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(54) **Title**: LIQUID STORING AND OFFLOADING DEVICE AND DRILLING AND PRODUCTION INSTALLATIONS ON THE SEA BASED THEREON

(54) **发明名称**: 液体储存、装卸装置及以其为基础的海上钻井和生产设施

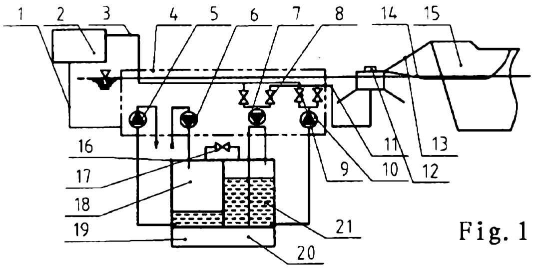

Fig. 1

(57) **Abstract**: A fixed or floating liquid storing and offloading device for loading, storing and offloading the storing liquid underwater or on the surface, and fixed or floating platforms or movable artificial islands structurally based on the combined tanks in water of the device all adopt "the airtight pressure connectedly pressing seawater and storing liquid equal mass flow rate automatic replacement flow system", the operational mass is invariable in the course of offloading the storing liquid and the center of gravity can change only along the vertical Z coordinate axis of the installation.

(57) **摘要**:

一种用于在水下或水面装载、储存和卸载储液的固定式或潜浮式液体储存、装卸装置，以及由该装置的水中组合罐为结构基础的固定式或浮式平台或可搬迁的人工岛，均采用“密闭气压连通式压载海水和储液等质量流率自动置换流程系统”，在储液装卸过程中操作重量均不变，且重心只能沿设施中心竖直的 Z 坐标轴变化。

WO 2009/117901 A1

A LIQUID STORAGE, LOADING & OFFLOADING SYSTEM AND ITS APPLICATIONS FOR OFFSHORE DRILLING AND PRODUCTION FACILITIES

TECHNICAL FIELD

The present invention is generally related to a type of liquid storage and transportation system underwater or at water surface in offshore oil/gas industry, such as crude, liquid hydrocarbon, methanol and etc. The system functions are like those of underwater oil depots, an offshore terminal or an oil wharf. In addition, the invention also applies to bottom-supported fixed or floating offshore facilities with multi-function of drilling, production and storage based on the system for offshore oil/gas development.

BACKGROUND ART

THE PRESENT OFFSHORE OIL STORAGE, LOADING & OFFLOADING TECHNOLOGY

The storage and transportation of the oil is very important for offshore oil/gas production. It may decide the selection for the oilfield development and have great impacts on the initial investment, operation cost and business benefit of the development. Current offshore oil storage, loading & offloading system is always as a part of the offshore oil/gas production facilities except for FSO, which is a kind of sole and dedicated offshore storage and offloading system. The prior arts include:

1. To store oil above water surface: such as oil tank(s) installed on a fixed platform (or an artificial island), with offloading facilities, like oil tank jacket platform and attached offloading berth structure for a shuttle tank, used for shallow and calm water development only, which is not cost-effective and used only for some particular situations due to its very small storage capacity.

2. To store oil underwater (at the seabed): such as gravity platforms with storage at the seabed, like concrete gravity platforms with an attached SPM, which are stabilized by their own massive weight at the seabed. The most popular concrete caisson structures have multi-interconnected cylinders for oil storage and form a honeycomb-shaped sub-base. Similar to the said forms of concrete platforms relied on their own gravity at the seabed, there are other types of platforms with underwater storage, such as fixed or jack-up platforms with gravity-mat storage.

As to underwater oil storage method, to store oil and water in a same tank to realize direct oil-water equal volume replacement is adopted for most of gravity platforms. In this method, the storage tank is always full of two kinds of insoluble liquids with different specific gravities during loading and offloading operations, such as the oil on the top of water in the same tank. This method is called as wet storage or water pillow storage. The traditional dry storage method is also adopted for gravity platforms with storage. This traditional dry storage method needs a system to generate, blanket and vent inert gas to prevent outside air entering. In this method, the total operating weight is reduced as the oil pumped out and sufficient pre-filled solid ballast is a must to assure enough operating weight keeping the gravity platform stabilized at the seabed in a storage empty condition.

3. To store oil at water surface in a floating condition, such as a ship-shaped FPSO (floating production storage offloading), a FSO (floating storage offloading), a column-shaped floating platform with storage (also called as a floating artificial island), i.e. SSP (Sevan stabilized platforms). In the above-mentioned units, the oil is stored in cargo tanks. The said units have a self-adjusted function between loading and draught due to their larger water plane areas to maintain the balance between operating weight and buoyancy, and could keep a required draught for

stability through the seawater ballast and de-ballast systems. The dedicated bottom pumps and/or submersible pumps for oil offloading and seawater de-ballast and an inert gas generation, blanketing and venting system are required for the said units. Relative to the wet storage, such oil tanker storage is also defined as oil tanker dry storage.

4. To storage oil underwater in a floating condition, such as floating platforms with underwater storage, is considered as a better way for oil storage than storage at water surface because it reduces the wave-induced hydrodynamic loads to the system. Great efforts have been made in research and development for floaters with underwater storage capacity as offshore oil/gas developments go into deeper and deeper waters. For examples, making a semi-submersible platform (SEMI) and a SPAR with the function of oil storage, i.e. using some tanks in the pontoon of a SEMI or in the lower part of a SPAR as oil storage tanks. In addition, other concepts/inventions, such as the concept of semisubmersible BOX SPAR were developed.

There are two types of underwater oil storage applications commonly used for surface floaters now: a) the wet storage method, in which the system follow equal-volume replacement principle to make its operating weight changing due to the specific gravity difference between oil and water, and an automatic water balance system is required to keep the operating weight constant in the process; b) improved tanker dry storage of oil-water equal mass flow-rate replacement to keep the operating weight constant. The said concepts and solutions of floating platforms with underwater storage have no practical application reported, except for a very few special cases of the SPAR or SEMI with storage for extended well test during exploration.

Among the said four methods and facilities, only two of them are ripe and common for offshore oil/gas industry now, i.e., 1) the water surface floating facilities with large waterplane area, in which the oil tanker dry storage method are used, and 2) the fixed gravity-base units sitting at the seabed, in which the wet storage method are used. However, both methods have their own intrinsic deficiencies nonetheless.

A water surface floating tank could be greatly impacted by environmental conditions, such as winds, currents and waves, and it has to bear very large environmental loads and may be difficult to withstand the harsh and severe sea states like ice. Taking an FPSO/FSO in severe environmental conditions as example, a stronger mooring positioning system is required because of large environmental loads. At the same time, the fatigue problems in the hull structures, mooring leg systems, and flexible riser systems are needed to be taken seriously. The inert gas generating, blanketing and venting system for the method of oil tanker dry storage will cause the problems of oil/gas emission and pollution during venting. Those underwater floating tanks, in which the oil tanker dry storage method with oil-water equal mass flow-rate replacement are used, will have to design and construct their steel hulls according to external pressure vessel design principles because the pressure of the inert gas inside the tank is just little higher than the atmosphere and lower than the hydrostatic pressure outside the tank.It costs more, especially for ultra deep water applications.

There are four intrinsic deficiencies for the wet storage method.

First, pollution is a problem resulted from the direct contact between oil and sea water.

Second, the difference between the two specific gravities of crude oil and sea water makes the system weight continuously changing in the process of equal-volume replacement. If the available capacity of crude oil storage is 100 thousand tons, then the weight difference could be in 10 thousand tons. A gravity tank is needed to increase the solid ballast of the system to ensure the stability at seabed, and the alternating loading change on the ground foundation caused by the specific gravity difference shall be solved. For floating platforms, an auto-adjusted ballast water system is required to keep the total system operating weight constant during oil-water replacement process.

Third, the wet method could only be used for storing a water-insoluble liquid such as crude oil only rather than a water-soluble liquid such as methanol.

Fourth, if the oil stored above water in a tank needs to be heated during storage, the changing oil-water interface makes it difficult to achieve.

A gravity based storage tank sitting at the seabed by its gravity has two deficiencies.

First, a gravity based tank could have specific requirements to its foundation bearing capacities, resulting in some locations at the seabed where the development program utilizing a concrete gravity platform could not be applied.

Second, in order to meet the required operating weight in survival conditions, a gravity platform usually requires a large number of additional permanent solid ballasts, resulting in that the dry weight of the platform is much heavier than its buoyancy and makes it unfeasible for the platform to re-float, re-move and be re-used for other fields at the end of its oil production.

THE PRESENT FIXED OFFSHORE PLATFORM TECHNOLOGY

There are two most important and common types of fixed offshore platforms in the world at present, including steel piled jacket platforms and concrete gravity platforms as mentioned above. The former includes traditional jacket platform, deep water jacket platform and compliant tower being used up to 530 meter in water depth. The said platforms usually do not have an oil storage function and could not be removed and reused. The characteristics of the latter are described above and no need to repeat. In addition, jack-up drilling, production integrated platform, as a type of removable and fixed platform, with same form and structures as jack-up drilling platform, has been used in 150 meters water depth, of which only the mat-typed jack-up platform could save a small amount of liquid in the mats.

THE PRESENT FLOATING OFFSHORE PLATFORM TECHNOLOGY

There are three main and common types of floating platforms for offshore oil/gas production in the world at present, including tension leg platform (TLP), SPAR and semi-submersible platform (SEMI). The said three types of platforms usually have no oil storage functions and have some disadvantages, such as high construction/maintenance costs and long construction period. The water plane areas of these three types of platforms are small and the majorities of their hulls submerged in deeper water depth, and so the hydrodynamic characteristics of them are very good. They are based on different methods to ensure platform stability, i.e. the positioning system of tension legs for TLP, the self-righting doll effect caused by the center of buoyancy (COB) above the center of gravity (COG) for SPAR, and the moment of inertia of the water plane areas of the columns for SEMI. Because the heave motions of TLP and SPAR are very small, well-head oil trees, i.e., the dry well trees, could be installed on the platforms and each tree is connected with each well respectively through a riser. SEMI is always matched with subsea wells (wet wells), and is possible to equip with dry wells only in limited waters with very good environmental conditions. Subsea well technology has matured, but the cost is high. Dry well is better than the wet well in both aspects of the investment and operating costs. However dry well application is subject to the hydrodynamic (heave) performance of the floater. In recent years, as deepwater platform technology matures, the heave motion could be very small and dry well applications have therefore been widely utilized. In addition to TLP and SPAR, there are other patented forms of floating platforms using dry wells. For example, a kind of floating platform with very good hydrodynamic performance, namely Tendon-Based Floating Structure (also called as Floating Tower). The Floating Tower has some characteristics of both SPARs and TLPs. Both catenary legs and tensioned legs (soft tendon) are adopted as the mooring positioning system of a Floating Tower and its COB is higher than its COG like a SPAR. However, the Floating Tower is also difficult to store oil. The portion piercing through water surface of the floating tower is jacket-shaped structure with good transparency, so its water plane area is much smaller compared with a SPAR. The required stiffness in heave direction for a floating tower has to be mainly from the tension of its soft tendons. Similar to a SPAR and different from a TLP, the heave natural period of a floating tower is usually higher than the period of the significant waves. As mentioned above, the main and popular floating production facilities with storage in the world is the ship-shaped FPSO, and however, it is very difficult for a FPSO to install drilling facilities and dry trees due to the restriction of its hull motions. In addition, a FPSO has also some disadvantages, such as great amount of interfaces, complicated facilities, longer construction period and expensive initial investments. Similar to a FPSO, there are many patented concepts of floating systems with large waterplane area and storage capacities. In 80s of last century, conical buoys was proposed as a concept of floating platform; then EXTENDED BASE FLOATER, also known as SINGLE COLUMN FLOATER, referred to the concept of SCF; and then SEMO (SEMI-SUBMARSIBLE MONOHULL) concept. All of them are cylindrical buoy floating platforms or multilateral cylindrical buoy floating platforms with a number of catenary mooring legs. Among them, SSP has been used in the North Sea and Brazil for oil field development and production. There are three biggest differences between the said concepts and a SPAR platform as following: First, the hull diameter and water plane area of them are much larger than a SPAR. Second, the draught of them is less and they all have a bottom brim for the purposes of damping and added mass. Third, their COGs are higher than COB, and their initial GMs for stability are from their inertial moments of water plane areas. The storage methods adopted for the said concepts are wet storage or tanker dry storage. Another patented concept of floating platform with underwater wet storage is the aforementioned semi-submersible " BOX SPAR", which consists of a rectangular box submerged in a sufficient water depth (for instance, about 40m) for oil wet storage, two rows of supporting legs and each row with a couple of rectangular cross-section tubular legs up piercing water surface from the box, topsides facilities to be installed on the supporting legs. The draught of the legs provides the vast majority of the required buoyancy. The pattern of mooring system for the box spar is as same as SEMI. However, the box spar is still difficult to use dry wells. The above-mentioned new patented schemes or concepts of floating platforms, except for cylindrical buoy platform (SSP-SEVAN STABILIZED PLATFORM), do not have any reports of practical applications in field developments. The SSP, with the tanker dry storage method used, still has FPSO's main disadvantages somewhat. In conclusion, the present floating platforms with good hydrodynamic performances, suitable for deep water applications with dry wells, such as the TLP and the SPAR, are difficult to store oil; whereas FPSO with storage function is difficult to use dry wells and to have drilling functions. Therefore, it is a great challenge for international offshore industry to research and develop floating platforms which have multi-functions of drilling, oil production and liquid storage simultaneously, and are also suitable for dry wells, convenient for workover operations, particularly in deep water applications.

