Further facilities equipment and storage tanks can be located in the columns.

Fig. 4a

Abstract: Apparatus and method for processing of production fluids from a subsea oil or gas well, in order to recover hydrocarbons from the well. In an embodiment, the apparatus is a column stabilised structure having an interconnected array of three columns, with the upper portion protruding above the surface of the sea. The apparatus described has processing facilities in a lower portion of a first column, power generation facilities in a lower portion of a second column and service and utilities in a lower portion of a third column. Further facilities equipment and storage tanks can be located in the columns.
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APPARATUS AND METHOD

The present invention relates to the field of offshore production of hydrocarbons, and provides an apparatus and method for processing of production fluids from a subsea oil or gas well, in order to recover hydrocarbons from the well. More particularly, though not exclusively, the invention relates to a column stabilised underwater, unmanned, offshore production fluid and hydrocarbon processing facility.

BACKGROUND

Exploitation of hydrocarbon reservoirs has become increasingly challenging as exploration has expanded into deep water environments, with the complexity, and corresponding cost, of the production equipment required to produce and export hydrocarbons from such reservoirs escalating. The conditions at deep water locations can be extremely rough with the production apparatus being subject to significant wind and wave loading. Present designs of unmanned production apparatus can suffer from instability due to wave impact, wind loads, or ice accumulation, and offshore production equipment needs to be increasingly robust in order to cope with the higher demands on structure.

As reserves deplete and extraction becomes more difficult, a business decision may be taken to cease operations, despite there still being a sizeable volume of hydrocarbons left in the reservoir. Similarly, viable but small reservoirs may be adjudged as too uneconomical to exploit. The costs, and risks, of maintaining a FPSO (for example) above a wellhead are high, and may result in production from aging reservoirs becoming unviable. At this point, the operator may seal the well, writing off the remaining reserves.

SUMMARY

According to an aspect of the present invention, there is provided apparatus for processing of production fluids from a subsea well, the apparatus comprising an interconnected array of at least three columns, wherein each column comprises an upper portion and a lower portion, and wherein the lower portion comprises at least one compartment, and wherein said at least one compartment incorporates processing equipment for processing of production fluids from the subsea well.

Optionally the apparatus is unmanned or normally unmanned.
Optionally the subsea fluids comprise hydrocarbons and the processing equipment is adapted to separate the hydrocarbons from other components of the production fluids.

Optionally the lower portions of the columns incorporating the processing equipment are submerged beneath the waterline when the interconnected array is fully installed. Optionally, the majority of the total mass, and optionally the majority of the displaced volume of the array, is in the lower portions of the columns. Optionally the compartments in the lower portions of each column can also contain, either separately or in combination, processing equipment in addition to hydrocarbon processing facilities, such as water treatment and/or injection facilities, gas compression apparatus, oil metering and export, and the like; power generation and distribution equipment; one or more fluid storage chambers, e.g. for oil, fuel, chemical, potable water, or water ballast storage and the like; and service and/or utilities equipment, for example HVAC, control and telecommunications systems, firefighting systems; and crew facilities including a control room, refuge space, workshops, and life-saving equipment. Optionally, the equipment installed in one column may take up substantially less space within that column that the equipment that is installed in another column; for example, HVAC in comparison to processing equipment. Additional ballast can be added to the column with more free volume in order to maintain the array in a level position. It is possible to adjust the dimensions of one or more columns, i.e. one column can be larger or smaller than others.

Optionally the columns pierce the surface of the sea. Optionally the upper portion of each column is above the sea surface. Optionally the centre of gravity and centre of buoyancy positions within each column is not critical, as stabilisation is optionally achieved by column stabilisation. Optionally the columns provide vertical stability via column stabilisation. The interconnected array also optionally addresses the technical challenge in optimising the motion response of a submerged production facility to offshore weather conditions by using both column stabilisation and the righting moment from the waterplane area. Optionally, due to the processing and optionally other facilities and equipment being below the surface of the water, the majority of the displaced volume and mass
is below the most extreme wave action, and hence the forces generated by passive waves are reduced due to the relatively small area of each column that pierces the surface of the sea. This configuration also acts to minimise the effects of wind loading on the array.

