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(54) Waved steel production riser, offshore hydrocarbon production system, and method of producing a hydrocarbon stream

(57) A waved steel production riser (100), which in addition to a primary buoyancy section (103) wherein the waved steel production riser is provided with a first set of external buoyancy modules (130) and an upward buoyancy force in the body of water is greater than a downward gravity force, further comprises an auxiliary buoyancy section (106) in the hanging section (102) in which the waved steel production riser is provided with a second set of external buoyancy modules (120) and wherein the upward buoyancy force in the body of water is smaller than the downward gravity force. The sag point (125) is located within the auxiliary buoyancy section. The waved steel production riser may be used in a method for producing a hydrocarbon stream, whereby mineral hydrocarbon fluids produced from a subsea hydrocarbon reservoir are conveyed to a floating structure via the waved steel production riser.

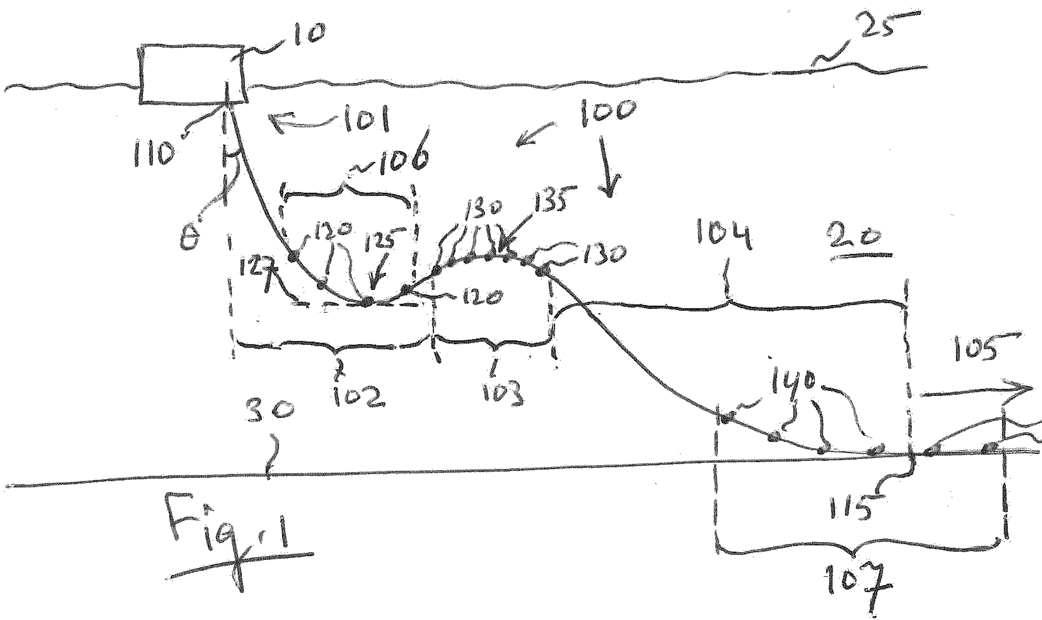

Fig. 1

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Description

[0001] The present invention relates to a waved steel production riser. In a further aspect, the present invention relates to an offshore hydrocarbon production system provided with such a waved steel production riser. In another aspect the present invention relates to a method of producing a hydrocarbon stream.

[0002] A waved steel production riser is a steel riser, typically formed out of a string of pipes made out of steel, arranged to convey mineral hydrocarbon fluids produced from a subsea hydrocarbon reservoir to a floating structure such as a floating production platform, a floating production storage and offloading (FPSO) structure, a semi-submersible.

[0003] The steel production risers under consideration in the present disclosure are configured along a waved path. A segment of the length along the riser is provided with a set of external buoyancy modules to create a primary buoyancy section wherein an upward buoyancy force on the riser in the body of water is greater than a downward gravity force. As a result, part of the riser is raised in the water thereby an upwardly convex curved section (so-called hog bend or arch bend) is typically be formed in the primary buoyancy section. The primary buoyancy section lifts up parts of the riser adjacent to the primary buoyancy section as well, whereby a downwardly convex section (so-called sag bend) can form hanging between the floating structure and the primary buoyancy section. This causes the waved configuration which characterizes the waved steel production risers.

[0004] The use of waved steel production risers, steel lazy wave risers and steel steep wave risers in particular, as such has already been proposed in the past for connecting a floating structure to a pipeline or well head located under water on a seabed.