THE PRESENT CONCRETE ARTIFICIAL ISLAND

At present, fixed platforms with storage for oil and gas development in shallow waters include artificial islands and concrete gravity platforms. Concrete artificial island includes a large-sized conventional backfilling type and a concrete pre-constructed type. As permanent facilities to store oil by conventional dry storage method or wet storage method, the mentioned two types of artificial islands could not be relocated. A small concrete artificial island, same as a concrete gravity platform, needs more solid ballast and relies on its massive gravity to be sit at the sea-bed. Different from the underwater storage tanks of a gravity platform, the storage tanks of an artificial island extend upwards out of water surface from the sea-bed to facilitate shuttle tanker berthing alongside directly. Floating artificial island suitable for deep waters is mainly defined as the above-mentioned cylindrical buoy floating platform (SSP-SEVAN STABILIZED PLATFORM), and no need to repeat.

The above 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 as it existed in Australia before the priority date of each claim of this application.

SUMMARY OF INVENTION

In accordance with a first aspect, the invention provides a liquid storage, loading and offloading system comprising:

a storage tank comprising at least one water ballast compartment to store water and at least one liquid storage compartment to store a liquid;

a volume of inert gas disposed in upper ends of the water ballast compartment and the liquid storage compartment;

wherein the upper ends of the water ballast compartment and the liquid storage compartment are fluidly coupled to each other to form an inert-gas-pressurized closed interconnected system; and

wherein the structure of the storage tank is configured symmetrically.

2009229435 25 Jan 2011

The present invention therefore provides a liquid storage, loading & offloading system to automatically implement equal mass flow-rate displacement between ballast seawater and stored liquids and its application for both fixed and floating facilities (platforms, artificial islands) with multi-functions of drilling, production & liquid storage for offshore oil and gas developments. The system and facilities of the invention address at least in part some disadvantages of the existing technologies of crude oil storage, loading and offloading, such as weight fluctuating during loading and offloading operations, pollution to the environments, and etc., as well as the disadvantage of the existing platforms being difficult to store oil.

When the present invention works as a hydrocarbon storage, loading and offloading system used underwater or at water surface conditions to perform loading, storage and offloading operations, the system typically comprises of 1) a plurality of multi-tanks, 2) pump module, 3) power and control wokring stations, 4) fixing component or mooring positioning system.

The described multi-tank comprises of one solid ballast compartment on occasion and at least one storage cell, wherein the said solid ballast compartment is below the cell or on the bottom of the cell. The said storage cell comprises of one seawater ballast compartment and one liquid storage compartment. Both seawater ballast compartment and liquid storage compartment are subject to internal or external pressures; and closed and pressurized inert gas is injected into the space above the liquid surface. The system is characterized in that, 1) any section level profiles of graphic of the multi-tank is rotation symmetry to its centroid in every fixing angle, or center of symmetry, or bilateral axial symmetry. The projections of the multi-tank's COB/ COG in the section profiles and the centroid overlap to each other; 2) the seawater ballast compartment and the liquid storage compartment within each set of cell are connected by a tube between the tops of the two compartments for gas-flowing, which form, in conjunction with a pump module, an automatic equal mass flow-rate displacement system between ballast seawater compartment and liquid storage compartment to ensure the operating weight of the multi-tank and its attached facilities constant and its operating COG changing only along the vertical Z axis which passes through the multi-tank's COB during loading and offloading operations.

The said pump module comprises of at least one pump group, each group containing two pairs of linkage pumps: one for offloading pair including one seawater ballast (loading) pump and one liquid offloading (discharging for transportation) pump to be linked to each other; another for loading linkage pump pair including one seawater offloading pump and one liquid loading pump to be linked to each other. Each pair of pumps is synchronized starting, running and stopping based on the equivalent mass flow-rate principle.

The said power and control working station to provide electricity and to implement operational control for the liquid storage, loading and offloading system, is usually installed on the system-served offshore or onshore facilities.

The described fixing component is a kind of piled-foundation for anti-sliding to fix the multi-tank of the system at the seabed for a fixed platform. The described mooring positioning system is a group of mooring legs to moor and anchor the multi-tank of the system at the seabed for a (submersible) floating system.

According to the present invention, optimization is made that an automatic control valve will be installed on the gas-flowing tube connecting the seawater ballast compartment and the liquid storage compartment. When the said liquid storage, loading and offloading system is in normal operations of loading or offloading, the control valve automatically opens, so the inert gas inside the seawater ballast compartment and liquid storage compartment connected to form a closed pressure-equalized compartment. When the control system alarm of the two operations occurs, or there is an accident and in an emergency, or when the two operations stop, the automatic control valve will be automatically shut down, so inert gas inside the two compartments is no longer connected and to form two separate compartments.

According to the present invention, the structural configurations of the storage cell of multi-tank include the forms of tank-in-tank configuration and non tank-in-tank configuration. The latter configuration refers to a configuration in which a seawater ballast compartment and a liquid storage compartment are adjacent or separated to each other in a symmetrical way. The forms of tank-in-tank configuration include: a single set of vertical and cylindrical storage cell, one or more sets of vertical and cylindrical petal-shaped storage cells, multi-sets of master and secondary storage cells. The forms of the non tank-in-tank include: single or multi-set of storage cells in the form of a single horizontal bamboo pole with multi-sections, single tube (layer) storage cell in the form of a bamboo raft, two kinds of symmetrical honeycomb storage cells, and the up-down arranged vertical storage cell(s).

The multi-tank optimization for one of the following types: vertical multi-tank liquid storage with a single set of cylinder storage cell, which is in a cylinder tank-in-tank form, or in up-down arranged vertical form; vertical multi-tank liquid storage with a single set of pedal-shaped cylinder tank-in-tank storage cells; vertical multi-tank liquid storage with multiple sets of pedal-shaped cylinder tank-in-tank storage cells; A-type vertical single-layer honeycomb multi-tank liquid storage with multiple sets of rotational symmetric storage cells; vertical multi-tank liquid storage with multiple sets of master and secondary storage cells; B-type vertical single-layer honeycomb multi-tank liquid storage with multiple sets of rotational symmetric storage cells; C-type vertical single-layer honeycomb multi-tank liquid storage with rotational symmetric storage cells; multi-layer tower ladder multi-tank liquid storage with multiple sets of storage cells; A-type SPAR multi-layer multi-tank liquid storage; B-type SPAR multi-layer multi-tank; C-type SPAR multi-layer multi-tanks; A-type horizontal multi-tank with tank-in-tank storage cells in the form of a bamboo raft; B-type horizontal multi-tank with single layer storage cell in the form of a bamboo raft with multiple poles, wherein every four unit-tubes forming a group of symmetrical storage cells; C-type horizontal multi-tanks with multi-set of storage cells in a single horizontal bamboo pole configuration with multi-sections; A-type flat box-shaped honeycomb multi-tank with cylinder tank-in-tank storage cells; B-type flat box-shaped honeycomb multi-tank with a single set of up-down vertically arranged storage cells; C-type flat box-shaped multi-tank with every four cells forming a symmetrical honeycomb-shaped storage cell.

According to the present invention, two liquid inlets of the liquid storage, loading & offloading system are located at the top and bottom of the liquid storage compartment and one outlet is located at its bottom. When there is a need for heating the stored liquid to maintain the design temperature, the stored liquid will be pumped out by a circulating pump and heated by an outside heater to achieve the heating purpose.

According to the present invention, the liquid storage, loading & offloading system also includes a single point mooring system or a spread mooring system. The system may not only receive liquid products or commodities from onshore facilities or offshore platforms, but also from shuttle tanks. The stored liquid will be discharged by the offloading pump for transportation, not only to shuttle tankers, but also to onshore facilities.

According to the present invention, when the design pressure of the pressurized inert gas is less than the outside hydrostatic pressure of seawater, the multi-tank will be built with concrete materials; as the described design pressure higher than the outside hydrostatic pressure, steel or concrete materials could both be used.

The upper and lower portions of the multi-tank may be built with lighter or heaver concrete respectively, and may use different types of concrete structures. The described concrete structures include one or more types of reinforced concrete, pre-stressed concrete, CFT, steel-framed reinforced concrete, fiber reinforced concrete, steel sandwich concrete structures and steel could be coated with outer concrete structure.

A type of bottom-supported and fixed platform with seabed storage has multi-functions of drilling, workover, production, utilities and accommodation, and includes the following: a fixed liquid storage, loading and offloading system (not including the single point mooring or spread mooring system).The multi-tank of the system is a kind of concrete structure fixed at the seabed as the foundation of the platform. A pump module and power/remote control station of the system are installed on the platform top, or installed in water outside the underwater multi-tank if underwater pumps are selected as the offloading pump and offloading pump. Platform legs are installed on the top of the fixed multi-tank. Platform topsides, installed on the supporting legs, are selected as same as the topsides of existing fixed platforms or the watertight bulkheads and rise-and-fall topsides of jack-up platforms. Its technical features are that it does not rely on its own massive gravity, but mainly rely on piled-foundation for anti-sliding to fix the platform at the seabed. The total operating weight of the platform equal to or greater than the overall buoyancy of the underwater part of the platform; and also, if necessary, stayed-cable fixed system could be supplemented for anti-sliding and anti-overturning.

A type of floating platform with underwater storage capacity has multi-functions of drilling, workover, production, utilities and accommodation, and includes the following: a floating liquid storage, loading and offloading system (not including the single point mooring or spread mooring system), wherein the multi-tank of the system is a kind of concrete structure is submerged in sufficient water depth as the underwater foundation of the platform, the pump module and power/remote control station of the system installed on the platform top, or installed in water outside the underwater multi-tank if underwater pumps are selected as the offloading pump and offloading pump, platform legs installed on the multi-tank top, which are one or three or four concrete cylindrical or conical tube shaped legs, platform topsides installed on the supporting leg(s), which is selected as same as watertight bulkhead structure or similar to a SPAR platform, and mooring positioning system to moor the floating platform at the seabed. It is characterized in that: 1) the draught and floating condition of the floating platform has little change during loading and offloading operations, and the COG is always located along the center axis of floating platform; 2) deep-draught, small water plane surface area; and 3) the COB of the single-leg floating platform above its COG.

A kind of removable concrete artificial island, having two types such as a fixed one and a floating one, which include concrete multi-tanks as the body of the islands. A solid ballast compartment may be set in the multi-tank as per the actual requirements. An equal mass flow-rate displacement system between ballast seawater and stored liquid is utilized for the multi-tank, and a traditional pump module installed on the multi-tank of the island body or instead using deep well pumps installed in the interior of the island. Topsides facilities are installed on the top of the multi-tank of the island body. It is characterized in that: the island body stretches upward piercing water surface, the island freeboard high enough to reduce or avoid green water over the top of the island, and the gap between the lower deck of the topsides and the top of the multi-tank to assure no green waters over the lower deck in design sea conditions with a minimum safety margin.

The present invention of liquid storage, loading and offloading system guarantees that the operating loads are constant during loading, storage and offloading operations, and no pollution to the environments and no waste of oil/gas resources based on closed and dry storage process. The system could store both water insoluble liquids and water-soluble liquids such as methanol, and could easily achieve the insulated liquid storage heating. Pressure vessel structure is adopted for the seawater ballast compartment and liquid storage compartment of the multi-tank to ensure structure stress reasonable to the strength of the tank design, construction convenient and saving investment. In addition, when the liquid storage, loading, offloading system needs to be removed and reused, it could easily float up and remove after removing the piled-foundation for anti-sliding or mooring legs with emptying or reducing the liquids inside the multi-tank. Based on the said liquid storage, loading and offloading system, the present invention also provides for some offshore facilities with integrated functions of drilling, oil production, utilities, accommodations and oil (liquid) storage used for offshore oil and gas development.

In accordance with a second aspect, the invention provides a process of a loading and offloading system with equal mass flow rate displacement system comprising:

transporting a stored liquid or water from a bottom of a liquid storage compartment or a water ballast compartment to an inlet of a liquid offloading pump or a water offloading pump by a pressure energy of an inert gas;

offloading the stored liquid or water by the respective offloading pump or only by the pressure energy of the inert gas;

supplying the inert gas to maintain pressure of the inert gas of the liquid storage compartment or the water ballast compartment;

and wherein the supplied inert gas is from the water ballast compartment which is loaded with water at the same mass flow rate as the offloaded liquid, or from the liquid storage compartment which is loaded with liquid at the same mass flow rate as the offloaded water.

In accordance with a third aspect, the invention provides a liquid storage, loading and offloading system comprising:

an artificial island comprising at least one water ballast compartment to store a water and at least one liquid storage compartment to store a liquid inside;

a topside facility disposed above the artificial island to produce hydrocarbon;

a volume of inert gas in the water ballast compartment and the liquid storage compartment; and

wherein the hydrocarbon generated by the topside facility is stored directly in the artificial island.

