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(54) **Method of protecting a flexible riser and an apparatus therefor**

(57) The present invention provides a method of protecting one or more flexible risers which can carry a riser fluid, for instance a hydrocarbon production fluid such as natural gas, to or from a floating structure and an apparatus therefor, said method comprising at least the steps of:

(a) providing a floating structure (100), one or more flexible risers (10), each of said flexible risers carrying a riser fluid and having a first end (20) connected to the floating

structure(100) and a second end (30) on the sea bed (500) and in fluid connection with one or more riser fluid reservoirs (250);

(b) closing the fluid connection between the one or more flexible risers (10) and the one or more riser fluid reservoirs (250);

(c) replacing at least a portion of the riser fluid in one or more of the flexible risers (10) with a protection fluid, wherein the density of said protection fluid is greater than the density of said riser fluid.

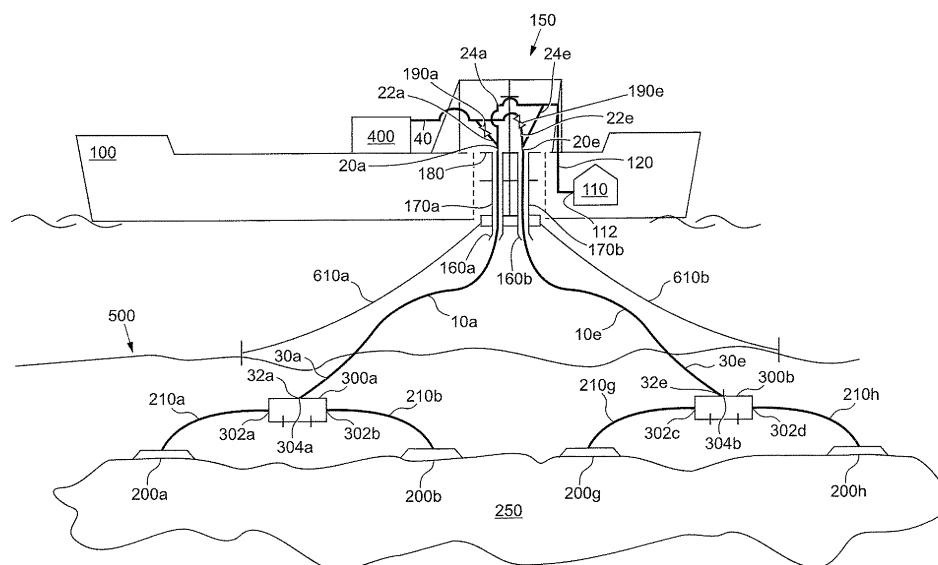


Fig. 2

Description

[0001] The present invention provides a method of protecting one or more flexible risers which can carry a riser fluid, for instance a hydrocarbon production fluid such as natural gas, to or from a floating structure and an apparatus therefor. In particular, the method disclosed herein seeks to protect the flexible risers from buckling caused by the heave and/or the pitch of the floating structure in response to wave motion in severe weather conditions.

[0002] The Floating Liquefaction of Natural Gas (FLNG) concept combines the natural gas treatment, liquefaction process, storage tanks, loading systems and other infrastructure into a single floating structure. Such a structure is advantageous because it provides an offshore alternative to on-shore liquefaction plants. A FLNG vessel can be moored close to or at a gas field, in waters deep enough to allow off-loading of the LNG product onto a carrier vessel. It also represents a movable asset, which can be relocated to a new site when the gas field is nearing the end of its productive life, or when required by economic, environmental or political conditions.

[0003] The floating structure can be in fluid communication with the producing well heads of the reservoir. The floating structure can be connected to one or more flexible risers. The flexible risers can be secured to the sea bed by a riser base manifold. A subsea flowline can connect the riser base manifold directly to the well heads or optionally via a well manifold.

[0004] In such a configuration, a production hydrocarbon, such as natural gas, from a hydrocarbon reservoir, such as a gas field, can be passed along a sub sea pipeline from one or more well-heads, which can be in the same or different hydrocarbon reservoirs, to the riser base manifold. The riser base manifold is the point at which the production and any injection pipelines are connected to the flexible risers which convey the production hydrocarbon to the floating structure. The flexible risers are connected to the floating structure at a hangoff point. The hang-off point may be at a side of the floating structure, or situated within a moonpool in the floating structure, for example at the bottom of a turret. The floating structure can be moored to the sea bed by a plurality of mooring lines which are anchored to the sea bed.

[0005] The flexible risers are flexible pipes suspended between the floating structure and riser base manifold, and can be configured as free-hanging catenaries or alternative configurations using buoyancy modules such as lazy wave and lazy S types. A detailed discussion of flexible risers can be found in the American Petroleum Institute's publication titled "Specification for unbonded pipe", API Specification 17J, Second edition, effective date December 2002.

[0006] A discussion of flexible riser operation can be found in the American Petroleum Institute's publication titled "Recommended Practice for Flexible Pipe", API Recommended Practice 17B, Third Edition, March 2000.

[0007] When the vertical motion of the hangoff point

from the floating structure is severe, such as in heavy seas, compressive forces can arise in the flexible risers which can cause global buckling. The compressive forces are even more severe in those cases in which the hangoff point is distanced from the centre of motion of the floating structure because one or both of the heave and pitch of the structure is correspondingly amplified.