[0005] The lazy wave riser and the steep wave riser are two distinct types of waved production riser. They have in common that they both comprise a primary buoyancy section. The characterizing difference between these types is that in the case of the lazy wave configuration the production riser touches down on the seabed in a downwardly convex curve whereby in the touchdown point the riser is in tangential alignment with the seabed, whereas the steep wave riser touches down at a pronounced non-tangent angle (typically vertical or near-vertical). It is noted that the presence of both a hog and a sag bend distinguish a waved production riser from, for instance, a so-called steel catenary riser or a shaped steel catenary riser. The shaped steel catenary riser also has a buoyancy section, similar to the primary buoyancy section and which also changes the trajectory of the riser in the body of water, but the amount of buoyancy is not enough to raise the buoyancy section high enough to form actual hog and arch bends.

[0006] The hog and sag bends in waved steel production risers help to decouple the touchdown point from horizontal and vertical motion of the floating structure as a result of factors such as wind, currents, waves and tides.

[0007] The dynamic response of deepwater lazy wave catenary risers has been subject of a paper by Songcheng Li and Chau Nguyen, presented at Deep Offshore Technology (DOT) International conference (Amsterdam, 30 November to 2 December 2010). The paper describes behavior of lazy wave risers with respect of a variety of input parameters, such as critical curvature radii, hang-off angle, top tension and buoyancy distribution. Some of these parameters are mutually coupled whereby a change in one of the parameters incurs a change in one or more of the other parameters.

[0008] It turns out that the hang-off angle, which is the inclination of the waved steel production riser in the hang-off point where the riser is suspended from the floating structure, is subject to a certain minimum. Attempts to lower the hang-off angle beyond the minimum may result in excessive curvature around the bends (e.g. the sag bend) causing bending stress beyond tolerance.

[0009] In a first aspect of the present invention, there is provided a waved steel production riser, comprising a string of pipes made out of steel, which string of pipes is suspended from a floating structure into a body of water above a seabed, on which body of water the structure floats, wherein at a hang-off end of the production riser the string of pipes is connected to the floating structure in a hang-off point, and wherein, as described along the string of pipes starting from the hang-off point, the waved steel production riser comprises a hanging section, a primary buoyancy section wherein the waved steel production riser is provided with a first set of external buoyancy modules causing an upward buoyancy force on the primary buoyancy section in the body of water that is greater than a downward gravity force in the primary buoyancy section, and a landing section extending between the buoyancy section and a first point of contact with the seabed, wherein a vertical riser plane is defined, which contains both the hang-off point and the first point of contact and extends parallel to a vertical direction, wherein the hanging section hangs between the floating structure and the primary buoyancy section whereby a downwardly convex curved section is formed in the hanging section, whereby a sag point is defined in the downwardly convex curved section there where the waved steel production riser has a tangent in a horizontal direction and parallel to the vertical plane, wherein the waved steel production riser further comprises an auxiliary buoyancy section in the hanging section whereby the sag point is located within the auxiliary buoyancy section whereby part of the auxiliary buoyancy section is located between the hang-off point and the sag point, in which auxiliary buoyancy section the waved riser is provided with a second set of external buoyancy modules and wherein the upward buoyancy force in the body of water is smaller than the downward gravity force.

[0010] There is also provided an offshore hydrocarbon production system, comprising a floating structure floating on a body of water above a seabed, and a waved steel production riser according to any aspect of the present invention suspended from said floating structure into said body of water.

[0011] In another aspect there is provided a method of producing a hydrocarbon stream, comprising conveying mineral hydrocarbon fluids produced from a subsea hydrocarbon reservoir to a floating structure via a steel production riser in accordance with the first aspect of the invention, and processing the mineral hydrocarbon fluids on the floating structure whereby forming the hydrocarbon stream out of the mineral hydrocarbon fluids.

[0012] The invention will be further illustrated hereinafter by way of example only, and with reference to the nonlimiting drawing in which:

Fig. 1 schematically shows a not-to-scale side view of an offshore hydrocarbon production system including a steel lazy wave riser;

Fig. 2 schematically shows a not-to-scale side view of an offshore hydrocarbon production system including a steel steep wave riser; and

Fig. 3 schematically shows a side view of a pull-in tube with a male tool part engaged into a receptacle.

Same reference numbers refer to similar components. The person skilled in the art will readily understand that, while the invention is illustrated making reference to one or more a specific combinations of features and measures, many of those features and measures are functionally independent from other features and measures such that they can be equally or similarly applied independently in other embodiments or combinations.

[0013] A waved steel production riser is presently proposed, which in addition to a primary buoyancy section wherein the waved steel production riser is provided with a first set of external buoyancy modules and an upward buoyancy force in the body of water is greater than a downward gravity force, further comprises an auxiliary buoyancy section in the hanging section in which the waved steel production riser is provided with a second set of external buoyancy modules and wherein the upward buoyancy force in the body of water is smaller than the downward gravity force, whereby the sag point is located within the auxiliary buoyancy section.