BRIEF DESCRIPTION OF THE DRAWINGS

Combined with accompanying drawings and examples of application, further description of the invention is as follows:

Figure 1 is a liquid storage, loading and offloading system flow chart;

Figure 2-1 is pressure distribution lines with water depth changes inside the seawater ballast compartment and the liquid storage compartment of the "tank-in-tank" storage cell, on working conditions of the liquid storage compartment empty-loaded and the seawater ballast compartment full-loaded at the same time, and the pressure of inert gas inside the two compartments less than the outside seawater hydrostatic pressure;

Figure 2-2 is pressure distribution lines with water depth changes inside the seawater ballast compartment and the liquid storage compartment of the "tank-in-tank" storage cell, on working conditions of the liquid storage compartment full-loaded and the seawater ballast compartment empty-loaded at the same time, and the pressure of inert gas inside the two compartments less than the outside seawater hydrostatic pressure;

Figure 2-3 is pressure distribution lines with water depth changes inside the seawater ballast compartment and the liquid storage compartment of the "tank-in-tank" storage cell, on working conditions of the liquid storage compartment empty-loaded and the seawater ballast compartment full-loaded at the same time, and the pressure of inert gas inside the two compartments larger than the outside seawater hydrostatic pressure;

Figure 2-4 is pressure distribution lines with water depth changes inside the seawater ballast compartment and the liquid storage compartment of the "tank-in-tank" storage cell, on working conditions of the liquid storage compartment full-loaded and the seawater ballast compartment empty-loaded at the same time, and of the pressure of inert gas inside the two compartments larger than the outside seawater hydrostatic pressure;

Figure 3-1 is a sectional view of a vertical multi-tank liquid storage with a single-set of the cylinder tank-in-tank storage cells;

Figure 3-2 is a cross-sectional view of Figure 3-1 taken along line A-A;

Figure 4-1 is a sectional view of a vertical multi-tank liquid storage with multiple sets of the pedal-shaped cylinder tank-in-tank storage cells;

Figure 4-2 is a cross-sectional view of Figure 4-1 taken along line A-A;

Figure 5-1 is a sectional view of an A-type vertical single layer honeycomb multi-tank liquid storage with multiple sets of rotational symmetric storage cells (circle).

Figure 5-2 a top view of Figure 5-1;

Figure 6-1 is a sectional view of an A-type vertical single layer honeycomb multi-tank liquid storage with multiple sets of rotational symmetric storage cells (rectangular);

Figure 6-2 a top view of Figure 6-1;

Figure 7-1 is a top view of an A-type horizontal multi-tank liquid storage with multiple bamboo poles storage cells;

Figure 7-2 is a cross-sectional view of Figure 7-1 taken along line A-A;

Figure 8-1 is a sectional view of a multi-layer tower ladder multi-tank liquid storage with multiple sets of storage cells;

Figure 8-2 is a cross-sectional view of Figure 8-1 taken along line A-A;

Figure 9-1 is a sectional view of an A-type SPAR multi-layer multi-tank liquid storage;

Figure 9-2 is cross-sectional view of Figure 9-1 taken along line A-A;

Figure 10-1 is sectional view of a protruding skirt-shaped lower solid ballast compartment;

Figure 10-2 a cross-sectional view of Figure 10-1 taken along line A-A;

Figure 11-1 is a top view of a vertical multi-tank liquid storage with multiple sets of master and secondary storage cells taken along line A-A in Figure 11-2;

Figure 11-2 is a sectional view taken along ling B-B in Figure 11-1;

Figure 12-1 is an elevated view of a C-type honeycomb multi-tank liquid storage in flat box-shaped;

Figure 12-2 is a top view of the C-type honeycomb multi-tank liquid storage in flat box-shaped;

Figure 13-1 is a elevated view of a B-type vertical honeycomb multi-tank liquid storage with multiple sets of rotational symmetric storage cells (also the artificial island made of steel tank coated with concrete);

Figure 13-2 is a top view of Figure 13-1;

Figure 13-3 is a horizontal sectional view of an anti-sliding fixing device-apron pile;

Figure 13-4 is a horizontal sectional view of an anti-sliding fixing device-suction pile;

Figure 14-1 is a top view of a wheel-shaped solid ballast compartment;

Figure 14-2 is the enlarged view of Figure 14-1 taken along line A-A;

Figure 15 is an illustration of a liquid storage, loading and offloading system with a bottom-supported and fixed platform near shore;

Figure 16 is an illustration of a liquid storage, loading and offloading system with a bottom-supported and floating platform offshore;

Figure 17 is a drawing of bottom-supported and fixed platform with liquid storage at the seabed and a concrete cylinder platform leg;

Figure 18 is a drawing of a bottom-supported and fixed platform with liquid storage at the seabed and a conventional jacket leg;

Figure 19 is a drawing of a bottom-supported and fixed platform with liquid storage at the seabed and a compliant tower leg;

Figure 20 is a drawing of a bottom-supported platform with liquid storage at the seabed and a jack-up platform leg (for the integrated towing and offshore installation program);

Figure 21 is a drawing of a bottom-supported platform with liquid storage at the seabed and a jack-up platform leg (for pre-installed multi-tank liquid storage program);

Figure 22-1 is a front view of a bottom-supported and floating platform with underwater liquid storage and a single leg;

Figure 22-2 is an enlarged view of Figure 22-1 taken along line A-A;

Figure 23 is a drawing of a bottom-supported and floating platform with underwater liquid storage and multiple legs;

Figure 24-1 is a front view of a floating platform with an A-type SPAR multi-layer multi-tank liquid storage;

Figure 24-2 is an enlarged view of Figure 24-1 taken along line A-A;

Figure 25-1 is a front view of a floating platform with a C-type SPAR multi-layer multi-tank liquid storage;

Figure 25-2 is a cross-sectional view of Figure 25-1 taken along line A-A;

Figure 25-3 is a cross-sectional view of Figure 25-1 taken along line B-B;

Figure 25-4 is a cross-sectional view of Figure 25-1 taken along line C-C;

Figure 26 is a front view of a removable and fixed concrete artificial island;

Figure 27 is a front view of a removable and floating concrete artificial island;

Figure 28 is a plane schematic diagram of the overall surface facilities with multi-functions of drilling, production, storage, utilities and accommodation for oil & gas development in shallow waters using a fixed concrete artificial island;

Figure 29-1 is a sectional view of a B-type SPAR multi-layer multi-tank liquid storage (taken along line A-A in Figure 29-2);

Figure 29-2 is a cross-sectional view of Figure 29-1 taken along line B-B;

In above Figures: 1. composite cable for electrical power and control; 2. working station providing electrical power supply and remote control; 3. subsea pipeline; 4.pump module; 4-1 traditional pump module; 4-2 underwater pump module; 5. seawater offloading pump; 6. seawater loading pump; 7. liquid loading pump; 8. converting valve for an inlet of liquid; 9. converting valve for an outlet of liquid; 10. liquid offloading pump; 11. subsea flexible riser; 12. SPM (single point mooring) system; 13. mooring line for a shuttle tank; 14. floating hose; 15. shuttle tanker; 16. storage cell; 17. automatic control valve of storage cell; 18. seawater ballast compartment; 19. multi-tank liquid storage; 20. solid ballast compartment or solid ballast materials; 20-1. implicit bottom solid ballast compartment; 20-2. protruding skirt-shaped bottom solid ballast compartment; 20-3. protruding skirt-shaped lower solid ballast compartment; 20-4. implicit lower solid ballast compartment; 20-5. wheel-shaped solid ballast compartment; 21.liquid storage compartment; 22. arch-shaped end seal plate; 23. ring and arch-shaped end seal plate; 24. flat-shaped end seal plate; 25. petal-shaped storage cell; 26. radial frame inside a pedal-shaped cylinder; 27. moon pool; 28. sleeve and locking devices; 29. steel leg for sliding; 30. extended structure accompanying multi-tank liquid storage piercing through the water surface ;31anti-sliding fixing device underwater; 31-1. pile; 31-2 apron pile; 31-3. suction pile; 32. underwater base plate; 33. mooring positioning system for SPM; 34. mooring positioning system for a floating platform or floating artificial island; 35. small underwater plate of floating multi-tank liquid storage; 36. topsides facility; 37. fixed platform leg; 37-1. concrete leg; 37-2. conventional jacket leg; 37-3. compliant tower leg; 37-4. jack-up leg; 38. platform leg of a floating platform; 39. leveling template; 40. tower base template; 41. tower base section of a compliant tower leg; 42. tower top section of a compliant tower leg; 43. stayed-cable for a positioning system for a fixed platform; 44. jack-leg joint; 45.watertight bulkhead compartment; 46. protecting shield from falling objects; 47. upholder for a protecting shield from falling objects; 48. offshore production facilities; 49. fixed artificial island; 49-1. a fixed concrete artificial island with multi-function of drilling, production, storage and offloading; 49-2. a fixed concrete artificial island with multi-function of storage, offloading utilities and accommodation; 50. multi-tank liquid storage for being an island body; 51. multi-tank liquid storage with a master and secondary storage cell; 51-1.master compartment; 51-2. secondary compartment; 52. honeycomb multi-tank liquid storage cell; 53. interconnecting plate between steel honeycomb storage cells; 54. arc-shaped connecting plate between steel honeycomb storage cells; 55. reinforced concrete outer protection and weight coating of steel tank; 56. seal plate between honeycomb storage cells; 57. partition plate in a vertical honeycomb storage cell; 58. wheel-shaped solid ballast compartment; 59. connecting device; 59-1. connecting radial plate; 59-2. inclined tie bar at the top; 60. small platform for mooring dolphin; 61. trestle; 62. underwater multi-tank liquid storage with bamboo raft storage cells mounted at the seabed; 63. multi-tank liquid storage with bamboo raft storage cells; 64. pipe for connecting different compartments, which belong to different storage cells arranged adjacently in vertical; 65 horizontal frame; 66 horizontal bar for connecting; 67 damping plate for horizontally connecting.

In the above drawings, the same number is for the same component.

DESCRIPTION OF SPECIFIC EMBODIMENT

LIQUID STORAGE, LOADING & OFFLOADING APPARATUS AND SYSTEMS

The invention of the "liquid storage, loading and offloading system" constituted mainly of four parts (see Figures 1, 15 and 16):The first part, including underwater multi-tank liquid storage 19 (hereinafter referred to as multi-tank) and its fixing components or positioning system (station keeping system).The multi-tank includes a solid ballast compartment 20,(if necessary, and one or more sets of storage cellcell 16; each storage cell includes at least one seawater ballast compartment 18 and one liquid storage compartment 21. Inert gas in the top spaces inside the said two compartments is connected through an automatic control valve 17. The fixed multi-tank sit at the seabed is fixed by an anti-sliding fixing device 31. Underwater floating multi-tank is moored at the seabed by mooring positioning system 34. The seawater ballast compartment on the bottom of multi-tank may be added with ballast material 20 to replace the solid ballast compartment (see Figure 7-2). The solid ballast compartment could be canceled for those multi-tanks not needing solid ballast. The second part, a pump module 4, which includes: 1) At least one group, each group containing two pairs of linkage pumps: offloading linkage pumps, including one seawater ballast pump (loading pump) 6 and one liquid offloading (discharging for transportation) pump 10 linked to each other; loading pump linkage, including one seawater offloading pump 5 and one liquid loading pump 7 linked to each other. Each pair of linkage pumps are synchronized starting, running and stopping in equal mass flow-rate. 2) Corresponding piping, (control) valves, field instrumentation, control and implementation components. It could be a "(wet) underwater pumps (subsea pumps) module 4-2", directly installed on the underwater multi-tank; also it could be a "(dry) traditional pump module 4-1," installed on the multi-tank attached structures 30 out of the water surface (such as on a small platform). Traditional pumps mean the normal centrifugal pumps or submersible centrifugal pumps (deep well pumps).

The third part, a SPM (single point mooring) system 12 for a shuttle tanker 15: it could be constructed and integrated with the multi-tank, using SALM or similar SPM systems; also it could be constructed separately and installed above or near to the multi-tank, using any of other forms of SPM systems compatible with the sea conditions of the field, such as CALM, STL or others. Spread mooring system may be used instead of SPM system in waters with good environmental conditions.

The fourth part, a working station 2 to provide electrical power and to implement operational control to the liquid storage, loading and offloading systems, which could be built onshore, or also on the systems served offshore fixed or floating production facilities 48, such as a platform.

The said four parts form an integrated system through a corresponding underwater power and control composite cable 1, a subsea pipeline 3 and a subsea flexible riser 11, wherein the multi-tank together with the pump module form "an equal mass flow-rate displacement system between ballast seawater and stored liquid with closed, pressurized inert gas and inter-connected process". The flow system could be: 1).To receive and store liquid products, such as crude oil produced from an offshore production facilities 48 or a land-based plant, and then transfer it to a shuttle tanker 15 for transportation on a regular basis through a single point mooring system 12, as shown in Figures 1, 15 and 16; among them, the shuttle tanker 15 connected with the single point mooring system 12 through a mooring line 13 and a floating hose 14. In this condition, the present invention becomes an offshore liquid storage and export terminal. 2). To receive liquid products, such as crude oil transported from the shuttle tankers 15 by a single point mooring system 12 periodically, then to store and uninterruptedly transport the liquid products through a subsea pipeline 3 to land where it is needed, or again through a single point mooring system 12 to transfer the liquid products to a transit transportation tanker for export, as shown in Figures 1 and 15. In this condition, the present invention becomes an offshore liquid receiving, storage and distribution terminal with the same functions of the existing oil depot and oil wharf. It could be constructed as a bottom-supported and fixed underwater (liquid) storage, loading & offloading system to fix its multi-tank at the seabed by the underwater anti-sliding fixing device (see Figure 15), or as a submerged floating (liquid) storage, loading & offloading system to moor its multi-tank to the seabed by underwater mooring legs (positioning system) (see Figure 16).