To achieve stability by column stabilisation, a minimum number of three surface-piercing columns is useful, but optionally more may be used; this arrangement offers improved static stability of the array over that of a single column. Optionally, each column is spaced apart from its immediately adjacent columns by regular intervals, for example, where there are three columns, they can be spaced by 120 degrees; four columns can be spaced by 90 degrees, five by 70-75 degrees etc, optionally measured from a geometrically central point of the interconnected array. Optionally the angular spacing between the columns is generally consistent, optionally measured to the central axis of each column. Optionally the central axes of the columns are parallel.

Optionally the interconnected array having at least one line of symmetry between the central axes of the columns. Optionally there is more than one line of symmetry between the central axes of the columns. Optionally at least one line of symmetry of the interconnected array bisects or otherwise passes through at a central axis of at least one column.

Increasing the horizontal distance between each column optionally increases the rotational stability of the array.

Optionally, the interconnected array may have more than three columns, for example four, five, or six. An increase in the number of columns optionally offers increased stability of the array.

Optionally one or more columns have a cylindrical cross-section, however other cross-sections may be suitable, such as triangular, square or pentagon shaped etc. Optionally the corners of non-cylindrical cross-sections are rounded.
Rounded edges offer the advantage of reducing stress concentrations at the joint between each side of the column.

Optionally each column of the interconnected array is connected to at least two other columns. Optionally the columns are connected above the surface of the sea. Optionally the columns are interconnected by structural braces or similar connectors. Optionally the columns are connected below the sea surface by structural braces, optionally having a larger diameter than the structural braces above the sea surface. Loading on the columns can place stress on the connecting braces between each column, creating potential stress hotspots in critical areas. The addition of diagonal bracing stiffens the structure and mitigates the effects of loading on the columns. This is increasingly useful with larger arrays as a means of reducing the effects of fatigue on the structure, which generally increases with increasing numbers of columns.

Optionally the processing facilities and associated equipment are submerged with the majority of the displaced volume and mass below the wave affected zone subject to the most extreme disruption from wave action; this offers the advantage that the forces generated by a passing wave are reduced due to the relatively small area of each column which is exposed to the wave affected zone. In addition, positioning the majority of the projected area and volume of the columns well below the sea surface minimises the wind loads that are experienced by each column, and by the interconnected array as a whole. In one example of the invention, more than 90% of the weight of the facility is typically below the waterline, with typically all the primary functions of the array located below the sea surface, such as oil processing, power generation, water cleaning, transformers, pumps, fuel and oil storage.

Optionally processing equipment, power generation equipment and service and utilities functions are located in different and separate columns, separated from one another in the array. Optionally the processing equipment is located in the lower portion of a first column, the power generation equipment is located in the lower portion of a second column, and the service and utilities functions are
located in a third column. Optionally, one column (e.g. the third) also provides a principal means of access and egress for personnel. Optionally, where the equipment within the at least one compartment does not occupy the entirety of the available space, ballast may be added to maintain the stability of the interconnected array. Separating the functions and services within the interconnected array can improve safety and enhance flexibility of the layout. The separation of the functions minimises the impact of the heat generated from hot process fluids on adjacent columns, processes, and functions, and isolates the noise and vibration from power generation into its respective compartment. The third column optionally provides a relatively safe and quiet environment and thus allows maintenance and access in a more comfortable environment.

Optionally the interconnected array comprises access and egress points for personnel in more than one column, optionally in each column. Optionally the interconnected array comprises walkways between columns. Optionally the walkways are located above the waterline, optionally on structural braces. Optionally the walkways are located within structural braces below the waterline. Optionally the structural braces below the waterline are enhanced with blast- and water-resistant doors at the entrance points of each brace, to protect against blast damage and flooding.

Optionally the array comprises pipework for transfer of fluids or gases, or optionally cables or other conduits. Optionally the pipework extends between and optionally at least partially through one or more columns, for example from an oil storage compartment to an oil export conduit. Optionally the pipework extends between one or more columns, for example from hydrocarbon processing to oil stabilisation or storage compartments in different columns.

Optionally cables for transference of e.g. data or power extend at least partially through one or more columns, for example for transference of power from the power generation equipment to equipment requiring power elsewhere in the same column. Optionally the cables travel between one or more columns to transport power or data signals between equipment across the array.
Optionally the cables and/or pipework run through horizontal braces. Optionally the cables and/or pipework comprise penetrations upon exit from and entry to a column. Optionally the entry and exit penetrations are configured to be resistant to the effects of sudden ignition events and are optionally configured to resist water ingress.