[0008] The paper titled "Guidelines for compression modelling in flexible risers for deepwater applications" by McCann et al, Offshore Technology Conference 5-8 May 2003, OTC 15168, identifies the problem of riser buckling associated with compressive loading due to severe heave in Floating Production Storage and Offloading Vessels (FPSO), which can be moored in hostile environments. During downward heave and/or pitch, the riser is said to attempt to follow the applied motion of the structure. As the riser displaces through the water column, drag forces act opposite to the direction of motion, retarding the motion of the riser. The motion of the floating vessel is therefore translated into a reduction in effective tension. When the riser enters compression, it relies upon cross sectional bending stiffness to limit curvature. However, the cross sectional bending stiffness of the riser is small in comparison with the distances and forces involved.

[0009] The present invention seeks to address the problem of riser buckling during severe heave and/or pitch of the floating structure caused by extreme weather conditions.

[0010] In a first aspect, the present invention provides a method of protecting one or more flexible risers in a sub sea environment, comprising at least the steps of:

- (a) providing a floating structure, one or more flexible risers, each of said flexible risers carrying a riser fluid and having a first end connected to the floating structure and a second end on the sea bed and in fluid connection with one or more riser fluid reservoirs;
- (b) closing the fluid connection between the one or more flexible risers and the one or more riser fluid reservoirs;
- (c) replacing at least a portion of the riser fluid in one or more of the flexible risers with a protection fluid, wherein the density of said protection fluid is greater than the density of said riser fluid.

[0011] The forces experienced by the flexible riser in the water can most easily be understood by considering the movement of a free flexible riser. Downward motion of a flexible riser in water will occur under gravitational acceleration. As the velocity increases, the restoring drag force increases until it matches the gravitational acceleration and the flexible riser reaches terminal velocity. At the terminal velocity, the acceleration of the flexible riser is balanced by the restoring drag force such that:

$$V_{Term} = \sqrt{\frac{2 \cdot m \cdot g}{C_d \cdot \rho \cdot D_{drag}}}$$

wherein m is mass of the flexible riser, including internal fluid, g is gravity, C_d is normal drag coefficient, D_{drag} is the drag diameter, ρ is the water density and V_{Term} is the terminal velocity.

[0012] When a flexible riser is constrained, such that it is attached at a first end to a floating structure on the surface of the water and at a second end on the sea bed, vertical motion of the flexible riser can result from the heave and/or pitch of the floating structure in response to the water motion on the surface.

[0013] Damage to flexible risers may occur when the terminal velocity of the flexible riser in the sea water is exceeded by the velocity of the first end of the riser where it is connected to the floating structure. This point of connection is also called the hang-off point. When the downward velocity of the flexible riser at the hang-off point due to the heave and/or pitch of the floating vessel (the "hang-off velocity") is greater than the terminal velocity of the flexible riser in the water, the riser will come under compression. Such compressive stresses can lead to buckling and permanent damage to the flexible riser.

[0014] Compressive stress in the flexible riser can also be viewed as negative riser tension. Interpreted mathematically, the possibility of buckling can occur when the ratio of the downward hang-off velocity of the riser to the terminal velocity of the riser in the water exceeds 1. Compression modelling therefore allows the prediction of potential riser buckling for particular structure heave and/or pitch, riser type and the distance of the hang-off point from the centre of motion of the structure.

[0015] By filling at least a portion of a riser with a protection fluid, which has a higher density than the riser fluid, the apparent weight of the riser is increased. This leads to an increase in the terminal velocity of the riser in water. By increasing the terminal velocity of the riser, higher hangoff velocities can be accommodated without riser buckling. This means that larger vertical heave and/or pitch can be tolerated by the flexible riser before compression and riser buckling may occur. The flexible risers carrying protection fluid can therefore survive more severe weather conditions, and in particular increased wave heights, compared to those which have not been at least partly filled with protection fluid.

[0016] In a further aspect, the present invention provides an apparatus for protecting one or more flexible risers in a sub sea environment, said apparatus comprising at least:

- a floating structure comprising a protection fluid storage tank, said protection fluid storage tank comprising an outlet for a protection fluid stream;
- one or more flexible risers, each of said flexible risers

having a first end connected to said floating structure, said first end in direct fluid communication with a first end connection for a riser fluid stream and an inlet for the protection fluid stream in fluid communication with the outlet of the protection fluid storage tank, said inlet being separate from said first end connection, and each of said flexible risers having a second end on the sea bed, said second end having a second end connection for a riser fluid transfer stream in fluid communication with one or more riser fluid reservoirs.

[0017] Embodiments of the present invention will now be described by way of example only, and with reference to the accompanying non-limiting drawings in which:

Figure 1 shows a first embodiment of a typical method and apparatus scheme according to the invention. Figure 2 shows a second embodiment of a typical method and apparatus scheme according to the invention.

[0018] 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, streams or lines.

[0019] Figure 1 shows a cut-through section of a first method and apparatus 1 for the protection of one or more flexible risers 10, particularly during severe weather conditions. The flexible risers convey a riser fluid between one or more riser fluid reservoirs 250 underneath the sea bed and a floating structure 100 on the sea surface. Thus, the risers can be sub sea risers. As used herein, the term "sub sea" is intended to encompass both salt water and fresh water environments, and represents the region between the water surface and the bed of the body of water.

[0020] Thus, the floating structure 100 can be a floating vessel, or an off-shore floating platform. A floating vessel may be any movable or moored vessel, generally at least having a hull, and usually being in the form of a ship such as a 'tanker'.

[0021] Such floating vessels can be of any dimensions, but are usually elongated. Whilst the dimensions of a floating vessel are not limited at sea, building and maintenance facilities for floating vessels may limit such dimensions. Thus, in one embodiment of the present invention, the floating vessel or off-shore floating platform is less than 600m long such as 500m, and a beam of less than 100m, such as 80m, so as to be able to be accommodated in existing ship-building and maintenance facilities.

[0022] An off-shore floating platform may also be movable, but is generally more-permanently locatable than a floating vessel.