BOTTOM-SUPPORTED AND FIXED PLATFORM WITH SEABED STORAGE

The invention of "bottom-supported and fixed platform with liquid storage at the seabed" mainly consists of three parts (see Figure 17 - Figure 21). The first part is the liquid storage system, i.e. the said fixed liquid storage, loading and offloading system (excluding the SPM or spread mooring system). The concrete multi-tank 19 is fixed at the seabed by the anti-sliding fixing device 31 as the foundation of this platform. The traditional pump module 4-1 is installed on this platform or the underwater pumps, selected as the seawater offloading pump and the liquid offloading pump, installed outside the underwater multi-tank. The working station 2 for power supply and remote control is installed on this platform and integrated with the production and utilities systems of the platform. The second part is a fixed platform leg 37 installed at the top of the fixed multi-tank. It could be done as a concrete gravity platform, using one or more cylindrical or tapered cylindrical concrete legs 37-1 (see Figure 17), a conventional steel fixed platform jacket leg 37-2 (see Figure 18), a deepwater compliant tower leg 37-3 (see Figure 19), or a steel jack-up leg 37-4 for a jack-up platform (see Figures 20 and 21). The third part is a topside facility 36 installed at the top of the platform leg, which could be as same as the topsides facilities of a general fixed platform, or a self rise-and-fall platform to adopt watertight bulkhead compartment 45.

FLOATING PLATFORM WITH UNDERWATER STORAGE

The invention " floating platform with underwater liquid storage" mainly consists of four parts (see Figure 22 ~ 25): The first part, the liquid storage system, i.e. the said floating liquid storage, loading and offloading system (excluding the SPM or spread mooring system), wherein a concrete multi-tank 19 is submerged in sufficient water depth as the underwater foundation of this platform, wherein the traditional pump module 4-1 is installed in the pumps compartment inside the concrete cylindrical platform leg 38 of this platform or subsea pumps, selected as the seawater offloading pump and the liquid offloading pump, installed outside the underwater multi-tank, wherein the working station 2 for power supply and remote control is installed on this platform and integrated with the production and utilities systems of the platform. The second part is the platform leg 38 installed at the top of the submerged multi-tank. It could be done as a concrete gravity platform, using one or three or four concrete cylindrical or conical tube shaped legs. The third partis a topsides facility 36 installed at the top of the platform leg(s). It could be done as the semi-submersible platform, with watertight bulkhead compartment. It could also be similar to the topsides facilities of SPAR. The fourth part is a mooring positioning system 34 to moor the floating platform at seabed, of which the mooring leg system could be similar to the ones for a SPAR platform or a semi-submersible platform adopted in the present invention..

REMOVABLE ARTIFICIAL ISLAND

The invention "removable artificial island", including two types: a fixed one and a floating one, mainly consists of three parts (see Figure 26 and 27): The first part, the liquid storage system, i.e. the said liquid storage, loading and offloading system (excluding the SPM or spread mooring system).The underwater multi-tank 19 stretches upward piercing the water surface as the body of the island. The traditional pump module 4-1 is installed in the topsides or deep well pump selected and installed inside the island body. The power supply and remote control working station 2 is installed on the topsides and integrated with the production and utilities systems of the island. The second part is a topside facility 36 installed on the multi-tank of the island. The third part is ananti-sliding fixing device 31 to fix the fixed artificial island at the seabed, or a mooring positioning system 34 to moor the floating artificial island at the seabed, of which the mooring leg system same as or similar to the system of SPAR platform or semi-submersible platform is adopted in the present invention.

In short, according to the situations that the said multi-tank is fixed at the seabed or submerged floating in the water or stretched upward out of the water, the different methods of fixing or positioning the multi-tank underwater, whether the legs stretched out of the water being installed at the top of the multi-tank, whether the platform topsides structures/facilities being installed on the legs, or whether the topsides facilities being mounted directly on the top of the multi-tank, the present invention includes 6 types of different forms of systems/facilities: 1. Bottom-supported and fixed underwater (liquid) storage, loading & offloading - UNDERWATER GROUNDED STORAGE LOADING & OFFLOADING UNIT (UGSLO) (see Figure 15).Its multi-tank 19 is fixed at the seabed by the anti-sliding fixing device 31. 2. Submerged floating (liquid) storage, loading & offloading system- UNDERWATER FLOATING STORAGE LOADING & OFFLOADING UNIT (UFSLO) (see Figure 16). Its multi-tank is submerged and floating at a proper water depth to be moored at the seabed by the positioning system of catenary, taut or semi-taut mooring positioning system 34. 3. Bottom-supported and fixed platform with liquid storage at the seabed- FIXED PLATFORMS WITH SEABEDED STORAGE (FPSS) (see Figures 17 ~ 21), which is fixed at the seabed by the underwater anti-sliding fixing device 31 attached to the underwater multi-tank, and if necessary, supplemented by a stayed-cable 43 as an accessory fixing measure (see Figure 15). 4. Bottom-supported and floating platform with underwater liquid storage-FLOATING PLATFORMS WITH UNDERWATER STORAGE (FPUS) (see Figures 22 ~ 25). Its multi-tank is submerged and floating at a proper water depth and the platform is moored at the seabed by the positioning system of catenary, taut or semi-taut mooring positioning system 34. 5. Removable fixed artificial island-MOVABLE SEABEDED ARTIFICIAL ISLAND (MSAI). Its multi-tank of the island body stretches upward piercing water surface and it is fixed at the seabed by the anti-sliding fixing device 31 (see Figure 26). 6. Removable floating artificial isand-MOVABLE FLOATING ARTIFICIAL ISALDN (MFAI). Its multi-tank of the island body stretches upward piercing water surface and is moored at the seabed by the mooring positioning system 34 (see Figure 27).

EQUAL MASS FLOW-RATE DISPLACEMENT SYSTEM BETWEEN BALLAST SEAWATER AND STORED LIQUIDS WITH CLOSED, PRE-GAS-PRESSURIZED AND INTER-CONNECTED PROCESS

This system mainly includes multi-tank 19 and pump module 4, and Figure 1 is the Schematic diagram for the displacement process which shows that one set of storage cell 16 inside the multi-tank 19, and the inert gas inside the upper portions of the seawater ballast compartment and the liquid storage compartment of the storage cell is connected by an opened automatic control valve 17. In the different two operations of loading / offloading ballast water and offloading liquid / loading ballast water, the automatic control valve 17 automatically opens, and the upper inert gas within the seawater ballast compartment 18 and the liquid storage compartment 21 is connected to form a sole closed interconnected system with pressurized inert gas. The automatic control valve 17 will be automatically shut down and then the gas-phase spaces inside the two compartments will be as two independent systems, in case that the system in alarm status during the two operations, such as the liquid level or gas pressure inside any of the two compartments abnormal, or in accidents and other emergency situations; or, when the two operations stopped. The two independent systems is an important measure to reduce the risk of liquid leakage /pollution caused by tank broken. Displacement process as Figure 1 could be simplified to exclude the automatic control valve 17 and let the upper inert gas inside the seawater ballast compartments 18 and liquid storage compartment 21 directly connected. The emergent safety of this simplified process is worse than the former.

The process of the displacement system is illustrated as follows. First, while either seawater or liquid is offloaded, the other one will be loaded at equal mass flow rate to maintain constant equal mass through the operation of the linkage pumps. Second, two steps of offloading stored liquid or seawater are as follows. The first step is to transport stored liquid or seawater from the bottom of the compartment to the inlet of the offloading pump by the pressure energy of inert gas. In one embodiment, at equilibrium, the inert gas is not pressurized. In another embodiment, an operator can selectively pressurize the inert gas so that no pumps are necessary to offload the liquid and/or the water. The second step is to offload stored liquid or seawater by the offloading pump. In one preferred embodiment, if the back-pressure of inert gas is large enough, the liquid and seawater offloading pump is not necessary. While offloading stored liquid or seawater, the volume of inert gas increases in this compartment. Therefore, to supply with inert gas to maintain constant pressure is required. Third, at the same time, while the other liquid is loaded in the compartment at equal mass flow rate, the inert gas in this compartment will be discharged to the other compartment, where stored liquid or seawater is offloaded. Therefore, the pressure energy of inert gas in the compartment, where stored liquid or seawater is offloaded, could be supplied. Then, the variation of pressure of inert gas can be controlled within a small range. If the specific gravities of seawater and stored liquid are different, "equal mass flow rate displacement" can't be equal to "equal volume flow rate displacement." Therefore, the pressure of inert gas in the top of seawater ballast compartment 18 and liquid storage compartment 21 changes with the variation of volume. Based on theoretical calculation, the relation between the change of the maximum pressure of inert gas Pmax and the minimum pressure of inert gas Pmin, the specific gravity of stored liquid $\gamma 1$, and the specific gravity of seawater ballast γw (set: $\gamma 1 < \gamma w$) is as follows: $1 > Pmin/Pmax > \gamma 1/\gamma w$. It means that when the specific gravity of the stored liquid is less than the specific gravity of seawater ballast, the ratio of the Pmax and Pmin is slightly larger than the ratio of the gravity of stored liquid and the gravity of seawater ballast.

If the inert gas pressure is greater than or less than its hydrostatic pressure outside, the process consists of two design options, of which only ballast seawater and stored liquid discharged is slightly different. The two options are as follows: seawater is pumped in by a seawater loading pump 6 into the seawater ballast compartment 18 through an inlet filter and stored liquid is pumped into the liquid storage compartment by the liquid loading pump 7; a group for converting valves 8 is installed at the inlet of the liquid loading pump 7, and by the way of switch-over, the liquid products, both from on-land devices / offshore platforms or from a shuttle tanker 15 through the SPM 12, could be received. Different parts are respectively as follows: for the option that the inert gas pressure is less than its water static pressure outside, the ballast seawater is discharged out by the seawater offloading pump (submersible pump) 5 and stored liquid is pumped out by the liquid offloading pump (submersible pump) 10, both heights of their inlets shall assure that the pressure head heights are great than their allowable suction head heights; for the option that the inert gas pressure is larger than its water static pressure outside, as long as the inert gas pressure is large enough, both ballast seawater and stored liquid could be discharged out by the pressure energy of the inert gas and the seawater loading pump 5 and the liquid offloading pump 10 could be canceled or just used as a back-up one. A group of converting valves is installed at the outlet of the liquid offloading pump 10 in both the two mentioned options, and by the way of switch-over, the stored liquid could be transported out to the shuttle tanker15 through the SPM 12 or to on-land facilities through the subsea pipeline 3. In order to achieve that the equal mass flow-rate, the loaded liquid and the offloaded ballast seawater should be equal in mass value, both the liquid loading pump 7 and the seawater offloading pump 5 are linked through automatic control of backflow line or adjustment of the pump rates, and Figure 1 does not indicate the above mentioned options because the said two automatic control systems and methods are the conventional technique. Similarly, in order to achieve that the equal mass flow-rate of the offloaded liquid and the loadded ballast seawater are equal in mass value, both stored liquid offloading pump 10 and seawater loading pump 6 are also linked through the same automatic control as mentioned above. If the two specific gravities of the stored liquid and ballast seawater are different, the condition, that the two mass flow-rates are equal in mass value, is the two volume flow-rates are inversely proportional to the two specific gravities.

In order to ensure that the bilge liquid is as less as possible after the seawater ballast compartment or the liquid storage compartment to be empty, the intakes of the seawater offloading pump 5 and the liquid offloading pump 10 shall be located at tank bottoms. In order to meet the needs of stored liquid heating and heat insulation, two outlets of the liquid loading pump 7 are required: One is at the bottom of liquid storage compartment 21, and the heated liquid is pumped directly to the tank bottom to suit the normal loading condition. Another one is at the top of the liquid storage compartment 21, when there is a need to cycle the stored liquid for heating and insulation, close the bottom outlet and open the top outlet. The heated stored liquid is loaded from the top inlet by the circulating pump, and at the same time, the equal mass cold liquid is offloaded out to the outside heat exchangers (Figure 1 does not indicate) for heating through a circulating pump, and then, the heated liquid is then back to the top inlet to achieve heating circulation.

Pressure Distribution Charts Inside and Outside the Compartment Wall and the Set Points of the Inside Inert Gas Pressure during Loading & Offloading

For those tanks which are surrounded by seawater outside, the loads exerting on the tanks are as follows: 1) linear distribution of external pressure as per "seawater depth × its specific gravity" (seawater hydrostatic pressure), 2) internal pressure of inert gas, 3) linear distribution of internal pressure of liquid inside the tank as per "liquid level height × its specific gravity". If the internal pressure of inert gas increases with the increasing water depth of the tank, it could guarantee that the tank wall-borne pressure basically does not increase with water depth, which means a lot for a deep water system with multi-tank. The wall of inner compartment within the "tank-in-tank" of a multi-tank is exposed only to the internal and external pressures of the liquids inside and outside the said compartment, which are both linearly distributed as per "liquid level height × its specific gravity" and not related to the inert gas pressure within the compartment, nor the seawater pressure outside the tank. Figures 2-1 ~ 2-4 show the pressure distribution lines inside and outside the walls of seawater ballast compartment 18 and the liquid storage compartment 21 within a "tank-in-tank" storage cellcell during loading and offloading, on working conditions when the liquid storage compartment empty-loaded and the pressure of inert gas in the two compartments less (Figure 2-1) and larger (Figure 2 - 3) than the outside seawater hydrostatic pressure, as well as on working conditions when the liquid storage compartment full-loaded and the pressure of inert gas in the two compartments less (Figure 2-2) and larger (Figure 2 - 4) than the outside seawater hydrostatic pressure. In the Figures: oblique line ABCD indicates the distribution line of seawater hydrostatic pressure changing with the water depth outside the multi-tank;dogleg line EFG indicates the internal pressure changing with the depth of the outer compartment within the tank-in-tank; and dogleg line HIJ indicates the internal pressure changing with the depth of the inner compartment within the tank-in-tank with Z-axis as vertical depth axis.