Optionally at least one column of the interconnected array comprises a flare. Optionally the interconnected array can be positioned to ensure the flare is downwind for the majority of the period of operation, based on the wind direction statistics.

The dimensions of the columns, and the separation of each column, also improve the stability and motions of the facility to the extent that the mooring system and dynamic riser system can be simplified due to the low motions of the array in ocean waves.

Optionally at least one column comprises a HVAC system. Optionally the heat generated from power generation and processing may be directed via the HVAC system to provide heating for the services/utilities column. Optionally the heat from the power generation and processing may be directed via the HVAC system to minimise build-up of ice and/or snow on the structural braces located above the sea surface. Loss of stability due to ice accumulation is minimised due to the small surface area of the array above the waterline and high inherent stability.

Optionally offloading or export of processed hydrocarbons from the facility may be performed via a remote offloading system located a distance away from the facility, to a separate facility, or to an export pipeline. Optionally the hydrocarbons are offloaded to a tanker.

Optionally the offloading of hydrocarbons to a tanker can be performed directly from the facility via a hose reel. The hose reel may be operated remotely, or may optionally be operated locally, and may be located either on top of or between two of the columns. Alternatively the hose reel may be contained within one of the columns for security and protection from the environment. Alternatively the hose may be floating on the sea surface rather than deployed from a hose reel.
Optionally the tanker is moored to the interconnected array by a mooring line. The interconnected array is sufficiently stable that it can resist the overturning forces from tension in the mooring line that is mooring the tanker to the array. The mooring line may be a single element, or a combination of bridle elements. Optionally the mooring connection may be onto more than one column in the interconnected array. The mooring loads and subsequent motions of the array are improved in comparison to other floating structures.

Optionally the central section of the interconnected array between the columns is open. Optionally the central section contains a subsea storage tank, which is optionally supported between the columns. Optionally the subsea storage tank is secured to the interconnected array during transport of the apparatus to the deployment location. Optionally the subsea storage tank can be released and optionally lowered to the seabed once the interconnected array has reached the deployment site, for example by using winches. The tank may be lifted or raised into position within the array or both items fabricated together at the same time. The tank may be recovered to the array when required, for example at the end of operations on the site, and re-secured to the array for transportation back to port, or to another installation location.

The array may also be used to transport and deploy additional equipment and components for use at the deployment location. For example, where the subsea storage tank is to be lowered to the seabed, the array may be used to transport and deploy a supporting base that is adapted to sit between the seabed and the subsea tank.

Optionally production fluids are stored in chambers or tanks within one column, e.g. the storage column. Optionally production fluids are stored in a separate subsea storage facility. Optionally the chambers or tanks within the storage column can also be used for separation of the production fluids and stabilisation of the separated oil. Stabilisation of the oil may optionally occur in the processing column, or optionally in a separate column. Optionally the stabilised oil may be stored on board the array, for example in one or more storage tanks that are optionally integral with at least one column, or optionally one or more storage tanks that are otherwise connected to the array. The array configuration optionally offers greater storage provision for
production fluids, oil, fuel, chemicals and the like compared to a single column. Optionally direct offloading of oil is possible from the array via, for example, a floating hose, or optionally a hose suspended in a catenary configuration to a tanker.

Optionally, the chambers or tanks may be detachable from the column. Having detachable tanks allows replacement, upgrade, cleaning or maintenance of the tanks as required.

The interconnected array may optionally also be configured to have chain lockers which are near the keel level. Optionally the chain lockers may be used to pre-connect and store chain prior to the load-out of the array. The stored chain may act as ballast for the array, improving stability during tow-out of the array, and optionally minimising the number and/or the length of mooring lines required to be installed at the deployment site prior to deployment of the interconnected array.

Optionally the mooring lines for mooring the interconnected array are in short sections when installed. By having short installed sections the pre-installed mooring lines can be laid straight on the seabed and it is thus relatively easy to ensure the free end of each mooring line is the same distance from the target array location. This allows connection of the chains on the array to the mooring lines without the requirement for further adjustment.

Optionally at least one column of the array can be connected to a dynamic riser. Optionally the dynamic riser or risers for the array can be brought onboard into the column corresponding to the required function, for example the power cable to the power generation column, and/or water injection to a water injection column. Optionally the control and optionally the power umbilicals are brought onboard to the relevant column, or columns, through an l-tube to above the water line. This allows the connection of the terminations in a dry, controlled atmosphere within the array.