[0023] The method and apparatus of the invention are for instance advantageous for applications in deep water, such as water depths greater than 200 m, for instance 250 to 500 m, or greater than 1000 m.

[0024] In one embodiment, the riser fluid is a hydrocarbon fluid such as natural gas, and the one or more riser fluid reservoirs 250 are hydrocarbon fluid reservoirs such as natural gas reservoirs. In this embodiment, the hydrocarbon fluid would be conveyed from the hydrocarbon fluid reservoirs 250 under the sea bed 500 to the floating structure 100, where the hydrocarbon fluid can be stored and preferably treated. When the hydrocarbon fluid is natural gas it is preferred that the floating structure 100 comprises natural gas treatment and/or liquefaction units such that the natural gas can be treated to remove unwanted impurities and cooled to provide liquefied natural gas. This will be discussed in more detail in relation to Figure 2.

[0025] In an alternative embodiment, the method and apparatus disclosed herein can be used for carbon dioxide sequestration.

[0026] Many hydrocarbon reservoirs, such as natural gas reservoirs may contain carbon dioxide, for instance in contents of 6-10%. This carbon dioxide could be separated in the floating structure from the hydrocarbon fluid, such as natural gas, removed from the reservoir, and then re-injected into the a riser fluid reservoir. 250. The riser fluid reservoir can be any sealed subsurface geological formation such as a hydrocarbon reservoir, a depleted hydrocarbon reservoir, an aquifer or other sealed water containing layer. In this case, the riser fluid can comprise carbon dioxide, preferably as a dense phase, such as supercritical carbon dioxide i.e. carbon dioxide having a pressure and temperature above the critical point. In contrast to the previous embodiment, the riser fluid comprising carbon dioxide would for instance be conveyed from a separation unit on the floating structure 100 to the one or more depleted hydrocarbon reservoirs 250 under the sea bed 500, where the riser fluid comprising carbon dioxide can be stored.

[0027] In a further alternative embodiment, also illustrating a carbon dioxide sequestration method, the riser fluid comprising carbon dioxide passed to the riser fluid reservoir 250 can come from any source. For example, the carbon dioxide may be generated at a location different from the floating structure 100, such as an on-shore location, and transferred to the floating structure 100 for sequestration underneath the sea bed. The riser fluid and riser fluid reservoir 250 may be as defined in the previous embodiment.

[0028] For maximum benefit of the invention, it is preferred that the density of the riser fluid is less than 0.9 g/cm³, more preferably less than 0.7 g/cm³, still more preferably less than 0.5 g/cm³.

[0029] In the exemplary embodiment of Figure 1, the floating structure 100 is a floating vessel. The floating vessel is held in position by a plurality of mooring lines 610 which are connected to the floating vessel at a mooring point and maintain the mooring point of the floating vessel in a fixed position. Figure 1 shows a trigonal arrangement of three bundles 620a, 620b, 620c of mooring lines, each bundle comprising four mooring lines 610a,

b, c, d. The mooring lines 610 are fastened securely to sea bed 500, for instance using anchor piles.

[0030] The one or more flexible risers 10 may be provided as free-hanging catenaries or in alternative configurations using buoyancy modules such as lazy wave and lazy S types. Each flexible riser 10 has a first end 20 connected to the floating vessel 100. Figure 1 shows eight flexible risers 10 a-h, arranged in first and second riser bundles of four, connected to the floating vessel 100 at first ends 20 a-h respectively.

[0031] The flexible risers 10 a-h each have a second end 30 a-h on the sea bed 500. The second ends 30 a-h of the flexible risers 10 a-h need not be in direct contact with the sea bed 500. It is preferred that the second ends 30 a-h of the flexible risers are adapted to be secured to the sea bed 500. In the embodiment shown in Figure 1, the second ends 30 of the flexible risers are connected to two riser base manifolds 300. Second ends 30 a-d of the first riser bundle are connected to first riser base manifold 300a, while second ends 30 e-h of the second riser bundle are connected to second riser base manifold 300b. The riser base manifolds 300 are fastened securely to sea bed 500, for instance using fixed piles. In this way, the first and second ends 20, 30 of the flexible risers 10 are secured to the floating vessel 100 and sea bed 500 respectively.

[0032] The riser base manifolds 300 provide a fluid connection between the flexible risers 10 and one or more riser fluid transfer streams 210. The one or more riser fluid transfer streams convey the riser fluid between the riser base manifolds 300 and the riser well heads 200. Figure 1 shows first riser base manifold 300a connected to four well heads 200 a-d via an optional well head manifold 220a. Four riser fluid transfer streams 210 a-d connect well heads 200 a-d to the well head manifold 220a. Two further riser fluid transfer streams 210 i, j connect the well head manifold 220a to the riser base manifold 300a. Similarly, second riser base manifold 300 is connected to four well heads 200 e-h via an optional well head manifold 220b. Four riser fluid transfer streams 210 e-h connect well heads 200 e-h to the well head manifold 220b. Two further riser fluid transfer streams 210 l, m connect the well head manifold 220 b to the riser base manifold 300b. The well heads 200 are in fluid communication with the one or more riser fluid reservoirs 250 which lie beneath the sea bed 500.

[0033] In this way, riser fluid such as a hydrocarbon fluid can be conveyed from one or more hydrocarbon reservoirs 250 to the floating vessel 100. Similarly, a riser fluid comprising carbon dioxide can be conveyed from the floating vessel 100 to the one or more riser fluid reservoirs for carbon sequestration.

[0034] The mooring lines 610 are intended to maintain the mooring point of the floating vessel 100 in a fixed position. However, the mooring lines 610, which may be steel chains, allow a degree of movement such that the mooring point of the floating vessel 100 can move in response to wave motion, such as the heave and/or pitch

of the floating vessel 100.