As mentioned above, according to the inert gas pressure distribution inside the seawater ballast compartment 18 and the liquid storage compartment 21 is less than or larger than the static water pressure outside, the present invention provides respectively two slight different options of equal mass flow-rate displacement system between ballast seawater and stored liquids with closed, pre-pressurized gas and inter-connected process. For the first one, the inside inert gas pressure is less than the outside seawater hydrostatic pressure. In order to make the pressure difference minimized between the inside and outside of the seawater ballast compartment 18 and to ensure that the inside inert gas pressure is less than the outside water static pressure, the maximum pressure of the inside inert gas in Figure 1 process shall be set to the outside seawater hydrostatic pressure at the top-point inside the seawater ballast compartments 18, that is equivalent to the horizontal segment B'B (E) in Figures 2-1 and 2-3. The pre-condition to select traditional centrifugal pumps for seawater offloading pump 5 and liquid offloading pump 10 in this process is that the inside inert gas pressure could lift the seawater or stored liquid from the compartment bottom to the compartment top, otherwise submersible pump should be used instead. In short, the pump inlet suction head height should be greater than the difference between the outside seawater hydrostatic pressure and the inert gas pressure inside the compartment. The multi-tank in this process should choose concrete as the most suitable material to build because its compression strength is much higher than its tensile strength. When this process is used for a platform, or for an artificial island in particular, or in case of reducing the inside inert gas pressure for safety reasons, the minimum pressure of inert gas in Figure 1 process could be set higher than atmospheric pressure to meet the requirement for the pump suction head height, and deep well pumps shall be used for seawater offloading pump and liquid offloading (export) pump, or instead using subsea pumps installed outside the underwater multi-tank. For the second one, the inside inert gas pressure is larger than the outside seawater hydrostatic pressure. In order to make the pressure difference between the inside and outside of seawater ballast compartment 18 minimized and to ensure that the inside inert gas pressure is larger than the outside water static pressure, the minimum pressure of the inside inert gas in Figure 1 process shall be set to that the outside seawater hydrostatic pressure at the same level of the bilge surface inside the seawater ballast compartments 18, that is equivalent to the horizontal segment C'C in Figures 2-2 and 2-4. Submersible pumps are not needed as the seawater offloading pump 5 and the liquid offloading pump10 in this process. Not only that, when the inert gas pressure inside the multi-tank is large enough to form a "pressure spring piston" with sufficient strength at the tops of the ballast seawater and the stored liquid, the seawater offloading pump 5 and the liquid offloading pump10 could be cancelled, the ballast seawater or the stored liquid will directly be lifted to the required height based on the energy of the inert gas pressure. Steels with its tensile strength is higher that its compression strength is more suitable to be used for the multi-tank in this second process.

The Advantages and Disadvantages of this Process System

First, the process is different from the process of the traditional dry storage method or the oil tanker dry storage method. Comparing to the four intrinsic deficiencies of wet storage, its advantages are: stored liquid and ballast seawater are separated to avoid any contamination; it could store not only crude oil, but also water-soluble liquid such as methanol; equal mass flow-rate replacement is utilized to ensure the operating system weight constant during loading and offloading operations; stored liquid heating and insulation could be easily achieved. In addition, compared with the traditional dry method and the tanker dry method, closed inert gas in this process does not need to have further injection and has no emissions during loading and offloading in an environmental friendly way. Second, as the inert gas pressure inside the seawater ballast compartment 18 and the liquid storage compartment 21 in this process is set with reference to their external hydrostatic pressure as per the water depth, and after setting, the pressure difference changing inside and outside the seawater ballast compartment 18 and the liquid storage compartment 21 is mainly related to the liquid head heights inside the two compartments, rather than the water depth. The method to set the inert gas pressure in this invention makes the pressure differences inside and outside the seawater ballast compartments 18 and the liquid storage compartment are to be minimum, which could significantly reduce tank wall stress, and therefore benefits the compartment wall designs. This is an important advantage of the invention, and it has a special significant advantage to the multi-tank applications in extra deep waters For example, for a 50 meters height storage cell (conservatively ignore the top inert gas and the height of bottom liquid residue), the pressure difference between inside and outside of the storage will be less than 50 meter water column static pressure, about 5 bar.cellThird, the capacity ratio of seawater ballast compartment and the liquid storage compartment is approximately 1: 1 in the present invention, and therefore the void capacity is large and the available storage capacity small inside the multi-tank respectively. Underwater multi-tank will have large buoyancy due to its void capacity and additional solid ballast may be needed for a balance, which seems to be a disadvantage. However, if the self-weight of the multi-tank or platform is large enough and the required negative buoyancy (operating weight of less buoyancy difference) is small or zero, these shortcomings could turn into an advantage.

UNDERWATER MULTI-TANK LIQUID STORAGE

Refer to Figures 1, and 3 to 14, the underwater multi-tank 19 in the invention contains a solid ballast compartment 20 at or below its bottom, one or more sets of storage cells 16 above the solid ballast compartment 20. Each storage cell consists of at least one seawater ballast compartment 18 and one liquid storage compartment 21. The said two compartments, with closed and pressurized inert gas inside, are top-connected by a tube for gas-flowing. Optimization is made through opening or closing the automatic control valve 17 to connect or disconnect the gas inside the two compartments (see Figure 2-1 to Figure 2-4). The solid ballast compartment 20 could also be replaced by solid ballast materials added directly to the bottom of seawater ballast compartment 18 in the lower part of the multi-tank Or the solid ballast compartment could be cancelled if there is no need for additional solid ballast. Multi-tank could be either a vertical type or a horizontal type. The following is the shared characteristics of various types of multi-tanks in the present invention: first, both seawater ballast compartment and liquid storage compartment within the storage cell are pressure vessels designed to withstand external pressure and internal pressure, and their configurations and structures should follow the pressure vessel design principles. The basic configuration of the compartment is a cylindrical vessel with arch or flat end seal plates, or a spherical vessel, or other configurations beneficial to withstand pressures, such as a petal-shaped cylindrical vessel. Second, the multi-tank and its attached facilities must meet the following: suitable for the process of equal mass flow-rate displacement to ensure the operating weight constant and its center of the operating weight changing only along its vertical Z axis in which its COB is located during loading and offloading operations. The said features mean that the floating condition and draught of a floating system should have little change during loading and offloading operations. To this end, the projected figure of the multi-tank on a horizontal sectional plane should be a rotational symmetric or central symmetric or up-down and left-right axis symmetric figure, and the center of projected figure should be overlapped by the projected center of gravity and center of buoyancy. In other words, the vertical level of sections or projection planes of a multi-tank must be not only to ensure the geometric symmetry of the structure, but also ensure the symmetry of operating weight distribution during loading and offloading operations. Third, in order to prevent damage to the multi-tank from falling objects and pollution caused by vessel broken, some protection measures should be taken in the present invention. For example, the possible damage portion of a multi-tank, such as the tank top, double wall structures or special strengthened walls could be utilized. Another example, falling-objects shield installed above the top of a cell, and so on. In addition, as mentioned above, the liquid storage compartment inside the seawater ballast compartment, so-called "tank-in-tank" type of storage cell is an important measure to prevent pollution caused by a broken liquid storage. Fourth, in order to ensure stability of a submerged floating multi-tank of the invention, the system COB should be always above the system COG.

Storage Cell

In the present invention, the basic configuration of seawater ballast compartment and liquid storage compartment within the storage cell of multi-tank includes two types: tank-in-tank configuration and non tank-in-tank configuration. The former's liquid storage compartment is inside the seawater ballast compartment, so-called "tank-in-tank" type (see Figures 2-1 to 2-4) and the latter is to set seawater ballast compartment and liquid storage compartment adjacent or separated to each other symmetrically, or adjacent and bilateral symmetry by the two compartments to each other about the symmetric axial in the plane, or about vertically up-down and adjacent to each other.

"Tank-in-tank" type of storage cell includes four forms.

The first form, cylinder "tank-in-tank" type single-set storage cell, its basic structure is that both seawater ballast compartment and liquid storage compartment are cylindrical vessels, and that the storage compartment is inside water ballast compartment and the two cylinder center axis coincided to each other. In other words, the cross sectional view of a vertical multi-tank and the vertical sectional view of a horizontal multi-tank are two concentric circles cell(see Figure 3-2). Cylinder "tank-in-tank storage cell has three forms about its end seal plates: flat-shaped end seal plate 24 (see Figure 3-1 bottom seal plate), the overall height or total length of its seawater ballast compartment and liquid storage compartment to share the same end seal plate; centric arch-shaped seal plate 22 and ring and arch-shaped seal plate 23 for seawater ballast compartment (see Figure 3-1 upper seal plate), the overall height or total length of its seawater ballast compartment and liquid storage compartment are same; two centricarch-shaped seal plates for inner liquid storage compartment and outer seawater ballast compartment respectively (see Figures 2-1 ~ 2-4), the liquid storage compartment is completely surrounded by the seawater ballast compartment. Different types of seal plate's combination could also be used for two ends of the storage cell.

The second form, petal-shaped "tank-in-tank" single-set storage cellwhich is suitable for large diameter of vertical structure (see Figure 4). The basic structure of this configuration is similar to that the cylinder tank-in-tank storage cell and its seawater ballast compartment and inner liquid storage compartment are vertically cylindrical vessels with the overlapping of two vertical central axes. The horizontal section of this storage cell is rotational symmetry. The horizontal section of the pedal-shaped storage cell 25 two concentric figures with even arc "petals" (a total of 2 pieces) and each "petal" with the same curvature to its center. The connecting lines between the adjacent "petals" connection points and the graphic center form of a radial frame 26 with uniform radial pattern. This configuration of the storage cellcell contains only one seawater ballast compartments and one liquid storage compartment. The end seal plate of this petal-shaped "tank-in-tank" storage cell is a flat end seal plate, the same as the said cylinder "tank-in-tank" storage cell.

The third form, petal-shaped "tank-in-tank" multi-set storage cell, which resembles the second form of petal-shaped "tank-in-tank" single-set storage cell; and the only difference between the two configurations is that the inner radial frame 26 of this configuration is replaced by watertight bulkheads to form 2nd pairs of seawater ballast compartments and liquid storage compartments in a total. In order to ensure its COG position in the plane coordinates unchanged, the two pairs of seawater ballast compartments and liquid storage compartments are connected with a pipe to form n-set of storage cell. The remaining of this configuration is as same as the second one.

The fourth one, a master and secondary storage cell 51(see Figure 11), of which the master compartment 51-1 is a shared seawater ballast compartment 18 in the form of a big vertical cylinder. The master compartment 51-1 has at least one group of small vertical cylinders (2 pieces) arranged in a centre symmetric pattern, which are the secondary compartments 51-2 for being liquid storage compartments 21 (7 secondary compartments in Figure 11).The secondary compartment also can be set in the center of the master compartment to form a set of storage cell. Each group of secondary compartment is to store same liquid and to be synchronized during loading and offloading operations. The equal mass flow-rate displacement system between ballast seawater and stored liquids with closed, pre-gas-pressurized and inter-connected process could be utilized used in this form to store, load and offload one or more kinds of ordinary liquids in a normal temperature. In order to ensure that the closed and pressurized inert gas at the tops of each group of secondary compartment 51-2 and the master compartment 51-1 could keep a constant pressure system during the process of loading/offloading operations, the automatic control valve for the secondary compartment 51-2 within the group in operation are opened and connected with the master compartment 51-1, and meanwhile, those automatic control valves of other secondary compartments within the group are closed.

The "tank-in-tank" configuration has some advantages in structural stress distribution to handle liquid storage process, a small range of the COG variations in the vertical direction and some defects in completed unit during the construction. The master and secondary storage cellis relatively simple, except for one disadvantage that there may be a large liquid sloshing effect to cause a big rolling in the system, due to the large diameter of the shared seawater ballast compartment (master compartment), if the system is a floating system utilized in poor sea conditions. In addition, there are other forms of storage cells, such as spherical "tank-in-tank" type of storage cell. The inner liquid storage compartment and outer seawater ballast compartment are both concentric spherical vessels.