The array may optionally be configured with a deck to carry additional drilling or production equipment. In one example the deck may carry a drilling derrick to allow intervention on a well head, thus allowing the array to be located above a drill centre with multiple wells. In this example, the array could optionally change from
unmanned to "not normally manned"; however the operations and functions carried out in the subsea lower portions of the columns would remain unmanned.

Optionally, to supplement the power generation onboard the array, at least one wind turbine may be installed on the array. The configuration of the array offers sufficient stability to facilitate the installation of such equipment. Optionally the wind turbine can be installed on a column, or alternatively, it may be installed in a location that is more central to the array. Optionally, either in combination with at least one wind turbine, or as an alternative method, wave or solar energy devices may be connected to the array. Optionally any excess power generated by the supplemental devices on the array may be exported to an electrical grid network.

The various aspects of the present invention can be practiced alone or in combination with one or more of the other aspects, as will be appreciated by those skilled in the relevant arts. The various aspects of the invention can optionally be provided in combination with one or more of the optional features of the other aspects of the invention. Also, optional features described in relation to one aspect can typically be combined alone or together with other features in different aspects of the invention. Any subject matter described in this specification can be combined with any other subject matter in the specification to form a novel combination.

Various aspects of the invention will now be described in detail with reference to the accompanying figures. Still other aspects, features, and advantages of the present invention are readily apparent from the entire description thereof, including the figures, which illustrates a number of exemplary aspects and implementations. The invention is also capable of other and different examples and aspects, and its several details can be modified in various respects, all without departing from the scope of the present invention. Accordingly, each example herein should be understood to have broad application, and is meant to illustrate one possible way of carrying out the invention, without intending to suggest that the scope of this disclosure, including the claims, is limited to that example. Furthermore, the terminology and phraseology used herein is solely used for descriptive purposes and should not be construed as limiting in scope. In particular, unless otherwise stated, dimensions and numerical values included herein are presented as examples illustrating one possible aspect of the claimed subject matter, without limiting the
disclosure to the particular dimensions or values recited. All numerical values in this disclosure are understood as being modified by "about". All singular forms of elements, or any other components described herein are understood to include plural forms thereof and vice versa.

Language such as "including", "comprising", "having", "containing", or "involving" and variations thereof, is intended to be broad and encompass the subject matter listed thereafter, equivalents, and additional subject matter not recited, and is not intended to exclude other additives, components, integers or steps. Likewise, the term "comprising" is considered synonymous with the terms "including" or "containing" for applicable legal purposes. Thus, throughout the specification and claims unless the context requires otherwise, the word "comprise" or variations thereof such as "comprises" or "comprising" will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

Any discussion of documents, acts, materials, devices, articles and the like is included in the specification solely for the purpose of providing a context for the present invention. It is not suggested or represented that any or all of these matters formed part of the prior art base or were common general knowledge in the field relevant to the present invention.

In this disclosure, whenever a composition, an element or a group of elements is preceded with the transitional phrase "comprising", it is understood that we also contemplate the same composition, element or group of elements with transitional phrases "consisting essentially of", "consisting", "selected from the group of consisting of", "including", or "is" preceding the recitation of the composition, element or group of elements and vice versa. In this disclosure, the words "typically" or "optionally" are to be understood as being intended to indicate optional or non-essential features of the invention which are present in certain examples but which can be omitted in others without departing from the scope of the invention.

References to directional and positional descriptions such as upper and lower and directions e.g. "up", "down" etc. are to be interpreted by a skilled reader in the context of the examples described to refer to the orientation of features shown in the
drawings, and are not to be interpreted as limiting the invention to the literal interpretation of the term, but instead should be as understood by the skilled addressee.