[0035] Under severe weather conditions, the wave motion may become so significant that the one or more flexible risers are in danger of buckling. As previously discussed, riser buckling may occur when the terminal velocity of the riser in the sea water is exceeded by the hang-off velocity of the first end 20 of the riser 10 where it is connected to the floating structure 100.. When the downward velocity of the riser at the hang-off point due to the heave and/or pitch of the floating vessel 100 is greater than the terminal velocity of the flexible riser in the water, the riser will come under compression. Such compressive stresses can lead to buckling and permanent damage to the flexible riser.

[0036] The method and apparatus disclosed herein seeks to alleviate the problem of riser damage during severe weather conditions. In particular, at least a portion of the riser fluid, such as a hydrocarbon fluid or a carbon dioxide comprising fluid, in one or more of the flexible risers 10 is replaced with a protection fluid. The density of the protection fluid is greater than the density of the riser fluid, such that the mass of the fluid in the riser 10 is increased for an equivalent fluid volume. Increasing the mass of the fluid in the riser increases the overall mass of the riser (i.e. the mass of the riser plus fluid contents). Increasing the overall mass of the riser increases the terminal velocity of the riser in the water. This means that greater hang-off velocities can be tolerated by the flexible riser before the terminal velocity is exceeded. Greater hang-off velocities correspond to higher heave and/or pitch at the hang-off point, such that more extreme sea conditions can be tolerated.

[0037] It is preferred that the density of the protection fluid is greater than 0.9 g/cm^3 , more preferably greater than 1.0 g/cm^3 , still more preferably greater than 1.1 g/cm^3 . The greater density of the protection fluid compared to the riser fluid, the greater the terminal velocity increase of the flexible riser upon substitution of the riser fluid for the protection fluid. The greater the increase in the terminal velocity of the flexible riser, the greater the hang-off velocity which can be withstood without compressing the flexible riser. Thus, it is preferred that the difference in density between the protection fluid and the riser fluid is at least 0.2 g/cm^3 , more preferably at least 0.4 g/cm^3 , even more preferably at least 0.6 g/cm^3 .

[0038] Examples of suitable protection fluids are one or more of the group comprising monoethylene glycol and hydrocarbon condensate. These fluids are particularly useful as protection fluids in the case where the riser fluid is a hydrocarbon fluid. The floating vessel 100 can comprise one or more hydrocarbon treatment units, such as a separation unit, for instance a low pressure gas/liquid separator, to provide hydrocarbon condensate from a hydrocarbon riser fluid. The hydrocarbon fluid is preferably in stabilised form. Thus, a store of hydrocarbon condensate may be present in the floating vessel, for instance in a condensate storage tank. In those cases where the hydrocarbon condensate has a density greater

than the riser fluid, for example if the riser fluid is an unprocessed hydrocarbon stream, such as a natural gas stream, the store of hydrocarbon condensate can comprise one source of protection fluid.

[0039] In an alternative embodiment, in some cases where the riser fluid is hydrocarbon fluid, it may be necessary to inject a hydrate inhibitor, such as monoethylene glycol (MEG), into the hydrocarbon fluid. For instance, the hydrate inhibitor can be injected to the hydrocarbon fluid at or before it emerges from the well heads 200 to prevent hydrate formation in the riser fluid transfer streams 210 and the flexible risers 10. In this case, the floating vessel 100 could comprise a hydrate inhibitor storage tank, such as a MEG storage tank. The floating vessel 100 may also comprise a hydrate inhibitor regeneration unit, to separate the hydrate inhibitor from the riser fluid.

[0040] In those cases where the hydrate inhibitor has a density greater than the riser fluid, the store of hydrate inhibitor can comprise one source of protection fluid. In one embodiment, a MEG storage tank is provided having a capacity such that 15-20% of the tank capacity of MEG can completely fill all of the flexible risers 10 with protection fluid. In such a case, it is preferred to maintain a minimum content of MEG in the tank of 15-20% to ensure that sufficient MEG is available to provide maximum protection (i.e. completely fill) to each of the flexible risers 10.

[0041] It is preferred that the one or more flexible risers 10 are filled with protection fluid from the first end connected to the floating structure 100. This allows the protection fluid to be stored on the floating structure 100.

[0042] Preferably, a portion of the riser fluid in each of the one or more flexible risers 10 is replaced with the protection fluid. In this way, all of the flexible risers 10 may be protected from damage during adverse weather conditions. Still more preferably, the portion of the riser fluid replaced with the protection fluid is the same in each riser. This is advantageous because the same mass is added to each riser. For identical risers, each riser will thus have the same terminal velocity in the sea water and therefore exhibit similar dynamic behaviour.

[0043] It is not advisable to replace different portions of the riser fluid with protection fluid in each flexible riser, because different risers will exhibit different dynamic behaviour, which can lead to collisions between adjacent flexible risers in response to movement of the floating structure 100.

[0044] It is particularly preferred to completely replace all of the riser fluid in the flexible riser with protection fluid. In the case where each riser was initially completely filled with riser fluid, this would lead to completely filling each flexible riser with protection fluid. In doing so, a maximum gain for the overall riser mass using the method disclosed herein is achieved. This maximises the terminal velocity of the flexible riser in sea water. Consequently, the severity of the weather conditions which can be withstood by the flexible risers is increased.

[0045] In order to carry out the method disclosed here-

in, a decision must be taken to replace at least a portion of the riser fluid with protection fluid in one or more of the flexible risers. Thus, the method may comprise the further step of:

- monitoring the weather conditions in a zone around the floating structure 100 for one or more measured weather variables and carrying out steps (b) and (c) when said one or more measured weather variables meet predetermined criterion or criteria.