"Non tank-in-tank" storage cells, of which the seawater ballast compartment and the liquid storage compartment are adjacent and separated to each other, including:

Single or multi-set of storage cells in a single horizontal bamboo pole configuration with multi-sections - its outward appearance, similar to a bamboo pole configuration, is like a long horizontal cylinder with an arch-shaped end seal plate or a flat-shaped end seal plate plus some intermediate seal plates. Each seawater ballast compartment or liquid storage compartment is similar to a closed section inside the bamboo pole configuration. The said single-set of storage cell could be divided into three "sections": each end is a half seawater ballast compartment with about 50% capacity, and the intermediate one is the liquid storage compartment with 100% capacity. The two half water ballast compartments at both ends are connected to each other by pipes at the top and the bottom (passing the liquid storage compartment or buried in the concrete wall inside) to form a substantial water ballast compartment. Taking the vertical circular cross-section at the midpoint of the pole configuration as a symmetrical plane, the same number of the said single-set of storage cells is connected head-to-end and in left-right symmetry to form multi-set of storage cells in the form of a single bamboo pole with multi-section.

Single tube (layer) storage cell in the form of a bamboo raft with multiple poles– each cell consists of one group of 4 unit-tubes which are connected adjacently and tightly in a horizontal plane and in a shape of bamboo raft configuration through a lateral connected structure or a framework to form an integrated structure. Each single-tube is a tube-shaped cylinder vessel (i.e., single-wall tube with end seal plates). Both seawater ballast compartment and liquid storage compartment are in a group of 2 single tubes with bottom-connected and top-connected, which are arranged in the order of water - oil - oil - water, or oil - water - water - oil to form a Single tube (layer) storage cell in the form of a bamboo raft with multiple poles. In the condition of the geometric symmetry of the horizontal cross-sections or the horizontal projections for the cell structure, as well as the symmetry during loading and offloading operations, a number of the of storage cells are connected adjacently and tightly in a horizontal plane to form a multiple sets of single tube storage cells in the form of a bamboo raft with multiple poles.

The storage cell, in which the seawater ballast compartment and liquid storage compartment are arranged an adjacently up-down configuration (see Figures 9, 13 and 29, referred to as up-down arranged storage cell) – a single-set of up-down arranged vertical storage cell is a cylindrical tank with an intermediate partition plate 57 in the middle in addition to end seal plates at both ends (arch-shaped or flat-shaped 22 or 24), to divide the cylinder into upper and lower sub-cells: one for seawater ballast compartment and another for liquid storage compartment, as shown in Figure 13-1. This single-set of storage cell could guarantee its COG and COB are located in the same vertical cylinder axis, but its disadvantage is the elevation of its COG varied too much during the process of loading and offloading operations to be directly used for floating facilities. To avoid these shortcomings, two inner intermediate partition plates are used, the middle part of the storage cell for liquid storage compartment and the two end parts for two half of seawater ballast compartments respectively and connected by a pipe 64 (passing the liquid storage compartment) to form an integrated seawater ballast compartment (see Figure 9). Many of the said single-set of storage cells are connected in up-and-down and head-to-end configurations to form a multi-set of up-down arranged vertical storage cells (see Figures 9 and 29). Note that the inert gas pressure set-point of each storage cell is based on its water depth, and the set-point of the lower cell is higher than one of the upper.

The storage cell, in which the seawater ballast compartment and liquid storage compartment arranged separately and centrosymmetrically, and the storage cell, in which the seawater ballast compartment and liquid storage compartment arranged bilaterally symmetry in a plane section – they are the one of configurations of honeycomb storage cells, referred to as "symmetrical honeycomb storage cell". The said two forms of honeycomb storage cells are included in C-type honeycomb multi-tank, as shown in Figure 12. The honeycomb storage cell is formed by a number of vertical cells arranged closely with defined clearances in a horizontal plane as an integrated cellular structure. The arrangement of the honeycomb storage cell may be in the form of rotational symmetry (see Figures 5, 6, 13, 25 and 29), or in the form of a level piece and flat box-shaped (see Figure 12). The flat box-shaped arrangement means the cell or the single-set of storage cell (subsidiary cell) arranged in the form of centrosymmetry or bilateral symmetry. According to the position of the cylinder center of the cell in the horizontal profile of the honeycomb storage cell, the cellular cells arrangement includes three forms: "equilateral triangle arrangement", of which the center lines of any three adjacent cylinder circles form an equilateral triangle, resulting in equilateral triangle-, regular hexagon- (see Figures 5 and 13) or long hexagonal-shaped (see Figure 12) multi-set storage cells; "square arrangement", of which the center lines of any four adjacent cylinder circles form a square (see Figure 6 and Figure 25) or rectangular-shaped structures; "circular arrangement", of which all cylinder centers distributed uniformly on a big circle (single layer, see Figure 29), or on multiple concentric circles (multi-layer, see Figure 5). Regardless of any kind of arranged forms, it must ensure that the cells' COG position in a level plane remains unchanged during the process of loading and offloading operations.

There could be three forms of the storage cells, i.e. a cylinder "tank-in-tank" single-set storage cell (see Figures 5 and 6), a single-set of up-down arranged cylinder storage cell (see Figures 13 and 29) and a vertical and cylinder storage cell with arched end seal plates (see Figure 12). The first two forms will automatically meet the condition that the COG plane position remains unchanged. The third form of "symmetrical honeycomb storage cell", of which the cell, i.e. the vertical and cylindrical pressure vessel, could be as a seawater ballast compartment or a liquid storage compartment, will not automatically meet the said condition and must be symmetrically arranged. To achieve this, 4 cells could be compiled into a set of a storage cells to form a "single-set of symmetrical honeycomb storage cell", which contains two seawater ballast compartments and two liquid storage compartments respectively and is arranged separately from the form of centrosymmetry, or arranged adjacently in symmetry, with simultaneously loading and offloading function. A number of "single-set of symmetrical honeycomb storage cell" could form a "multi-sets of symmetrical honeycomb storage cells", which are arranged in a shape of multi-level flat box to guarantee bilateral symmetry, or symmetry to the COG of the whole storage cell in a plane section (see Figure 12). In order to achieve a "multi-sets of symmetrical honeycomb storage cells" with simultaneously loading and offloading function, two methods could be used: 1) each group storage cell is equipped with only one set of two pairs of linkage pumps (seawater loading pump – liquid offloading (export) pump, and seawater offloading pump - liquid loading pump) in the condition that every two same liquid compartments within the cell are connected by two pipes between the two tops and the two bottoms respectively to form an integrated seawater ballast compartment and an integrated liquid storage compartment (note: there are 4 pipes in a total for each group cell); or 2) each group storage cell is equipped with two sets of four pairs of linkage pumps to load and offload simultaneously with the same flow rate. If the number of the cells within a honeycomb storage cell is not a multiple of 4, special arrangement is needed for the extra unit vessels to ensure that the cells' COG projection in a level plane remains unchanged.

The storage cell and the multi-tank configurations in the invention involve three kinds of symmetries: axial symmetry, centrosymmetry and rotational symmetry. Three of them are referring to the symmetrical nature of the geometry in any horizontal profile of storage cells and multi-tank configurations, i.e. the geometric centroid symmetry (the centroid is also the COG of the storage cell of multi-tank in the horizontal plane projection) - the axial symmetry of which the symmetric axis passes through the centroid; centrosymmetry or rotational symmetry, of which the symmetrical center or the center of rotation is the centroid. Axisymmetric or centrosymmetric geometry has its standard definition and there is no need to repeat. Rotational symmetry means when a figure is rotated in a fixed angle around a fixed-point in turn to form a new figure, the new one completely coincides with the original one. The said fixed angle is equal to $360° / n$ ($n = 3, 4, 5, 6$ .... Note: When $n = 2$, it shall be centrosymmetric).

Taking equilateral triangle arrangement as example to explain how "symmetrical honeycomb storage cell" to be arranged separately in the form of centrosymmetry or bilateral symmetry. In order to facilitate the cells to be grouped, you first need to bring numbers with them as follows: in the horizontal direction, each row from the top to the bottom followed by the A, B, C, D ..., and each row from the left to the right, in turn, to 1, 2, 3, 4 .... Each cell has only one number consisting of letters and numbers. Figure 12 shows that 29 cells form a "multi-set of symmetrical honeycomb storage cells" in a shape of long 6-gon, of which the grouping method could be as follows: A1/A5 water-A2/A4 oil, E1/E5 water - E2/E4 oil, B1/B6 oil-B2/B5 water, D1/D6 oil-D2/D5 water, C1/C7 water-C2/C6 oil (the above are bilateral symmetry in the two); A3/E3 water-C3/C5 oil, B3/D4 water-B4/D3 oil, C4 for a reserve tank, or an open bay for drilling risers (the above are centrosymmetry to the center of the storage cells). The said method should be considered as an example only, if the principle of symmetry is followed to ensure that the COG position in a level plane project is unchanged. People could also come out with other combinations.

Solid Ballast Compartment within a Vertical Multi-tank

According to the design requirement, the function of a solid ballast compartment is to balance the redundant buoyancy of the multi-tank, and to vertically lower the COG of the multi-tank by adding ballast material into the tank, such as iron ore or ballast seawater. There is another way to replace the solid ballast compartment is to add the solid ballast material directly at the bottom of the seawater ballast compartment 18 of the bottom of the multi-tank 19. For those systems, in which there is no need for solid ballast, the solid ballast compartment of the multi-tank could be canceled.

The solid ballast compartment of vertical multi-tank in the present invention has 5 different configurations, the third, fourth and fifth configurations are only used for floating systems, not for the fixed systems.

As Figure 3-1 shows, the first configuration is the extension of its above storage cell's cylinder (seawater ballast compartment 18), their geometries of the horizontal section's profiles are the same, which is the intrinsic bottom solid ballast compartment 20-1 (see Figures3-1, 6-1, 9-1, and 25-1).

As Figure 4-1 shows that the second configuration is the protruding skirt-shaped bottom solid ballast compartment 20-2, of which the hull "enclosure" around the "heel" of the storage cell's cylinder (seawater ballast compartment 18) from outside. The radial section of the hull could be a U groove shape with opening top (without top cover plate) being beneficial to add solid ballast, and it also could be either rectangle or O shape pipe with enclosed top (with top cover plate) (see Figures 4-1, 5-1, 8-1 and 23). Compared with the first configuration, the advantages of the protruding skirt-shaped one are: for a bottom-supported and fixed system, it benefits to reduce scour to the bottom; for a submerged floating tank, it helps to increase the added mass, radius of gyration, damping and damping moment of inertial for the floater in its 6-DOF, especially in the three directions of heave, pitch and roll, thereby to improve the motion response and hydrodynamic performance of the floater.

The third one is shown in Figures 10-1 and 22-1, which is "protruding skirt-shaped lower solid ballast compartment" 20-3. The hull of the ballast compartment has the same structure as the second form. There are several vertical upward steel legs 29 built on the hull of the ballast compartment. At the bottom of the multi-tank and on the outer wall of storage cell, there are sleeves and locking devices 28, which has the same number as the steel legs. Legs 29 could slide up-and-down along the leg and could be locked / fixed in the sleeves 28. Before the completion of construction, towing and installation of the positioning / mooring system, raising the solid ballast compartment, making its bottom a little bit higher than the bottom of the storage cell, and temporarily fixing the sliding legs 29 on the tank of the storage cell. After completion of the positioning / mooring system installation, vertically moving solid ballast compartment 20-3 down to the pre-concerted place, and then locking the sliding legs 29 onto the storage cell. Compared with the second configuration, this third one of the solid ballast compartment is much easier to be moved down the COG vertically, but its structure and installation is complicated.

As Figure 24 shows, the forth one is "intrinsic lower solid ballast compartment" 20-4. It uses the body of the ballast compartment in the first configuration, and uses the sliding legs 29, sleeve and locking devices 28 in the third configuration. Thus the body of the ballast compartment could slide down and be fixed.

The fifth configuration is shown in Figure 14. It is a "wheel-shaped solid ballast compartment" 20-5, which includes: 1) a wheel-shaped solid ballast compartment

58. It is a horizontal ring shaped container with either opened or closed top, which has the same structure as the second configuration of the solid ballast compartment. The inner diameter of the wheel-shaped solid ballast compartment 58 is larger than the outer diameter of the multi-tank 19 with the two vertical central axes coincided. 2) Connecting device 59, which fixes the wheel-shaped solid ballast compartment 58 on the heel of the multi-tank 19, including connecting radial plates 59-1, and inclined tie bars at the top 59-2 matching with the connecting radial plates 59-1 if necessary. Compared with the second configuration of the solid ballast compartment, a floating system with a wheel-shaped solid ballast compartment 20-5 has a better hydrodynamic performance. This is because that the up and down water between the wheel-shaped solid ballast compartment 58 around the multi-tank 19 is well transparent, and both the damping moment and radius of gyration of the hull 58 are larger than ones of the protruding skirt-shaped bottom solid ballast compartment 20-2.

Vertical Multi-Tank of Rotation Symmetry

This kind of multi-tank ("vertical multi-tank") is formed by one single layer & single set or one single layer & multi-set vertical storage cell with rotational symmetry in every fixed angle, and one solid ballast compartment which is installed below or at the bottom of the storage cell. The solid ballast compartment is one of the above-mentioned five forms matching with the vertical multi-tank, or the solid ballast material could be directly added into the bottom of the storage cell. For those multi-tanks with no need for a solid ballast compartment, the solid ballast compartment could be cancelled.

The technical features of this kind of multi-tanks are: It has a vertical central axis and the multi-tank structure is rotational symmetry to this axis in every fixed angle. Both the COB and the COG of the multi-tank shall be on that center axis during load / offload operations. This kind of multi-tanks are suitable for both fixed and floating structures, whereas, if the solid ballast compartment is required for a fixed structure, only the first and the second of the said five configurations of the solid ballast compartment could be selected, i.e. the intrinsic bottom solid ballast compartment 20-1 and the protruding skirt-shaped bottom solid ballast compartment 20-2.