[0014] Such auxiliary buoyancy section may be advantageously applied on steel lazy wave risers as well as on steel steep wave risers. In the case of a steel lazy wave riser, the lazy wave riser may comprise a similar type of auxiliary buoyancy section extending at least to a point between the primary buoyancy section and the touchdown section, in which the lazy wave riser is provided with a third set of external buoyancy modules and wherein the upward buoyancy force in the body of water is smaller than the downward gravity force. This may be instead of the auxiliary buoyancy section configured in the hanging section as described herein, or in addition to the auxiliary buoyancy section configured in the hanging section as described herein. The (additional) buoyancy section between the primary buoyancy section and the touchdown section may be referred to as additional auxiliary buoyancy section, regardless of whether or not the lazy wave riser has the auxiliary buoyancy section configured in the hanging section.

[0015] It has been found that the auxiliary buoyancy section helps to reduce the curvature in the sag and hog bends for a given hang-off angle. As a result, the curvature is a less constraining factor and the hang-off angle may be reduced to a point where the curvature is back to where it was before adding the auxiliary buoyancy section(s). Similarly, any additional auxiliary buoyancy section extending from the touchdown section into the landing section of a lazy wave riser helps to reduce curvature in the touchdown point and the hog bend.

[0016] The sets of external buoyancy modules each comprise a plurality of external buoyancy modules. The external buoyancy modules in any of the first, second, and third set, may be embodied in distributed buoyancy configuration, whereby distinct external buoyancy modules are attached to the riser with a selected spacing between successive adjacent external buoyancy modules. This includes a so-called full coverage configuration, whereby the spacing is zero or close to zero and the successive adjacent external buoyancy modules are configured in a physically abutting configuration.

[0017] The term "hang-off angle" refers to an angle of inclination of the lazy wave riser at the hang-off point. This corresponds to an angle of excursion from the vertical, of the tangential direction of the riser in the hang-off point.

[0018] The term "gravity force" in any named section of the waved steel production riser refers to the downward force exerted by gravity on the mass of the production riser in the section, normalized to a unit of length, including contents of the production riser and any external buoyancy modules. Contents include the fluids that are being conveyed through the production riser, typically from the seabed to the floating structure. Preferably, these fluids comprise mineral hydrocarbon fluids produced from a subsea hydrocarbon reservoir.

[0019] The term "upward buoyancy force" in any named section of the waved steel production riser refers to the upward force imposed on the production riser within the section by the weight of water from the body of water that is displaced by that section of the production riser (including the riser pipes and the external buoyancy modules), normalized to the same unit of length.

[0020] The upward buoyancy force on the (additional) auxiliary buoyancy section is generally lower than the upward buoyancy force on the primary buoyancy section. This can be achieved for instance by selecting external buoyancy modules in the second and third sets that per external buoyancy module have less buoyancy than the external buoyancy modules in the first set (per module). This may be achieved by selecting buoyancy modules with higher density and/or smaller volume for use in the second and/or third set than those for use in the first set. Alternatively, or in addition thereto, the spacing between successive adjacent external buoyancy modules in the second set and/or in the third set may be selected larger than the spacing between successive adjacent external buoyancy modules in the primary buoyancy section. In this case, the external buoyancy modules in the second and/or third sets can be exact copies of those employed in the first set.

[0021] The waved steel production riser according to the present invention can be used on any type offshore hydrocarbon production system on any type of floating structure. Examples of floating structure include a floating production platform, a floating production storage and offloading (FPSO) structure, a semi-submersible structure, and a SPAR. A tension leg platform (TLP) may also be considered a floating structure on which the steel production riser of the invention can be beneficial. A floating liquefied natural gas (FLNG) barge is a special example of FPSO, and it contains process equipment and utilities by which natural gas can be produced from a subsea reservoir, treated, and finally cooled down to produce liquefied natural gas (LNG) at a pressure of less than 2 bar absolute.

[0022] Fig. 1 shows an offshore hydrocarbon production system including a waved steel production riser 100 embodied in the preferred form of a steel lazy wave riser. The system comprises a floating structure 10, which floats on the surface 25 of a body of water 20, above a seabed 30. The waved steel production riser 100 is suspended from the floating structure 10, into the body of water 20. The waved steel production riser 100 is generally constructed in the form of a string of pipes made out of steel. The waved steel production riser 100 extends all the way to the seabed 30. At a hang-off end of the waved steel production riser 100, generally indicated at 101, the string of pipes is connected to the floating structure 10 in a hang-off point 110.