The zone around the floating structure 100 should be of a size sufficient to allow the method disclosed herein to be carried out before the arrival of the adverse weather conditions at the floating structure 100. For instance, the zone may be 200 km around the floating structure 100, and more preferably 500 km around the floating structure 100 to allow sufficient time to replace the riser fluid with protection fluid.

[0046] The adverse weather conditions are evaluated using one or more weather variables. The one or more weather variables include one or both of wind speed and wave height.

[0047] It is preferred that the predetermined criterion or criteria is indicative or predictive of a situation in which the hangoff velocity of the first end 20 of the flexible riser 10 approaches the terminal velocity of the flexible riser 10 in operation i.e. when filled with riser fluid.

[0048] The predetermined criterion can be selected from wind speeds in excess of 60 ms^{-1} . For instance, wind speeds in the range of $70\text{--}74 \text{ ms}^{-1}$ are indicative of a 10000 year cyclone.

[0049] Alternatively the predetermined criterion can be selected from significant wave heights. For instance the predetermined criterion can be 16 m or greater significant wave height. The significant wave height is for instance the wave height which is exceeded by 2/3 of the waves during a storm.

[0050] Once the severe weather has passed, the flexible risers 10 can be returned to normal operation. Thus, the method may comprise the further steps of:

- (d) opening the fluid connection between the one or more flexible risers 10 and the one or more riser fluid reservoirs 250;
- (e) passing the protection fluid from the one or more of the flexible risers 10 to the floating structure 100 as a spent protection fluid stream; and
- (f) treating the spent protection fluid stream on the floating structure 100 to regenerate the protection fluid.

Although it is possible to provide a dedicated unit for the treatment of the spent protection fluid on the floating structure 100, it is preferred if the spent protection fluid can be processed by a unit already present for the treatment of the riser fluid. For instance, when the riser fluid is a hydrocarbon fluid which has been treated with a hy-

drate inhibitor, the spent protection fluid, which will be rich in hydrate inhibitor such as MEG, but may also contain a small amount of hydrocarbon fluid not displaced from the flexible riser, can be sent to the hydrate inhibitor treatment unit for processing. This procedure may result in a plug of hydrate inhibitor, such as MEG, requiring processing. If this plug of hydrate inhibitor exceeds the capacity of the inlet facilities, which can be designed to process the hydrate inhibited hydrocarbon fluid, the flow rate to the inlet facilities can be reduced until all the spent protection fluid rich in hydrate inhibitor is processed. After the plug of spent protection fluid has been processed by the inlet facilities of the floating structure 100, normal production can be resumed.

[0051] Figure 2 provides a further schematic for the method and apparatus disclosed herein, and in particular shows the connectivity of the first and second ends 20, 30 of the flexible risers 10 to the sea bed 500 and floating structure 100. For the purposes of clarity, the numbers of mooring lines 610a, e and flexible risers 10a, 10e have been reduced to two each, although any number, such as 4-6 arranged in two or more separate bundles is envisaged.

[0052] The flexible risers 10a, 10e have first ends 20a, 20e connected to the floating structure 100, which is shown as vessel in Figure 2. The first ends 20 a, e of the flexible risers are secured to the floating vessel 100 at a turret 150. The turret 150 is connected to the sea bed 500 by the mooring lines 610a, 610b.

[0053] The floating vessel 100 is provided with one or more bearings allowing the rotation of the vessel around the turret 150. In this way, the floating vessel may weather-vane around the earth-fixed turret, such that the vessel may be orientated to present the bow to the direction of the prevailing weather conditions, such as the incoming wave or wind. In a preferred embodiment, the turret 150 is provided towards an end of the floating vessel 100, to allow optimal rotation in response to the prevailing weather conditions. This allows processing units 400, such as a natural gas treatment and liquefaction unit, which is discussed in greater detail below, to be placed behind the turret 150 along the deck of the floating vessel.

[0054] The turret 150 comprises one or more bending stiffeners 160a, b which route the flexible risers 10a, e through one or more l-tubes 170a, b to a hang-off deck 180. The hang-off deck 180 secures the first end 20 a, e of each of the flexible risers 10a, e.

[0055] The first end 20 a, e of each of the flexible risers 10a, e is in fluid communication with a first end connection 22a, 22e for the first riser fluid stream 40. The first ends 20 a, e can be in communication with the first end connections 22 a, e via a turret piping connection. Each first end connection 22a, 22e for the riser fluid stream 40 is connected to a riser emergency shutdown valve 190a, e. An inlet 24a, 24e for the protection fluid stream 120, which is in fluid communication with the outlet 112 of a protection fluid storage tank 110, is also in fluid communication with the first end 20 a, e of each flexible riser 10

a, e. It is apparent from Figure 2 that the inlets 24a, 24e for the protection fluid stream 120 are separate from the first end connections 22a, 22e for the first riser fluid stream 40. Rotating pipe connections in a swivel stack allow the riser fluid stream 40 and protection fluid stream 120 to pass between the turret 150 and the rest of the floating structure 100. Thus a constant fluid connection is maintained even when the floating vessel is rotating around the turret 150.

[0056] The protection fluid stream 120 can be passed to each first inlet 22a, g and on to the first ends of the flexible risers 10a, e. By filling the flexible risers 10a, e from their first ends, the protection fluid can displace at least a portion of the riser fluid in one or more of the flexible risers. The displaced riser fluid, which is less dense than the protection fluid, will be forced upwards as the flexible risers 10a, e fill with protection fluid such that the riser fluid can exit the risers at first ends 20 a, e, passing out of first end connection 24a, e, which can be an outlet. The riser fluid can be passed to the processing units 400 as the riser fluid stream 40.