Based on different storage cells selected, the introduced multi-tanks could have 12 different types. These are: 1) & 2) vertical multi-tank liquid storage with a single set of cylinder storage cell, which is in a cylinder tank-in-tank form, or in up-down arranged vertical form. 3) & 4) Vertical multi-tank liquid storage with single or multiple sets of pedal-shaped cylinder tank-in-tank storage cells (see Figure 4-1). 5) A-type vertical single layer honeycomb multi-tank liquid storage with multiple sets of rotational symmetric storage cells (the honeycomb cell is in a cylinder tank-in-tank form, see Figures 5-1 and 6-1). 6) Vertical multi-tank liquid storage with multiple sets of master and secondary storage cells (see Figure 11-2). 7) B-type vertical single layer honeycomb multi-tank liquid storage with multiple sets of rotational symmetric storage cells (the honeycomb cell is a single set storage cell in up-down arranged vertical form, see Figure 13-1). 8) C-type vertical single layer honeycomb multi-tank liquid storage with rotational symmetric storage cells (every 4 honeycomb cells constitute one group to become a symmetrical honeycomb storage cell, and each cell is a vertical and cylindrical vessel). 9) Multi-layer tower ladder multi-tank liquid storage with multiple sets of storage cells (see Figure 8-1). 10) A-type SPAR multi-layer multi-tank liquid storage (the appearance is a vertical long cylinder, and the multi-layer storage cell could be either in cylinder "tank-in-tank" form, see the multi-tank in Figure 25, or in up-down arranged form, see Figure 9-1). 11) B-type SPAR multi-layer multi-tank (the appearance is a vertical, tightly arranged pipe bundle with single layer shaped like a long cylinder, see Figure 29-1). 12) C-type SPAR multi-layer multi-tanks (the appearance is 3 or 4 vertical pipes arranged with spacing as a pipe bundle). The horizontal sections of both the said B- and C-type SPAR multi-tanks are rotational symmetry in every fixed angle, and the better choice for the each pipe in the bundle is the up-down arranged multi-set storage cell (see Figure 29-1). The said types 1) to 9) are so called as pedestal-type multi-tanks, wherein the cells in honeycomb shape and of rotational symmetry in every fixed angle storage are used for types 5), 7), 8) and no need to repeat their structures again. The followed paragraphs will describe the multi-tank configuration of multi-set of storage cells shaped like multi-round tower ladder and the SPAR multi-layer multi-tanks in details.

Multi-Layer Tower Ladder Multi-Tank Liquid Storage with Multiple Sets of Storage Cells (see Figure 8-1)

The appearance of this kind of multi-tank is a multi-round tower ladder shaped structure of a single set of or a multi-set of storage cells, which consist of at least two layers with large diameter in the bottom layer and small in the top layer. In the said large diameter bottom layer, (multi-set) honeycomb storage cells of rotational symmetry in every fixed angle, or a master and secondary storage cell, or a vertical and cylinder petal-shaped multi-set storage cell could be selected. In the said smaller diameter top layer, vertical and cylindrical tank-in-tank formed a single set storage cell, or a vertical and cylinder petal-shaped single set storage cell, or up-down arranged multi-set storage cells could be selected. If a solid ballast compartment is needed, the intrinsic bottom solid ballast compartment 20-1, or the protruding skirt-shaped bottom solid ballast compartment 20-2 could be used, see Figure 8-1. For floating platforms, the protruding skirt-shaped lower solid ballast compartment 20-3 also could be used, see Figure 22. Compared with the other 8 types of pedestal-type multi-tanks, this kind of multi-tank has bigger added mass, radius of gyration and damping moment of inertial, which will be beneficial to improve the platform's hydrodynamic performance.

SPAR Multi-Layer Multi-Tank (see Figures 9-1, 24, 25 and 29-1)

This kind of multi-tank is used for SPAR-type floating platforms described in the present invention. It also could be used for some special fixed systems, like the Application Example 5 "the bottom-supported and fixed platform with seabed storage and a compliant tower leg" (see Figure 19). The appearance of the A-type SPAR multi-tank is a vertical long cylinder, which is composed of several same sized, vertical and cylindrical tank-in-tank formed single set storage cells connected head-to-end (see Figure 24), or of the "up-down arranged multi-set storage cells" (see figure 9-1) directly. The appearance of B-type SPAR multi-tank is a vertical, tightly arranged pipe bundle with single layer shaped like a long cylinder, and the better choice for the pipe in the bundle is the up-down arranged multi-set storage cells (could also utilize other configurations), as shown in Figure 29-1, a single layer round and 6 "pipe" tightly arranged structure. The appearance of the C-type SPAR multi-tank is a set of vertical pipes arranged as a pipe bundle, wherein the 3-pipe bundle takes the structural configurations of regular triangle, the 4-pipe, square,(see Figure25) and that a better choice for the pipe in the bundle is the up-down arranged multi-set storage cells. The C-type SPAR multi-tank also contains several horizontal frames 65 and each horizontal frame contains 3 to 4 horizontal bars 66 for connecting in regular triangle shape or square shape, together with several triangle or square shaped levels and transverse interconnect heave damping plates 67 to make the 3-"pipe" or 4-"pipe" as a whole structure. SPAR-type multi-layer multi-tanks are designed for a floating platform in this present invention, A-type or B-type could be built in a SPAR-type platform with one single leg, and C-type could be built in a SPAR-type platform with 3-leg or 4-leg configurations. The solid ballast compartment of this kind of multi-tank could be an intrinsic type with a bottom solid ballast compartment, or the intrinsic type with a lower solid ballast compartment for the floating platform only, or the addition of a solid ballast directly in the bottom of the seawater ballast compartment.

Fixed System Oriented Multi-Tanks

Fixed systems oriented multi-tanks include horizontal bamboo raft multi-tank and flat box-shaped honeycomb multi-tank, which consist of the said horizontal multi-set storage cells or flat box-shaped honeycomb storage cells, and solid ballast compartment. The following could be used for the said solid ballast compartment: 1) adding the ballast material 20 directly into the bottom of seawater ballast compartment or liquid storage compartment such as iron ores (see Figure 7-2); 2) building a solid ballast compartment at the bottom of the storage cell based on its outer shape; 3) using the rooms between each cell of the honeycomb multi-tank for the solid ballast compartment. The solid ballast compartment could be cancelled if it is not needed. In theory, because the multi-tank of a fixed platform relies on the anti-sliding device of the pile foundation at the seabed, in in-place operating conditions, the COG and COB of the system could be located on different vertical axes, but this could cause extra bending moment. Hence, as the same as required for the floating systems, geometrical symmetry of structures and the symmetry of operating weight distribution during the loading and offloading operations are also required for the fixed platform multi-tank applications in the present invention. However, different from the vertical multi-tank of rotation symmetry in every fixed angle used for the floating platforms, the multi-tank used for the fixed platforms will only require the center symmetry or the bilateral symmetry in the level section profiles, rather than rotational symmetry in every fixed angle required for a floating system. Hence the structure in Figure 12-1 could only be used for fixed structure, while the structure in Figure 13-1 could be used for both fixed and floating structures. In addition, the horizontal section profiles of the said multi-tank for fixed platform is larger than its vertical section profiles, and that means it has a bigger waterplane area and a smaller draught, and its advantage is propitious to use one step dry construction method for the mentioned multi-tank construction.

Horizontal bamboo raft multi-tank which consists of several unit-tubes (tube-shaped cylinders) connected adjacently and tightly in the shape of a horizontal raft. Different types of the storage cells could be used for the unit-tubes with 3 different types in A, B, C. Type A, the unit-tube is the "tank-in-tank" storage cell, of which the seawater ballast compartment completely surrounds the liquid storage compartment and some radial supporting structures are needed between the two (in Figure 7-2, the transverse interconnecting structure or the framework are not shown). In addition, the liquid storage compartment inside the seawater ballast compartment could be moved a bit down to let the central axes of them parallel to each other and keep the rest parts of the structure unchanged. B type, every four unit-tubes functions as a group to form a "multiple single-wall tubes formed single-set storage cell", several groups to be connected to form a "multiple single-wall tubes formed multi-set storage cells". C type, the unit-tube is a "multi-set of storage cells with the configuration of a single bamboo pole with multi-section".

Flat box-shaped honeycomb multi-tank, wherein honeycomb storage cells are connected to form a flat box shape with three types as A, B, C. 1) A-type, the honeycomb multi-tank liquid storage 52 with cylinder tank-in-tank storage cells. 2) B-type, the honeycomb multi-tank liquid storage52 with is a single set storage cell with the up-down arrangement (see Figure 13-1). 3) C-type, every four cells forming a symmetrical honeycomb-shaped storage cell. Because the structures of these types have been described in details from the previous sections, there is no need to repeat it here.

When these kinds of multi-tank are used for a platform or an artificial island with a wellhead bay, one has to be aware: an up-down through hole such as a moon pool is set near the multi-tank, corresponding to the wellhead area at topsides, where conductors could be connected to oil wells down below. The component of No. 27 (moon pool) is shown in Figures 8-1, 10-1, 22-2, 24-2, 25 and 29. Since the design of multi-tank shall follow the pressure vessel design principle, the cylindrical moon pool is the best choice for the designs of a vertical multi-tank and a honeycomb multi-tank, while the rectangular moon pool is better for a bamboo raft multi-tank. The moon pool of a floating platform or a floating artificial island usually is located in the center of a multi-tank, with the damping frameworks installed inside to reduce the second-order motion effect.

The Material Selection for the Multi-Tank

The building material of the multi-tank in the present invention could be either concrete or steel. The concrete has a high compressive strength but with a low tensile strength, so it is good for external pressure vessel. Of course the high performance pre-stressed reinforced concrete could also be used to make the internal pressure vessel which suffers high pressure, but its difficulties and the higher cost in design and construction make them suitable for an external pressure vessel. Steel is more suitable for an internal pressure vessel. Hence, when using the equal mass flow-rate displacement system between ballast seawater and stored liquid compartments with closed, pre-pressurized gas in an inter-connected process, and if the pressure set point of the inert gas inside the seawater ballast compartment is lower than the outside seawater hydrostatic pressure, then concrete shall be used for the seawater ballast compartment, and conversely, steel shall be used. As for the liquid storage compartment inside "tank-in-tank" storage cell, no matter the pressure of the inert gas inside the tank is higher or lower than the seawater hydrostatic pressure outside the multi-tank, it sometimes suffers external pressure or internal pressure, but the pressure differences between inside and outside is not so big and could be just equal to the hydrostatic pressure due to the differences between the different liquid level heights inside and outside. So both concrete and steel could be used for the liquid storage compartment.

The other important factor in the material selection is the effect to the vessel's weight. Compared with steel, the reinforced concrete has low strength, so the vessel made of reinforced concrete normally has very thick vessel wall and heavier in weight. To use concrete for building a floating platform currently is always restricted because of its dead weight of structure, which is a drawback for the use of concrete material. As described previously, the equal mass flow-rate displacement system between ballast seawater and stored liquid compartment closed, pre-pressurized gas in an inter-connected process has a weakness: the storage cell could have a larger void capacity with a smaller available storage capacity, which brings too much redundant buoyancy in water. In order to balance such redundant buoyancy, the multi-tank could need some solid ballast as a balance weight. In that case, the materials which could increase its weight of the structure, such as reinforced concrete, are recommended for the construction in the present invention to reduce the requirement of solid ballasts as the balance weight. In the present invention, the lower portion of the concrete multi-tank, especially at its bottom, could be constructed by heavy concrete, and the upper portion, especially at its top, by light concrete, which will help the COG of the system down in the vertical direction.

There are many advantages to use concrete for building the multi-tank in the present invention: Compared with steel, the concrete has better performance in those characteristics: anti-seawater-corrosion, anti-fatigue, heat preservation, low maintenance cost, long working life, easy to construct, little requirement on the builders' skills, short construction period, low construction cost, and low operation and maintenance costs. Moreover, if one uses some low permeability concrete, and take some anti-cracking measures during the design and construction phase, some weak points of the concrete material could be further avoided. The good anti-seawater and corrosion characteristic and low maintenance cost are very important factor to the multi-tank in the present invention, since it works underwater all the time. Compared with normal concrete construction, another advantage in the present invention is, all concrete compartments and tanks are cylindrical containers with smooth wall surfaces outside and inside, which is easy to build at a low construction cost.

The concrete structure mentioned in the present invention includes reinforced concrete structure, pre-stressed concrete structure, CFT structure, steel-framed reinforced concrete structure, fiber reinforced concrete structure, steel-plate reinforced concrete structure, steel sandwich concrete structure, and steel coated with outer concrete structures. How to select the proper structure? It shall be based on the actual project conditions and the evaluation results of technical and economic comparison. The so called steel sandwich concrete structure means the outer wall and inner wall of the concrete structure are thin steel plates. Steel bars are welded between those two steel plates, to connect them and to form a shell-like structure, and then the concrete is poured between the steel plates. Only in minority or very special cases, such as the conversion of a steel SEMI and a SPAR platform with adding oil storage capacities, or some underwater facilities with small storage capability with a short design life, steel material for the multi-tank construction is recommended in the present invention.

