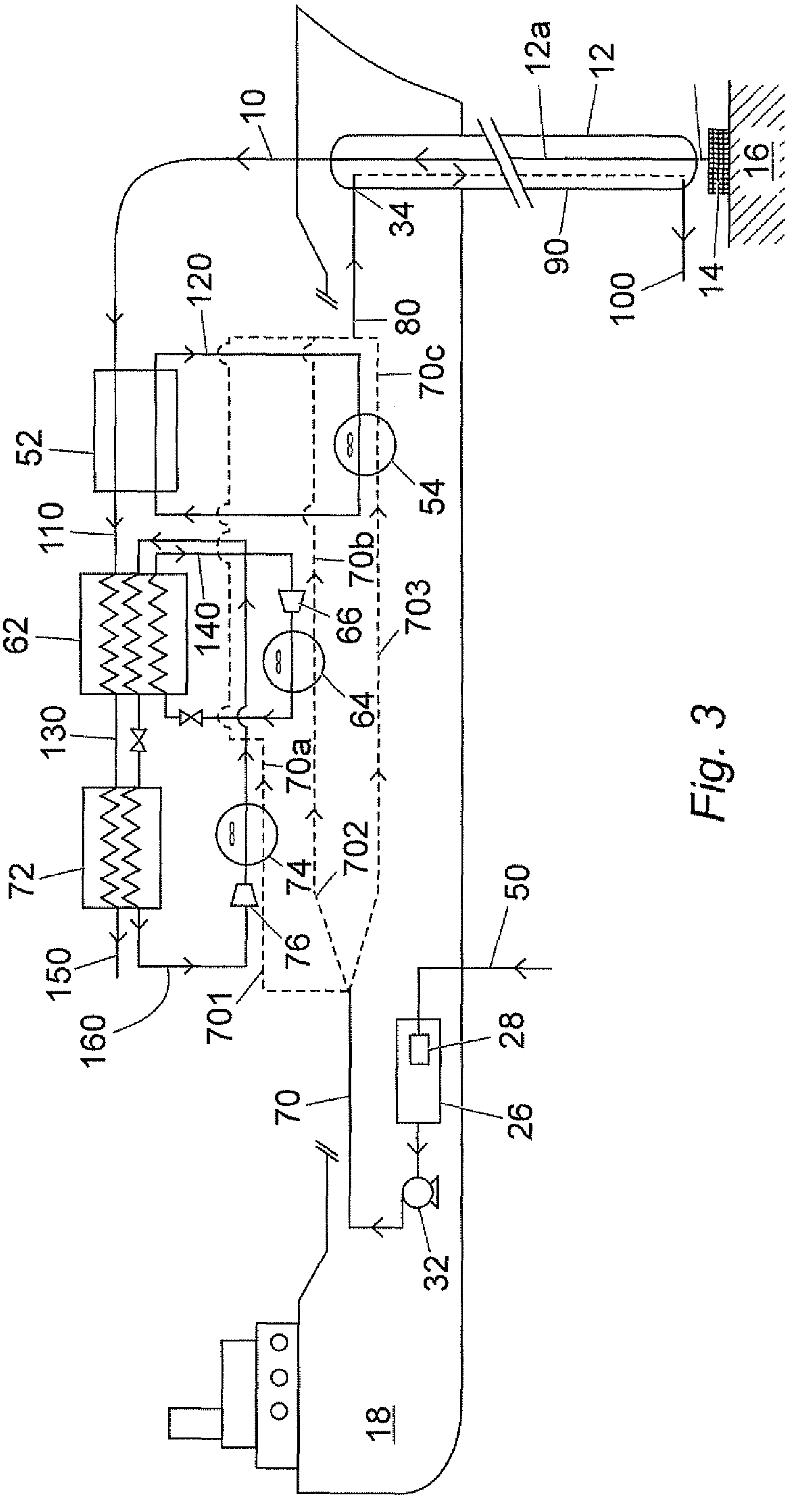
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Fig. 3