[0057] The second end 30a, 30e of each flexible riser 10a, e is on the sea bed 500. Each second end comprises a second end connection 32a, e which is in fluid communication with a riser fluid transfer stream 210a, b, g, h. The riser fluid transfer streams 210a, b, g, h are in fluid communication with one or more riser fluid reservoirs 250. In a preferred embodiment, the second end 30a, e of each flexible riser 10a, e is secured to the sea bed 500 by connection to a riser base manifold 300a, b. The riser base manifold 300a, b is rigidly fixed to the sea bed 500.

[0058] The riser base manifolds 300a, b comprise first manifold connections 302a, b, c, d to the riser fluid transfer streams 210a, b, g, h. Second manifold connections 304a, b are connected to the second end connections 32a, e of the flexible risers 10a, e.

[0059] In the embodiment of Figure 2, the riser fluid transfer streams 210 may be natural gas transfer streams. The one or more riser fluid reservoirs 250 can be natural gas reservoirs. The riser fluid stream 40 can be a natural gas stream. In this case, the natural gas reservoirs 250 may be connected to the riser fluid transfer streams 210 via well heads 200a, b, g, h.

[0060] Figure 2 shows a natural gas treatment and liquefaction unit 400 on the floating structure 100. This unit can be used for the pre-treating and cooling of the riser fluid when this is natural gas. The arrangement discussed below is exemplary only and is not limited to the combination of the units described. Other, alternative line-ups will be known to the skilled person.

[0061] Usually a natural gas stream 40 is comprised substantially of methane. Preferably the natural gas stream comprises at least 50 mol% methane, more preferably at least 80 mol% methane.

[0062] Depending on the source, natural gas may contain varying amounts of hydrocarbons heavier than methane such as in particular ethane, propane and the butanes, and possibly lesser amounts of pentanes and ar-

omatic hydrocarbons. The composition varies depending upon the type and location of the gas.

[0063] Conventionally, the hydrocarbons heavier than methane are removed as far as efficiently possible from the natural gas stream prior to any significant cooling for several reasons, such as having different freezing or liquefaction temperatures that may cause them to block parts of a methane liquefaction plant.

[0064] The natural gas stream can first undergo acid gas removal by passing through an acid gas removal (AGR) unit or system, which may be a separate or dedicated unit, or integrated with one or more other units or apparatus. The AGR system 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.

[0065] The AGR system provides a treated natural gas stream. The treated natural gas stream can then pass into a first cooling stage which may comprise part of a cooling system and/or liquefaction system. The first cooling stage may comprise one or more heat exchangers in parallel and/or series, and is able to reduce the temperature of the treated natural gas stream, preferably below 0 °C, and more preferably in the range -10 °C to -70 °C, and provide a cooled natural gas stream.

[0066] The first cooling stage 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. An example refrigerant circuit is a propane refrigerant circuit known in the art.

[0067] A first refrigerant circuit can pass through the first cooling stage, from which the refrigerant stream, expanded after providing its cooling to treated hydrocarbon stream, passes into a first stage compressor for recompression. The first stage compressor 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 heat exchangers downstream of the first stage compressor. The downstream heat exchanger(s) may comprise one or more ambient water and/or air coolers known in the art.

[0068] The cooled natural gas stream can pass through a second cooling stage, again comprising one or more heat exchangers in parallel and/or series and designed to further cool and/or liquefy the cooled natural gas stream, to provide a further cooled natural gas stream, which is preferably a liquefied natural gas stream. The further cooled natural gas stream can be passed into storage such as to one or more storage tanks, or be passed through a further pipeline or conduit to one or more storage tanks located elsewhere, such as on a land-based facility or other floating vessel. The other floating vessel may be an LNG carrier.

[0069] As with the first cooling stage, the second cooling stage may involve one or more refrigerant circuits having a refrigerant adapted to provide the further cooling

to the cooled natural gas stream. An example refrigerant circuit is a mixed refrigerant, and the second cooling stage could reduce the temperature of the cooled natural gas stream to below -100 °C, preferably below -150 °C.

[0070] In the second cooling circuit, expanded refrigerant from the second cooling stage can pass through a second stage compressor (which may comprise one or more compressors in parallel and/or series), to provide a compressed stream which is usually then cooled by one or more downstream heat exchangers, for example ambient water and/or air coolers. The refrigerant stream in the second refrigerant circuit can then pass through the first cooling stage in a manner known in the art, optionally with a first passage through the second cooling stage for further cooling, prior to reaching a valve for expansion and reuse in the second cooling stage in a manner known in the art.

[0071] One or more of the AGR system and the first and second cooling stages 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.

[0072] The person skilled in the art will understand that the present invention can be carried out in many various ways without departing from the scope of the appended claims.