[0023] In the example as shown in Fig. 1, the waved steel production riser 100 is a steel lazy wave riser. Seen from the floating structure 10, and as described along the string of pipes starting from the hang-off point 110, the waved steel production riser 100 comprises:

- a hanging section 102;
- a primary buoyancy section 103, wherein the waved steel production riser 100 is provided with a first set of external buoyancy modules 130;
- a landing section 104, extending between the primary buoyancy section 103 and a first point of contact 115 with the seabed 30; and
- a touchdown section 105 wherein the pipes rest on the seabed 30. The touchdown section 105, as seen from the hang-off point 110, is distal from a touchdown point which coincides with the first point of contact 115. The touchdown section 105 is not present in a steep wave riser, as is illustrated in Fig. 2. However, in the case of a steep wave riser additional subsea infrastructure is usually provided such as a subsea base 116.

[0024] Regardless of the type of waved riser, the totality of the external buoyancy modules 130 in the first set cause an upward buoyancy force on the primary buoyancy section 103 within the body of water 20, that is greater than a downward gravity force in the primary buoyancy section 103. Therefore, within the primary buoyancy section 103 the steel lazy wave riser 100 floats. The primary buoyancy section 103 generally does not reach the surface 25 of the body of water as it is pulled down by the hanging section 102 and the landing section 104.

[0025] The hanging section 102 hangs between the floating structure 10 and the primary buoyancy section 103. A downwardly convex curved section is formed in the hanging section 103. A sag point 125 is defined in the lowest point on the downwardly convex curved section, there where the waved steel production riser has a tangent 127 in a horizontal direction and parallel to an imaginary vertical plane, which spans between the hang-off point 110 and the first point of contact 115.

[0026] The waved steel production riser 100 further comprises an auxiliary buoyancy section 106 within the hanging section 102. The sag point 125 is located within the auxiliary buoyancy section 106. Part of the auxiliary buoyancy section 106 is located between the hang-off point 110 and the sag point 125, and part is located between the sag point 125 and the buoyancy section 103. In the auxiliary buoyancy section 106, the waved steel production riser 100 is provided with a second set of external buoyancy modules 120. Some of these external buoyancy modules 120 of the second set are located between the hang-off point 110 and the sag point 125, and some other of these external buoyancy modules 120 of the second set are located between sag point 125 and the primary buoyancy section 103.

[0027] As a result of the external buoyancy modules 120 in the second set, the upward buoyancy force of the auxiliary buoyancy section 106 in the body of water 20 is larger than the upward buoyancy force of the production riser would have been if it were made out of the same steel but without any external buoyancy modules. However, with the second set of external buoyancy modules 120 the upward buoyancy force of the auxiliary buoyancy section 106 in the body of water 20 is smaller than the downward gravity force. The fact that the upward buoyancy force is kept smaller than the downward gravity force is a distinct difference of the auxiliary buoyancy section 106 compared to the primary buoyancy section 103.

[0028] The upward buoyancy force in the body of water within the auxiliary buoyancy section 106 of the production riser 100 is preferably selected between 40% and 99% of the downward gravity force in the same section. At 99% the riser section is considered neutrally buoyant for practical purposes. More preferably the upward buoyancy force in the body of water within the auxiliary buoyancy section 106 of the production riser 100 is selected between 40% and 90% of the downward gravity force in the same section. The range of between 40% and 90% is preferred over the range between 90% and 99% in order to keep some strain on the hanging section of the production riser. Still more preferably, the upward buoyancy force in the body of water within the auxiliary buoyancy section 106 of the production riser 100 is selected between 50% and 90% of the downward gravity force in the same section, and most preferably between 60% and 90% of the downward gravity force in the same section. This is generally achieved by purposely selecting the spacing between the external buoyancy modules in the first set and/or their sizes. Thus, most preferably the spacing between the external buoyancy modules in the first set and/or their sizes are sized such that the pipe weight is reduced to between 10% and 40% of the bare pipe weight including its contents. The amount of auxiliary buoyancy that is needed depends on various geometric factors and constrains. These geometric factors and constraints may include the outer diameter of the pipes that make up the waved steel production riser 100, the desired hang-off angle θ, and the minimum bending radius that can be imposed on the waved steel production riser 100. The auxiliary buoyancy section 106 for instance helps to reduce the curvature in the sag and hog bends for a given hang-off angle θ, or to reduce the hang-off angle θ for a given curvature.

[0029] In one case, it was calculated for a production riser having an outer diameter of about 305 mm (12 inch) that an upward buoyancy force in the body of water within the auxiliary buoyancy section 106 of the waved steel production riser 100 had to be about 80% of the downward gravity force in the same section, to achieve a hang-off angle θ of just below 5°.