5 BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Figure 1a shows a side view of a first example of apparatus for processing of production fluids from a subsea well comprising an interconnected array having three columns;

Figure 1b shows a plan view of the array of Figure 1a;

Figure 1c shows a cross-sectional view of each column of the array of Figure 1a;

Figure 2a shows a plan view of a second example of an interconnected array having four columns;

Figure 2b shows a plan view of a third example of an interconnected array with five columns;

Figure 2c shows a plan view of a fourth example of an interconnected array with six columns;

Figure 3a shows a side view of an interconnected array with three columns during the mooring procedure, having chain lockers for storing chain that is pre-connected to the array;

Figure 3b shows a plan view of the configuration of Figure 3a;

Figure 4a shows a side view of an interconnected array substantially in line with Figure 1, with a typical arrangement for dynamic flexible risers;

Figure 4b is a plan view of the configuration shown in Figure 4a;

Figure 5a shows a side view of an interconnected array with three columns, the array comprising a tank or subsea structure that is ready to deploy onto a landing site;

Figure 5b shows a plan view of the array and subsea structure of Figure 5a;

Figure 5c shows a side view of the subsea structure beginning to be lowered to the landing site using winches on board the array;

Figure 5d shows a side view of the subsea structure having been landed on the seabed;
Figure 6a shows a side view of a hydrocarbon offloading configuration with an array substantially in line with Figure 2a;

Figure 6b shows a plan view of the configuration of Figure 6a, showing two possible positions for the hose reel;

Figure 7 shows a side view of an interconnected array substantially in line with Figure 1, with storage tanks underneath each column;

Figure 8a shows a side view of an interconnected array with three columns, with a drilling derrick and covered over main deck;

Figure 8b shows a plan view of the array and derrick of Figure 8a;

Figure 9a shows a side view of an interconnected array having four columns with a wind turbine connected to the array in a central location and a wave energy device incorporated within one of the columns;

Figure 9b shows a plan view of the array and centrally-installed wind turbine of Figure 9a;

Figure 9c shows an alternative installation site for the wind turbine on top of one of the columns of the array.

**DETAILED DESCRIPTION**

Referring to the drawings, an example of apparatus for processing of production fluids from a subsea well comprising a facility in the form of an interconnected array 1 with three columns 10, 20, 30 is shown in Figures 1a-1c. This configuration of columns provides good column stabilisation in all directions. Alternatively, a greater number of columns may be used as illustrated in Figures 2a-2c.

Each column 10, 20, 30 has an upper portion 10u, 20u, 30u and a lower portion 10l, 20l, 30l. The upper portions 10u, 20u, 30u comprise a portion of a long vertical neck section 10n, 20n, 30n, and refer to the part of the neck that is above the surface of the sea. The upper portions 10u, 20u, 30u extend above the sea surface to a height that is above the highest anticipated wave crest at the deployment site.

The lower portions 10l, 20l, 30l of the columns 10, 20, 30 comprise a submerged portion of the neck 10n, 20n, 30n, and a larger diameter section that is well below the surface of the sea, and thus at reduced risk of an impact with the keel of a passing vessel.
The dimensions (e.g. diameters and relative heights) of the upper 10u, 20u, 30u and lower portions 101, 201, 301 of the columns 10, 20, 30 may optionally be the same, or may optionally vary according to the functional requirement of what is contained within the columns 10, 20, 30 and to optimise the hydrodynamic behaviour of the overall array 1. The columns 10, 20, 30 are held structurally together typically by braces 7, 8, 9. An example configuration for the bracing is illustrated in the Figures, but other configurations may be used.

Access from one column 10, 20, 30 to another is via a walkway 5 above the water line, or via a series of watertight and blast-proof doors in the lower braces 8. Stores and equipment can be lifted onto the platform 3 by either the vessel's crane or the crane 15 located on column 10.

The array 1 is moored in position by mooring lines 4. The mooring lines 4 are typically installed to an outer surface of each column, however, in some configurations of the array it is not necessary to attach mooring lines to every column.

In the example shown in Figure 1a, the majority of the displaced volume of the array 1 is below the water line. The service and utilities column 10 is the normal point of access and egress to the array 1 either via access walkway from a vessel onto the platform 3, or via a smaller vessel and the ladder 11. The upper section 10u of column 10 contains the control room, crane 15, and telecommunications and radar mast 16. The overall height of this section 10u is greater than the upper sections 20u, 30u of the other two columns 20, 30, in order to maximise the height of the telecommunications and radar mast 16, and enable and enhance transmission and receipt of signals.

Column 20 contains the power generation equipment for the array 1 and is used to generate the required electrical power for facility and subsea functions. Any exhaust gases produced as a result of the power generation process are vented from the array 1 through exhaust tubes 25, on the uppermost surface of the column neck 20n.
Column 30 contains the processing area for the processing of, for example, hydrocarbon fluids, gases, solids and water. Excess gases that may be produced from the processing of production fluids are either sent to the power generator in column 20 for use as fuel, or vented via the flare 35 above the processing column 30. Subject to the design of the facility, the gas may be exported via one or more dynamic risers 38. The dynamic risers are typically hung off the column 30 on a support structure 37, connected to one side of the column 30.