Claims

1. A method of protecting one or more flexible risers (10) in a sub sea environment, comprising at least the steps of:
 - (a) providing a floating structure (100), one or more flexible risers (10), each of said flexible risers carrying a riser fluid and having a first end (20) connected to the floating structure (100) and a second end (30) on the sea bed (500) and in fluid connection with one or more riser fluid reservoirs (250);
 - (b) closing the fluid connection between the one or more flexible risers (10) and the one or more riser fluid reservoirs (250);
 - (c) replacing at least a portion of the riser fluid in one or more of the flexible risers (10) with a protection fluid, wherein the density of said protection fluid is greater than the density of said riser fluid.
2. The method according to any of the preceding claims wherein in step (c) the protection fluid displaces at least a portion of the riser fluid in one or more of the flexible risers (10), such that the displaced riser fluid exits at a first end connection (22), which is an outlet in direct fluid communication with the first end (20) of the flexible riser (10).
3. The method according to claim 1 or claim 2 wherein said riser fluid comprises carbon dioxide and said one or more riser fluid reservoirs (250) are sealed subsurface geological formations; said method further comprising, between steps (a) and (b), the step of:
 - passing the riser fluid comprising carbon dioxide from the floating structure (100) through at least the one or more flexible risers (10) to the one or more sealed subsurface geological formations (250).
4. The method according to claim 1 or claim 2 wherein said riser fluid is a hydrocarbon production fluid and said one or more riser fluid reservoirs (250) are hydrocarbon reservoirs; said method further comprising, between steps (a) and (b), the step of:
 - passing the hydrocarbon production fluid from the one or more hydrocarbon reservoirs (250) through at least the one or more flexible risers (10) to the floating structure (100).
5. The method according to any of the preceding claims wherein the protection fluid has a density of greater than 0.9 g/cm³, preferably greater than 1.0 g/cm³, more preferably greater than 1.1 g/cm³.
6. The method according to claim 4 or claim 5 wherein the protection fluid is selected from one or more of the group comprising monoethylene glycol and hydrocarbon condensate.
7. The method according to any of the preceding claims wherein in step (c) the one or more of the flexible risers (10) are filled with protection fluid from the first end (20) connected to the floating structure (100).
8. The method according to any one of the preceding claims, wherein the riser fluid is a hydrocarbon production fluid and the one or more riser fluid reservoirs (250) are hydrocarbon sub sea reservoirs, and further comprising the step of treating the hydrocarbon production fluid on board the floating structure (100) to provide a liquefied hydrocarbon stream.
9. An apparatus (1) for protecting one or more flexible risers (10) in a sub sea environment, said apparatus comprising at least:
 - a floating structure (100) comprising a protection fluid storage tank (110), said protection fluid storage tank comprising an outlet (112) for a protection fluid stream (120);
 - one or more flexible risers (10), each of said flexible risers having a first end (20) connected to said floating structure (100), said first end (20)

in direct fluid communication with a first end connection (22) for a riser fluid stream (40) and an inlet (24) for the protection fluid stream (120) in fluid communication with the outlet (112) of the protection fluid storage tank (110), said inlet (24) being separate from said first end connection (22), and each of said flexible risers (10) having a second end (30) on the sea bed (500), said second end having a second end connection (32) for a riser fluid transfer stream (210) in fluid communication with one or more riser fluid reservoirs (250).

10. The apparatus according to claim 9 wherein the second end (30) of the flexible riser (10) is connected to a riser base manifold (300) which is rigidly fixed to the sea bed, said riser base manifold having a first manifold connection (302) for the riser fluid transfer stream (210) and a second manifold connection (304) connected to the second end connection (32) of the flexible riser (10).
11. The apparatus according to claim 9 or claim 10 wherein the first end (20) of the flexible riser (10) is connected to the floating structure (100) at a turret comprising one or more bending stiffeners (160) to route the one or more flexible risers (10) through one or more l-tubes (170) to a riser hang-off deck (180) where the first end (20) of each of said flexible risers (10) is secured, with the first end connection (22) for the riser fluid stream being connected to a riser emergency shutdown valve (190).
12. The apparatus according to any one of claims 9 to 11 in which the riser fluid transfer stream (210) is a natural gas transfer stream, the one or more riser fluid reservoirs (250) are natural gas reservoirs, the riser fluid stream is a natural gas stream and the floating structure (100) further comprises one or both of a natural gas treatment unit and a liquefaction unit

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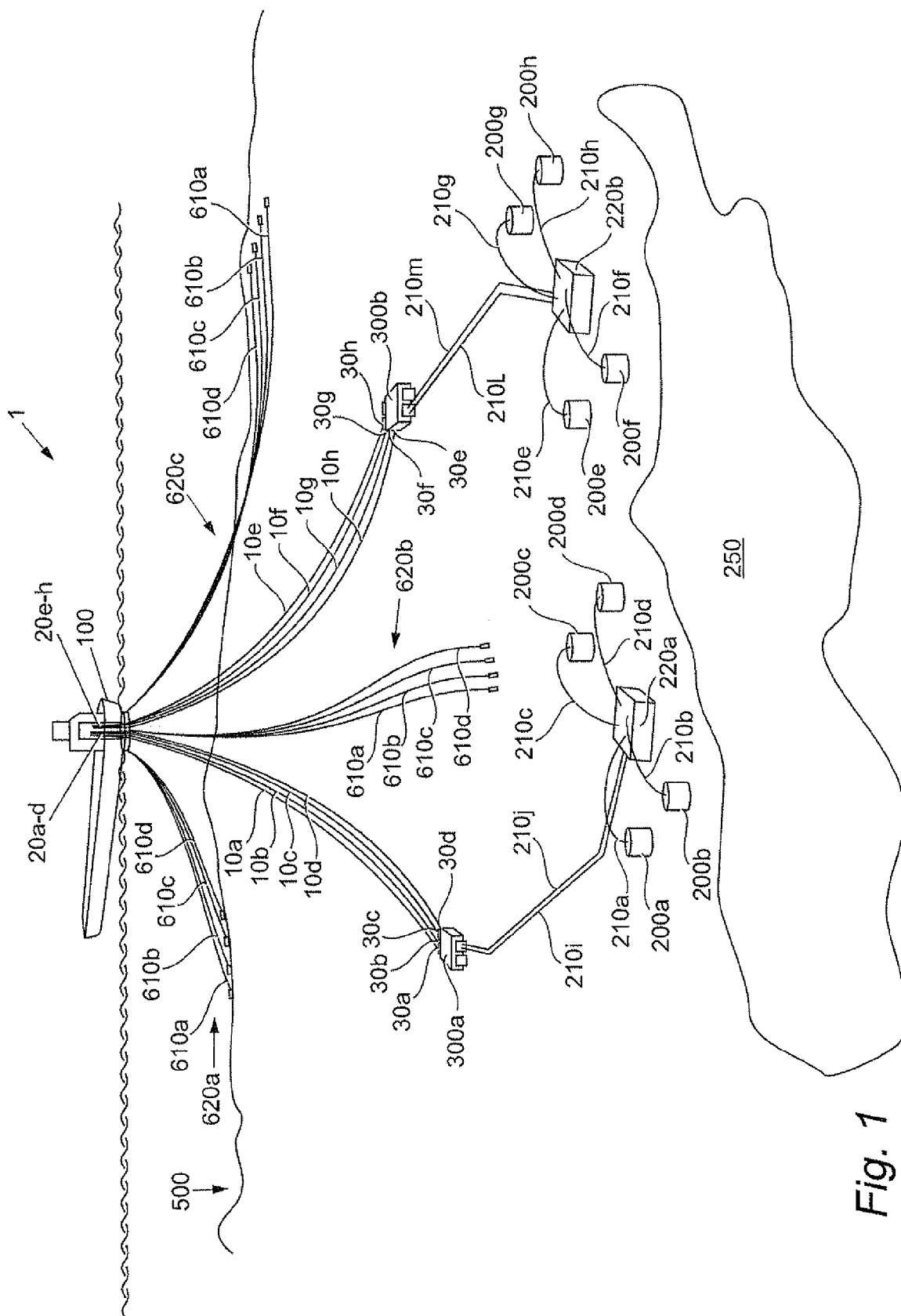