[0030] A hang-off angle of less than 5° is preferred, as this would facilitate a standardized hang-off design at the floating structure 10, for instance using the vertical pull-in tubes for all of the waved steel production risers regardless of their azimuthal orientation relative to the floating structure 10 or their radial reach away from the floating structure 10. Such pull-in tubes may be installed on a turret or directly on the floating structure 10. The turret may form a non-weathervaning part of the floating structure 10, to which a weathervaning part of the floating structure 10 can be moored with freedom to rotate about the turret in accordance with a vertical axis of rotation. With larger hang-off angles, a turret design may need slanted I-tubes that are inclined at the riser hang-off angle, or J-tubes having a slanted lower part, which therefore cannot be standardized.

[0031] A pull-in tube, as illustrated in Fig. 3, generally comprises a rigidly mounted receptacle tube 113, into which a male tool part 114 at the top of the production riser at the hang-off end 101 can slidingly engage. The male tool part 114 may be connected to the production riser via an interface connector 118. The pull-in tube is preferably straight and vertically aligned. The lower end 112 of the receptacle tube 113, facing the production riser 100, may be provided with a funnel shape to guide any pull in head with the male tool part 114 into the receptacle 113. Figure 3 illustrates how the waved steel production riser 100 may be configured in the straight vertically aligned pull-in tube at the hang-off point.

[0032] Suitably the first and/or second sets of external buoyancy modules are provided in distributed buoyancy configuration. Each of the modules may consist of parts (usually two halves provided with an internal recess) and a clamping system that can be clamped around the pipes in the production riser. The parts suitably comprise a syntactic foam. Suitable external buoyancy modules are available from a variety of vendors. One example is Balmoral Offshore Engineering, Aberdeen, Scotland. Reference is made to pages 29-31 of a Balmoral Offshore Engineering full brochure about Buoyancy, insulation and elastomer products (document number BOE-0410-REV00), for examples. Alternatively, buoyancy modules may be applied pendant to the riser pipes whereby the external buoyancy modules are anchored to the riser pipes by anchor lines. These external buoyancy modules would still be configured fully submerged to benefit from maximal buoyancy force.

[0033] The invention is applicable on waved steel production risers having pipes of any outer diameter. However, low diameter pipes of pipes not exceeding 199 mm generally are still relatively flexible such that the maximum curvature is in most cases not a constraint for reducing the hang-off angle to below 5°. Therefore, the invention has most benefits for larger diameter pipes, starting at pipes of which the outer diameter exceeds 199 mm, which includes 8-inch pipes. For most deployments of waved steel production risers of which the outer diameter exceeds 249 mm (which includes 10-inch pipes) the invention would be needed to meet the low hang-off angles, and it is envisaged that for almost all deployments of waved steel production risers of which the outer diameter exceeds 299 mm (which includes 12-inch pipes, and up) the invention would be needed in order to keep the hang-off angle to less than 5°.

[0034] The invention is applicable for deployments of waved steel production risers in any water depth. However, deep waters offer more clearance to accommodate a waved shape including sag and hog bends than shallower waters. Therefore, for the deepest waters, such as waters deeper than about 1800 m, the maximum curvature that can be applied on the production riser might not form a constraint for reducing the hang-off angle to below 5°. It is contemplated that the invention has most benefits if the vertical distance from the hang-off point to the seabed (or the water depth of the body of water 20) is smaller than 1800 m. For most deployments of waved steel production risers in bodies of water 1400 m depth or less (whereby the vertical distance from the hang-off point to the seabed is smaller than 1400 m) the invention would be needed in order to keep the hang-off angle below 5° while observing a maximum allowable curvature. Furthermore, it is envisaged that for almost all deployments of waved steel production risers in bodies of water of 900 m deep or less (whereby the vertical distance from the hang-off point to the seabed is smaller than 900 m) the invention would be needed to achieve the preferred low hang-off angle.

[0035] The invention becomes even more crucial for deployment of waved steel production risers with large outer diameter in a combination of relatively shallow waters. All combinations of the depths and outer diameters listed above are contemplated. It is envisaged that deployments of waved steel production risers of which the outer diameter exceeds 249 mm in a body of water of 1400 depth or less would be in particular need for this invention.

[0036] Calculations have shown that with the invention configurations with low hang-off angles on steel lazy wave production risers can be achieved in water depths as shallow as 600 m. Preferably the vertical distance, or the water depth, does however exceed 500 m. It is envisaged that below this depth the choice of steel for the production risers would generally be outcompeted by alternatives, such as flexible risers.

[0037] It has already been briefly indicated above that in the case of a steel lazy wave riser, at distal from the first point of contact 115 (i.e. the touchdown point), as seen from the hang-off end 101, the pipes of the waved steel production riser 100 rest on the seabed 30. This is referred to as the touchdown section 105 of the waved steel production riser. The string of pipes in the touchdown point are tangentially aligned with the seabed 30. Typically this means that in the transition between the landing section 104 and the touchdown section 105 the waved steel production riser 100 is curved with a downwardly convex curvature, as is the case in the sag bend.