The fluids and gases to be processed along with any electrical or hydraulic controls and electrical power may be transferred to the subsea via the dynamic flexible risers and umbilicals 38.

Figure 1c shows a cross-sectional view of the columns 10, 20, 30. The location and arrangement of functions and equipment described herein are exemplary and may be changed based on the required functionality of the array 1. For example, if it is required to store processed oil for an extended period of time, more space may be given over for fluid storage.

In Figure 1c, the processing area 32 has an access trunk 33a directly above it, which allows personnel to access the processing area 32 and other sections of the column 30 to install, maintain, or replace equipment. The power generation area 22 of column 20 similarly has an access trunk 23a above.

The service and utilities column 10 holds the main controls and telecommunications area 19, which is located well above the water line. The controls and telecommunications area 19 contains the control room, workshop, office and refuge for personnel working on the array 1, and is the principal area where personnel gain access to and egress from the facility. Below this area 19 there is an access shaft 13a to the utilities area 12, which in a typical configuration includes HVAC and fire control systems, but may also be used for supplementary functions such as e.g. water cleaning, or oil metering, as required.

The areas 13s, 23s, 33s surrounding the access trunks 13a, 23a, 33a are void spaces. The dimensions of the spaces 13s, 23s, 33s are optionally selected to provide sufficient buoyancy to support the upper portion of the columns above the
waterline, and optionally act as a buffer in the event of vessel impact with the column 10, 20, 30. The spaces 13s, 23s, 33s around the processing 32, power generation 22 and utilities 11 areas are used for storage of water ballast, fuel, chemicals and potable water as required and are typically below the keel of passing vessels.

Figures 2a-2c show some further examples of configurations of the array 1 with increasing numbers of columns, and the reference numbers for each separate and subsequent example have been increased by 100.

Figure 2a shows an array 100 having four columns 110, 120, 130, 140 interconnected by braces 107 and others (not shown). The four column arrangement 100 may use the additional column 140 to further sub-divide the functions of the facility, but equally may be used for storage of fuel, ballast, processed oils, chemicals or a combination thereof. Alternatively, the additional column 140 can be used to provide additional processing or power generation capacity. This configuration allows greater separation between the services and utilities column 110 and the processing column 130, which in some cases can allow greater stability of the array.

The five-column configuration 200, shown in Fig 2b, is typically a pentagonal configuration, and allows further separation between the processing column 230 and the service/utilities column 210.

The six-column configuration 300 in Fig 2c offers a more symmetrical arrangement of columns, and does not require mooring lines 304 to be connected to every column 310, 320, 330, 340, 350, 360. This configuration may be strengthened against flexing under wave loading by including cross braces 306 for additional resistance. This configuration could allow direct access for personnel via the cross-braces 306 to the processing column 330. Due to the addition of three further columns 340, 350, 360 over the array 1 shown in Figures 1a-1c, this configuration may be used to store increased volumes of oil.

Figures 3a and 3b shows the array 1 nearing completion of the mooring operation at the installation site, with eight out of nine mooring lines 4 connected. The last mooring line is within a chain locker 36 and is pre-connected to the outside surface
of column 30, with the other free end being accessible at the top of the chain locker 36. The free end is lifted out of the locker 36 to allow connection to a pre-installed mooring line on the seabed. By using this method there does not need to be personnel on board the facility for the mooring hook-up. This configuration increases the stability of the facility during towing by having the weight of the chain low down in the structure. This configuration also allows the connection between the top of the mooring line and the facility to be performed in sheltered water or alongside in port.

Figures 4a and 4b shows an example of a typical arrangement of dynamic flexible risers, umbilicals, and power cables connecting to the columns 10, 20, 30. Production fluids and water are transported through risers 38 and brought onboard the facility through a bulkhead towards the base of the processing column 30. A control umbilical 18 passes through the base of the service/utility column 10 in an I-tube and is hung-off well above the water line. This allows the individual cables and hoses to be attached in a dry environment. Similarly, a power cable 28 is brought up through the bottom of the power generation column 20 inside an I-tube and hung-off at a similar elevation as the control umbilical 18. This configuration ensures that the functions which are sensitive to water ingress are connected in a dry, controlled, and sheltered environment.