Fig. 1

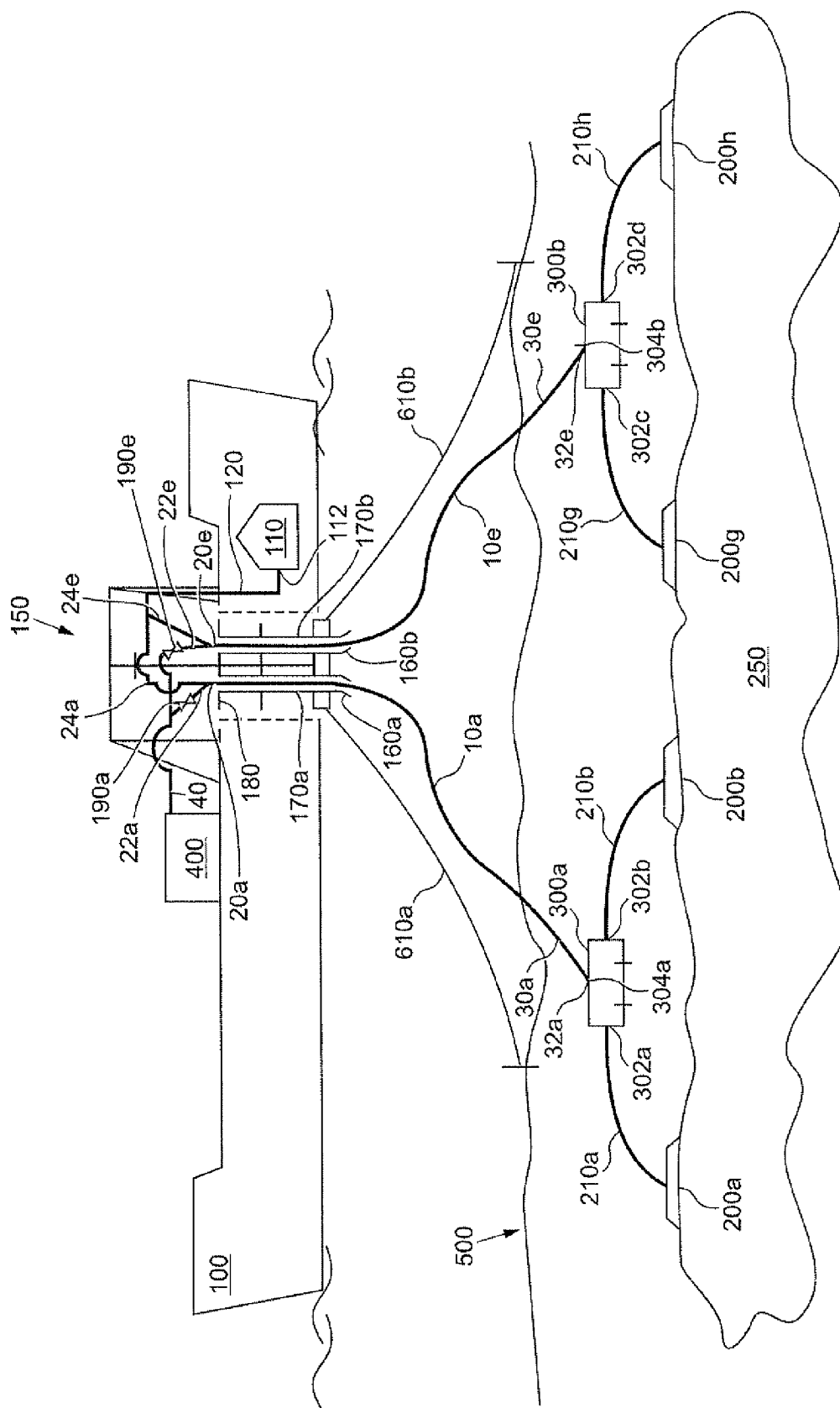


Fig. 2



EUROPEAN SEARCH REPORT

Application Number
EP 09 16 0763

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Place of search The Hague		Date of completion of the search 21 October 2009	Examiner Dantinne, Patrick
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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21-10-2009

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