[0038] The steel lazy wave riser is generally preferred over the steep wave riser because less seabed infrastructure is needed compared to steep wave risers. But unlike the steep wave riser the first point of contact 115 is dynamic as motion of the floating structure 10 causes the riser to be lifted off from or laid down on the seabed 30.

[0039] Fatiguing of the riser pipes around the transition between the landing section 107 and the touchdown section 105 can be reduced by reducing the downwardly convex curvature in this area. To this end, the steel lazy wave riser preferably comprises an additional auxiliary buoyancy section 107, which extends from within the touchdown section 105 at least to a point between the primary buoyancy section 103 and the touchdown section 105. Thus, the touchdown point is preferably within the additional auxiliary buoyancy section 107. In this additional auxiliary buoyancy section 107 the waved steel production riser 100 is provided with a third set of external buoyancy modules 140, whereby the upward buoyancy force in the body of water is smaller than the downward gravity force.

[0040] The requirements are similar to those explained above for the auxiliary buoyancy section 106. In other words, the upward buoyancy force in the body of water within the additional auxiliary buoyancy section 107 is higher than the upward buoyancy force in the body of water of the string of pipes made out of steel without any external buoyancy modules. The net force, however, remains downwardly directed (sinking). The upward buoyancy force in the body of water within the additional auxiliary buoyancy section 107 of the waved steel production riser 100 can (but does not necessarily have to be) be different than that in the auxiliary buoyancy section 106 in the hanging section 102. In fact, the additional auxiliary buoyancy section 107 may even be configured in embodiments that do not have any auxiliary buoyancy section 106 as described above. However, it is envisaged that both the auxiliary buoyancy section 106 and the additional auxiliary buoyancy section 107 are configured as both have their own specific advantages.

[0041] The external buoyancy modules used in the third set may be of the same type as those used in the first and/or second sets. However, the external buoyancy modules in the third set, which are intended for the touchdown area, the pendant version may be preferred if contact of the external buoyancy modules would cause unacceptable abrasion as a result of physical contact with the seabed 30. Such physical contact would be avoided using the pendant buoys.

[0042] In the case of a steel lazy wave riser, the upward buoyancy force in the body of water within the auxiliary buoyancy section of the waved steel production riser may be selected between A/150 and A/200, wherein A corresponds to the downward gravity force in the auxiliary buoyancy section 106 reduced by horizontal riser tension force in the touchdown section 105 of the waved steel production riser 100. This may be treated as an additional criterion to be applied in addition to the criterion mentioned before where the upward buoyancy force in the body of water within the auxiliary buoyancy section 106 of the waved steel production riser 100 is selected between 40% and 99% of the downward gravity force in the same section, or it may replace this earlier mentioned criterion and be applied instead.

[0043] The waved steel production riser described herein can be used in a variety of methods of producing a hydrocarbon stream. In such methods, mineral hydrocarbon fluids may be produced from a subsea hydrocarbon reservoir to the floating structure via the waved steel production riser. Subsequently, on the floating structure, the mineral hydrocarbon fluids are processed whereby the hydrocarbon stream is formed out of the mineral hydrocarbon fluids. Processing may include any kind of known hydrocarbon processing steps, including separation steps to remove undesired components from the hydrocarbon fluids such as water, acids, hydrate inhibitors, sulphur components, mercury. Processing may further include (field) stabilization of hydrocarbon liquids, and purification of hydrocarbon gases.

[0044] In cases of an FPSO or a SPAR, the produced hydrocarbon stream may be stored and off-loaded in batches (bulk transportation). In case the mineral hydrocarbon fluids comprise natural gas, process steps may be applied by which the natural gas is treated, and finally cooled down to produce the hydrocarbon stream in the form of liquefied natural gas (LNG). Such LNG is typically also stored in (or on) the floating structure, and off-loaded in batches like described for FPSO and SPAR.

[0045] The person skilled in the art will understand that the present invention can be applied and/or carried out in many various ways without departing from the scope of the appended claims.

[0046] For instance, auxiliary buoyancy sections to locally reduce the net downward vertical force may be located at any section in the waved steel production riser where the production riser hangs in a downwardly convex curved shape, to help reduce the curvature.