Figures 5a-5d show deployment of a subsea storage tank 40 using winches connected via winch lines 41. The storage tank 40 is likely to be fully submerged during transport and installation, and hence the tension in the winch lines 41 can be controlled using adjustment of the amount of ballast on the tank 40. During transit, the tank 40 is secured in place by guides (not shown) that are located between the columns 10, 20, 30 of the array 1.

Upon arrival at the offshore site the array 1 may be moored, either at its final location or above the planned location of the storage tank 40. Winches on the array 1 may be used to control the lowering of the tank 40 onto the seabed, by releasing the seafastening arrangement and then lowering the tank 40, using the winches to control the angle of the tank 40 via the winch lines 41. Once the tank 40 is on the seabed the winch lines 41 may be disconnected and the subsea tank 40 will be fully ballasted to its operational weight.
When the tank 40 is to be recovered, the installation procedure may be carried out in reverse. The tank 40 is deballasted and winched from the seabed to the array 1, and the array 1 and tank 40 are then towed to port together. The subsea tank 40 may be lowered underneath the array 1 in sheltered water in order to separate the tank 40 from the array 1.

Figures 6a and 6b show a direct offloading configuration from an example of an array with four columns, using a hose reel 161 which transports fluid to or from the facility to a tanker 160 via a hose section 162. The hose section 162 may be in a catenary configuration as illustrated, or it may be floating on the surface of the sea. The hose reel 161 may be in two positions, the first being on top of a column (in this example column 140), or being installed on a brace 107. The hose reel 161 may optionally be contained within the column 140 to protect it from the environment, and for security purposes.

The tanker 160 may be moored to one or more columns of the array via one or more mooring lines 164. The mooring line or lines 164 may be individual lines, or alternatively may be in a bridle arrangement as shown in Figure 6b. Alternatively, if the tanker 160 is dynamically positioned, mooring may not be necessary.

The oil which is to be offloaded to the tanker 160 may be extracted from a subsea storage tank (not shown) via flexible risers 138, or may be provided by storage tanks on, or within, the array itself.

Figure 7 shows an alternative configuration of the array 401, with three columns, where the columns 410, 420, 430 have additional tanks 470 under one or more of the columns 410, 420, 430, which may be used to enhance the stabilisation of oil, and/or provide storage for the oil. The inner chamber of the tank 470 may be segmented, or may contain baffles 477 to restrict movement or sloshing of oil, for example as a result of wave impacts, and potential destabilisation of the array 401 as a result. The oil would typically enter and exit the tank 470 via a connection 476, and water ballast levels may be adjusted via pipe 475. In an alternative arrangement, the water ballast may be held in a separate tank to prevent mixing of oil and water. The tanks 470 may be an integral part of the column (as shown for
columns 410 and 420), or may be detachable as shown for column 430, where clamping devices 474 connect the tank 470 to the base of the column 430.

Figure 8 shows an example of the array 1 with a covered-over main deck 82, onto which a drilling derrick 80 has been installed. This configuration allows the array 1 to either perform intervention on a well, such as retrieval of an electric submersible pump, or alternatively have dry trees. This allows the process fluid to rise vertically and directly onto the facility. In this example, the array 1 may require additional modules and functions to be added to permit either part- or fully-manned operation, such as accommodation blocks. However, the processing function is unaffected by the installation of the derrick, and this procedure may continue without requiring manual intervention, i.e. in unmanned examples.

Figures 9a and 9b show an example of the array having four columns 110, 120, 130, 140, with a wind turbine 150 installed at a central position equidistant from all four columns 110, 120, 130, 140. The wind turbine 150 is used to provide additional power generation capacity, thus reducing the fuel consumption of the array. Should excess power be produced, it can optionally be exported to an electrical grid. Figure 9c shows an alternative installation location for the wind turbine 150 on top of one of the columns.