Claims

1. A waved steel production riser, comprising a string of pipes made out of steel, which string of pipes is suspended from a floating structure into a body of water above a seabed, on which body of water the structure floats, wherein at a hang-off end of the production riser the string of pipes is connected to the floating structure in a hang-off point, and wherein, as described along the string of pipes starting from the hang-off point, the waved steel production riser comprises a hanging section, a primary buoyancy section wherein the waved steel production riser is provided with a first set of external buoyancy modules causing an upward buoyancy force on the primary buoyancy section in the body of water that is greater than a downward gravity force in the primary buoyancy section, and a landing section extending between the buoyancy section and a first point of contact with the seabed, wherein a vertical riser plane is defined, which contains both the hang-off point and the first point of contact and extends parallel to a vertical direction, wherein the hanging section hangs between the floating structure and the primary buoyancy section whereby a downwardly convex curved section is formed in the hanging section, whereby a sag point is defined in the downwardly convex curved section there where the waved steel production riser has a tangent in a horizontal direction and parallel to the vertical plane, wherein the waved steel production riser further comprises an auxiliary buoyancy section in the hanging section whereby the sag point is located within the auxiliary buoyancy section whereby part of the auxiliary buoyancy section is located between the hang-off point and the sag point, in which auxiliary buoyancy section the waved riser is provided with a second set of external buoyancy modules and wherein the upward buoyancy force in the body of water is smaller than the downward gravity force.

2. The waved steel production riser of claim 1, wherein the upward buoyancy force in the body of water within the auxiliary buoyancy section is higher than the upward buoyancy force in the body of water of the string of pipes made out of steel without any external buoyancy modules.

3. The waved steel production riser of claim 1 or 2, wherein the upward buoyancy force in the body of water within the auxiliary buoyancy section of the waved steel production riser is between 40% and 99% of the downward gravity force.

4. The waved steel production riser of any one of the preceding claims, further comprising a touchdown section wherein the pipes rest on the seabed, which touchdown section as seen from the hang-off point is distal from a touchdown point and wherein in the touchdown point coincides with the first point of contact of the waved riser with the seabed, whereby the string of pipes in the touchdown point are tangentially aligned with the seabed.

5. The waved steel production riser of claim 4, wherein the upward buoyancy force in the body of water within the auxiliary buoyancy section of the waved steel production riser is between A/150 and A/200, wherein A corresponds to the downward gravity force in the auxiliary buoyancy section reduced by horizontal riser tension force in the touchdown section of the waved steel production riser.

6. The waved steel production riser of claim 4 or 5, further comprising an additional auxiliary buoyancy section extending at least to a point between the primary buoyancy section and the touchdown section, in which additional auxiliary buoyancy section the waved steel production riser is provided with a third set of external buoyancy modules and wherein the upward buoyancy force in the body of water is smaller than the downward gravity force.

7. The waved steel production riser of claim 6, wherein the additional auxiliary buoyancy section extends into at least a part of the touchdown section whereby the touchdown point is located within the additional auxiliary buoyancy section.

8. The waved steel production riser of claim 6 or 7, wherein the upward buoyancy force in the body of water within the additional auxiliary buoyancy section is higher than the upward buoyancy force in the body of water of the string of pipes made out of steel without any external buoyancy modules.

9. The waved steel production riser of any one of the preceding claims, wherein the waved steel production riser is configured in a straight vertically aligned

pull-in tube at the hang-off point.

10. The waved steel production riser of any one of the preceding claims, wherein a hang-off angle of the waved steel production riser in the hang-off point is between 0° and 5°.

11. The waved steel production riser of any one of the preceding claims, wherein the pipes each have an outer diameter that exceeds 199 mm, preferably 249 mm, more preferably 299 mm.

12. The waved steel production riser of any one of the preceding claims, wherein a vertical distance from the hang-off point to the seabed is smaller than 1800 m, preferably smaller than 1400 m, more preferably smaller than 900 m.

13. The waved steel production riser of claim 12, wherein the vertical distance is larger than 500 m.

14. An offshore hydrocarbon production system, comprising a floating structure floating on a body of water above a seabed, and a waved steel production riser according to any one of the preceding claims suspended from said floating structure into said body of water.

15. A method of producing a hydrocarbon stream, comprising conveying mineral hydrocarbon fluids produced from a subsea hydrocarbon reservoir to a floating structure via a waved steel production riser according to any one of claims 1 to 13, and processing the mineral hydrocarbon fluids on the floating structure whereby forming the hydrocarbon stream out of the mineral hydrocarbon fluids.