Wave devices also may also be attached or incorporated within the facility and used to supplement power requirements, or create excess energy that can be exported. One example of such a device is illustrated in Figure 9a, installed on a column. There is a wide variety of different types of device that could be used and one typical Oscillating Water Column (OWC) system 190 is illustrated. In this example, the OWC system 190 is installed within the void space in the upper part of one of the columns, comprising an open input 193 below the water line, moving into a vertical tube 194 and through an OWC device 195. Typically, an OWC system 190 may be located on one column facing the dominant wave direction; however more than one OWC system may be attached to each column, or alternatively OWC systems could be installed on more than one column.
CLAIMS

1. Apparatus for processing of production fluids from a subsea well, the apparatus being a column stabilised submerged structure comprising an interconnected array of at least three columns, each column comprising an upper portion and a lower portion, the lower portion comprising at least one compartment, and wherein said at least one compartment incorporates facilitating equipment, the facilitating equipment comprising processing equipment for processing of production fluids from the subsea well in at least one column.

2. Apparatus according to claim 1 wherein the apparatus is unmanned.

3. Apparatus according to claim 1 or claim 2 wherein the production fluids comprise hydrocarbons and the processing equipment is adapted to separate the hydrocarbons from other components of the production fluids.

4. Apparatus according to any preceding claim wherein the lower portions of the columns incorporating the facilitating equipment are submerged beneath the waterline when the interconnected array is fully installed.

5. Apparatus according to any preceding claim wherein the majority of the total mass of the apparatus is in the lower portions of the columns.

6. Apparatus according to any preceding claim wherein the columns pierce the surface of the sea so that the upper portion of each column is above the sea surface.

7. Apparatus according to any preceding claim wherein the facilitating equipment comprises one or more from a group comprising: water treatment facilities, injection facilities, gas compression apparatus, oil metering and export, power generation and distribution equipment, and service equipment, utilities equipment, HVAC, control system, telecommunications system,
firefighting system; crew facilities, a control room, refuge space, workshops, and life-saving equipment.

8. Apparatus according to claim 7 wherein the lower portion in at least one column also includes one or more fluid storage chambers wherein the one or more fluid storage containers contain fluid selected from a group comprising: oil, fuel, chemical, potable water, and water ballast.

9. Apparatus according to claim 7 or claim 8 wherein the processing equipment is located in the lower portion of a first column, power generation equipment is located in the lower portion of a second column, and service and utilities functions are located in a third column.

10. Apparatus according to claim 9 wherein at least one column includes a HVAC system and the heat generated from power generation and processing is directed via the HVAC system to provide heating for the services and utilities functions in the third column.

11. Apparatus according to claim 9 wherein at least one column includes a HVAC system and the heat generated from power generation and processing is directed via the HVAC system to minimise build-up of ice and/or snow on the apparatus located above the sea surface.

12. Apparatus according to any preceding claim wherein each column of the interconnected array is connected to at least two other columns.

13. Apparatus according to claim 12 wherein the columns are interconnected above the surface of the sea by structural braces.

14. Apparatus according to claim 12 or claim 13 wherein the columns are interconnected below the sea surface by structural braces.
15. Apparatus according to any preceding claim wherein offloading of processed fluids to a tanker is performed directly from the apparatus via a hose reel contained within one of the columns.

16. Apparatus according to any preceding claim wherein a central section of the interconnected array between the columns is open.

17. Apparatus according to any one of claims 1 to 15 wherein a subsea storage tank is supported by the columns in a central section of the interconnected array between the columns.

18. Apparatus according to claim 17 wherein the subsea storage tank is secured to the interconnected array during transport of the apparatus to a deployment location and the subsea storage tank is released and lowered to the seabed once the interconnected array has reached the deployment site.

19. Apparatus according to any preceding claim wherein the interconnected array is configured to have chain lockers in at least one of the upper portions, wherein the chain lockers are used to pre-connect and store chain prior to load-out of the apparatus.

20. Apparatus according to any preceding claim wherein the apparatus includes mooring lines for mooring the interconnected array, the mooring lines being in sections and when laid straight on the seabed a free end of each mooring line is the same distance from a target array location.

21. Apparatus according to any preceding claim wherein apparatus further comprises a drilling derrick.

22. Apparatus according to any preceding claim wherein an additional power generation source is located on the apparatus, selected from a group comprising: wind turbine, wave energy device and solar energy device.
**INTERNATIONAL SEARCH REPORT**

**PCT/GB2018/051305**

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**A. CLASSIFICATION OF SUBJECT MATTER**

INV. B63B35/44  B63B1/12

ADD.

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

B63B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>US 3 556 033 A (BONNAFOUS GUY) 19 January 1971 (1971-01-19) figures 1-5 column 4, line 72 - column 5, line 56</td>
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X  See patent family annex.

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