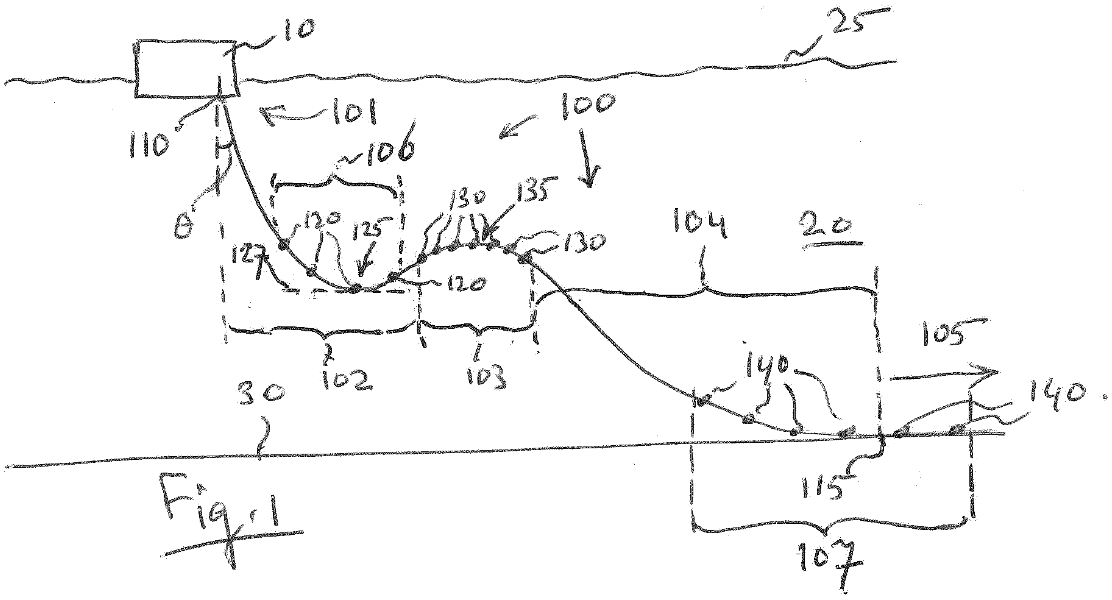
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Fig. 1

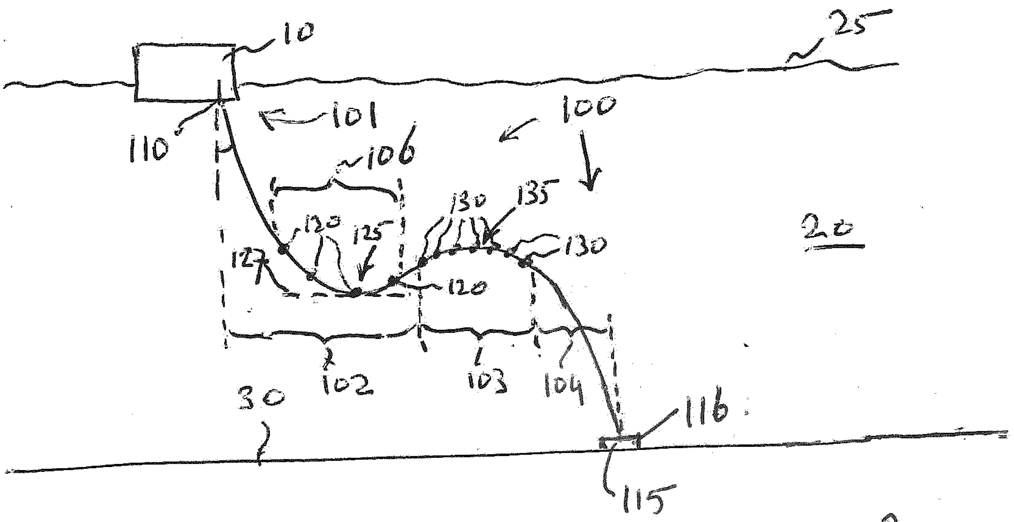
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Fig. 2

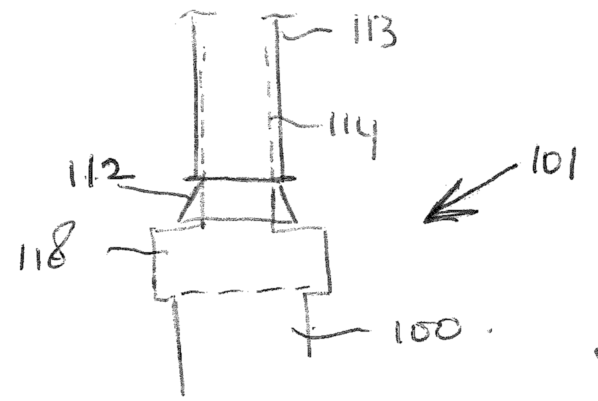

Fig-3

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EUROPEAN SEARCH REPORT

Application Number
EP 13 19 8737

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A	US 2012/263542 A1 (HOVDE GEIR OLAV [NO]) 18 October 2012 (2012-10-18) * abstract * * figure 1 * * paragraph [0027] - paragraph [0029] *	1-15	
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Place of search	Date of completion of the search	Examiner
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