CONSTRUCTION, INSTALLATION AND RELOCATION OF THE CONCRETE MULTI-TANK AND THE MULTI-TANK BASED FACILITIES

The construction and installation methods used for the multi-tank in the present invention and its derived facilities are as the same as the one for existing offshore concrete gravity structures, including (onshore) dry one-step construction and dry

& wet two-step construction. One-step construction means the construction of the multi-tank with the whole system is completed onshore, and then it is wet-towed to the offshore oilfield for installation. Two-step construction means to construct the lower portion of the multi-tank onshore first, and then wet-tow it to the offshore construction site where the water depth is deep enough for continuous construction of the whole structure in a floating status, and finally wet-tow the system to the oilfield. Dry dock or gravel dry dock is needed for both the two onshore construction methods. For the construction of a structure with small in size and light in weight, the dry dock could be replaced by launching ways with a semi-submersible barge or constructing it on semi-submersible barge directly. Compared with the two-step construction, the one-step has a shorter construction period and a less cost. However, the basic requirement is that the multi-tank shall have enough waterplane area and a light structure weight to ensure the unit / multi-tank floating in the dock with a limited draught. Offshore installation of the fixed system is similar to that of the existing concrete gravity platform; the difference is that the fixed system in the present invention is equipped with the piled-foundation for anti-sliding. Offshore installation of a floating system is similar to that of the existing SPAR or SEMI, which will not be described here again.

FIXATION OF THE BOTTOM-SUPPORTED MULTI-TANK & THE ATTACHED FACILITIES AND OPERATING WEIGHT CONTROL

The fixed systems in this invention are fixed at the seabed by piled-foundation for anti-sliding (Figures 13－2 、13－3 、15 、26 and 17～21). When the system need to be relocated to other place for re-use, simply release the constraint from the seabed to the fixed structures (if pipe pile is used, then it shall be cut off), then offload the liquids inside the multi-tank, it could be easy re-floated to move. The weight control principles of a fixed system in the invention are that: the dry weight shall accord with the requirement of buoyancy and stability during wet tow; the operating weight shall guarantee that the system could be stably fixed at the seabed by the piled-foundation for anti-sliding during operations; and when the system is moved for reuse, the total amount of dry weight plus with the weight of the residual liquid inside the multi-tank and weight of other items which could be removed shall be less than the displacement tonnage of the system to make sure that it is afloat. Since the multi-tank at the seabed will have small environmental loads, the horizontal and vertical forces, also the overturning moment on the piled-foundation are small too. However, when SPM installed on the multi-tank, the horizontal, vertical mooring forces and the overturning moment from the shuttle tanker on the piled-foundation could be high and more considerations should be paid. As to the bottom-supported and fixed underwater storage system in the invention, the operating weight (wet weight) of the multi-tank and the associated facilities do not need to be too heavy, which normally shall be around 100%~110% of its own buoyancy. If the bearing capacity of the seabed allows, the negative buoyancy during operation could have no top limit. In this invention, the loads from environments such as winds, waves and currents on the body of a fixed artificial-island, or on the legs and topsides of a fixed platform could be larger than that on their underwater bottom-supported multi-tanks. It shall be taken into more account how to resist settlement, sliding and overturning caused by the environments during the design of the piled-foundation for anti-sliding of the system. To sum up, the overall configurations and structures of the multi-tank, the legs and the topsides of a platform shall be considered in every possible angle based on the particular characteristics of the fixed systems. To these platforms for which a traditional steel jacket or a compliant tower is used as legs, dedicated underwater skirt piles for the platform could be also used and driven into the seabed through the multi-tank. According to the invention, the operating weight (wet weight) of a bottom-supported and fixed platform/artificial island doesn't need to be very big. If the buoyancy of a multi-tank/system is bigger than its operating weight, an up-lifting force on the foundation will happen. In order to avoid the up-lifting force, the operating weights of the various fixed systems in the invention shall be equal to or a bit more than their buoyancies and the differences could be adjusted accordingly to the vertical bearing capacity at the seabed. If the seabed's bearing capacity allows, the operating weight could have little strict limit. In one word, whether and how to set the void tank capacity and the bottom solid ballast compartment of the fixed system in this invention shall be based on the different scenarios of a project.

SUBMERGED FLOATING MULTI-TANK S' POSITIIONING AND OPERATING WEIGHT CONTROL

The submerged floating multi-tank 19 will rely on its mooring positioning system 34 to be moored at seabed and its fairleads are near the center of buoyancy. As mentioned above, the submerged floating multi-tank will be placed in the water depth where the effect from the wave-induced hydrodynamic load, except for the load from currents, is smaller. Therefore the mooring force is small accordingly, and the positioning requirements are also less too compared with a floating platform and a floating artificial island at water surface. If SPM 12 like SALM (Figure 16), installed on the multi-tank directly, then the fairleads of the mooring system will be moved up, even to the top of the multi-tank to reduce the tipping caused by the moored tanker. Meanwhile, the mooring force from the tanker shall be considered for the mooring positioning system. The mooring positioning system 34 could have catenary mooring legs or taut / semi-taut positioning system. The operating weight of submerged floating multi-tank and associated facilities installed above it, including mooring positioning system and underwater flexible riser's weight from the points touching the seabed, i.e. the total wet weight, equals the total buoyancy of the system(negative buoyancy is zero), and the gravity and buoyancy are dynamically balanced, and the COG is below the COB. If taut mooring positioning system is used, then the operating weight in still water will be less then buoyancy, the difference is the downward vertical component of mooring tension forces. Therefore, if the operating weight is less than buoyancy, solid ballast could be a must. If the operating weight is more than buoyancy, the weight of multi-tank shall be reduced: e.g. using light concrete, or reducing the wall thickness of the multi-tank on the condition to make sure sufficient structural strength, or adding new void tanks to increase the buoyancy. The positioning and operating weight control for a floating platform and a floating artificial island are more or less the same as submerged floating multi-tank, and will be explained later.

PUMP MODULE

In the present invention, the pump module 4 (see Figure 1) contains: two types of (dry) traditional pump module 4-1 and (wet) underwater pump module 4-2. Each type contains at least one pump-group, and the related items such as pipes, valves, field instruments, control and implementation of components, and a hydraulic station. Each pump-group contains two pairs of linkage pumps. These two pairs of linkage pumps are: offloading linkage pumps, including one seawater ballast pump (loading pump) 6 and one liquid storage offloading (discharging for transportation) pump 10 linked to each other; loading linkage pumps, including one seawater offloading pump 5 and one liquid storage loading pump 7 linked to each other. All pumps within each pair of linkage pumps are synchronized in starting, running and stopping with an equal mass flow-rate. Since these two types of pump module will be used in different place, they will have different working environment. Therefore, the selection and technical requirements of the devices, components and systems will be different as well. The traditional pump module 4-1 will be installed on the extended structures 30 upwards out of water, which is attached to the multi-tank, such as a small platform (see Figure 15). Since not used for underwater application, it could be called the "dry" type system. And this pump module could use traditional and ordinary equipment and components, such as a normal centrifugal pump or a submersible centrifugal pump (deep well pump). For both fixed/floating platforms and artificial islands, traditional pump module 4-1 could be installed inside the legs or on the topsides. Underwater pump module 4-2 could be used and installed on the outside of underwater multi-tanks as shown in Figure 16. Underwater pump module will bear the seawater pressure and corrosion and is a "wet" system which has inclement working environment, and difficult to repair and maintained. It must also be an independent and self-sustaining system, for instance, it must have its own underwater hydraulic pressure station. Therefore, the technical requirements and the cost of a subsea pump module could be higher than a traditional pump module. The underwater bottom-supported and fixed storage, loading & offloading system (see Figure 15), and submerged floating storage, loading & offloading system (figure 16) mentioned in this invention could use either a traditional pump module or a underwater pump module. Both of these two types shall be independent and self-sustained. The traditional pump module costs cheap and it doesn't need underwater maintenance, but it requires an extended structure out of water installed on the multi-tank, which increases the multi-tank construction cost. The underwater pump module fits the harsh sea, especially in deep waters.

BOTTOM-SUPPORTED AND FIXED PLATFORMS WITH SEABED STORAGE (see Figure 17-21)

As mentioned above, bottom-supported and fixed platforms in present invention contain storage system with the multi-tank, platform's leg and topside facilities. Theoretically, among 18 types of the multi-tank mentioned above, 17 of them could be used for bottom-supported and fixed platforms. In present invention, there are 4 different types of legs, which corresponding to 4 different types of platforms:

Using the concrete leg 37-1 in cylindrical shape (see Figure 17) for a current concrete gravity platform, a conventional jacket leg 37-2 made of steel (see Figure 18), a compliant tower leg 37-3 used in deep water (see Figure 19), or jack-up legs 37-4 (see Figures 20, 21) will respectively form 1) the bottom-supported and fixed platforms with seabed storage and a concrete tapered cylindrical leg, 2) the bottom-supported and fixed platform with seabed storage and a conventional jacket leg, 3) the bottom-supported and fixed platform with seabed storage and a compliant tower leg, or 4) the bottom-supported jack-up platform with seabed storage respectively. Among 17 types multi-tank which could be used, only A and B SPAR-type multi-layer multi-tank could be used with a compliant tower leg. Therefore, there are $15\times4+2\times1=62$ different types of bottom-supported and fixed platforms with seabed storage. In these 17 types of multi-tank, the height of multi-tank determines the draft of the platform and the wave loads on the platform. The 3 horizontal bamboo raft types of the multi-tanks with the least height are suitable for the shallow beach seas especially (water depth less than 10 meters) and have the least wave loads when the water depth is the same as the other types. The SPAR-type multi-layer multi-tanks with the maximum height are suitable for very deep waters. The solid ballast compartments matched with the said platforms shall be selected based on the particular features of their multi-tanks. "The equal mass flow-rate displacement system between ballast seawater and liquid storage compartments with closed, pre-pressurized gas in an inter-connected process" shall be used for the liquid storage system of the bottom-supported and fixed platforms, in which the inside inert gas pressure lower than the outside seawater hydrostatic pressure. In case of reducing the inside inert gas pressure for security reasons, the minimum pressure (g) of inert gas in Figure 1 process could be set slightly higher than atmospheric pressure providing that it meets the requirement of the pump suction head height. Therefore, deep well pumps (the inlets are located in the bottom of the multi-tank), or subsea pumps installed outside the multi-tank underwater shall be used for seawater offloading pump and liquid storage offloading (export) pump. Among 4 types of legs mentioned above, 3 of them are steel structure legs. These steel legs combined with concrete structure, become a composite platform. Compared with current concrete-only gravity platform, this composite platform will be more flexible during construction and installation, which make it suitable for deeper waters. Besides, a steel leg has smaller water plane area, better transparency, less load from waves. However, for the considerations about corrosion resistance, ice resistance and collision-resistance, concrete leg is a better choice. In order to simplify the construction of a concrete leg, cylinder one could be used instead of a cone type. As mentioned before, all mentioned platforms in present invention will use underwater piled-foundation for anti-sliding to fix them at seabed. This shall be done using one of the 5 methods below to fix the underwater multi-tank 19 at seabed: 1) anti-sliding apron piles 31-2; 2) suction piles; 31-3; 3) piles 31-1; 4) anti-sliding apron plus with suction piles; 5) anti-sliding apron piles and piles. And if accessory, supplementary fixing measures of stayed-cable 43 (Figure 19) could be used. For a platform using traditional jacket legs 37-2 or compliant tower legs 37-3, jacket or jacket base 40 could have its own piles passing though the multi-tank into seabed. Also, if necessary, jack-up type legs could also have own piles. In present invention, the topsides of a jack-up platform use watertight bulkhead structure, and the topsides structures of other platforms are the same as a traditional gravity concrete platform or a jacket platform.

Several construction and offshore installation methods could be used for the bottom-supported and fixed platforms in the present invention, including: 1) the multi-tank, legs and topsides modules are built and towed separately, and then installed offshore one after another, such as a jacket platform; 2) the multi-tank, legs and topside modules are built in a dry dock or onshore, then wet-towed as a whole and installed offshore, such as a concrete platform and a bottom-supported jack-up platform; 3) the multi-tank, legs and topside modules are built separately, the multi-tank will be installed offshore first, and then, legs and topsides module assembled in a dry dock, wet-towed as a whole, and then finally, connected and hooked-up with the multi-tank offshore, such as a bottom-supported jack-up platform. Detailed description could be found in Examples of Application 3 to 7. As mentioned above, the key to build the platform introduced in this present invention is the construction of concrete multi-tank, which determines the location of construction and whether it is one-step "dry" construction or it two-step "dry & wet" construction.

FLOATING PLATFORMS WITH UNDERWATER STORAGE

As mentioned above, the floating platforms in the present invention contain 4 parts: liquid storage system with multi-tank, platform legs, topsides facilities and mooring positioning system. The main characteristics of them are determined by the types of multi-tank and the number of cylinder (cone) legs attached. The number of legs in the floating platforms in the present invention could be single, three or four legs. For single leg, any multi-tank of vertical multi-set storage cells with rotational symmetry in every fixing angle, except for C-type-SPAR multi-layer multi-tank, could be utilized, which is in a total of 11 to form 9 types of pedestal-type single-leg floating platforms and 2 SPAR-type floating platforms (A-type and B-type). The outside diameter of the SPAR-type floating platforms with single leg could be the same as or less than the outside diameter of the multi-tank. A floating platform with 3-leg or 4-leg could use 9 types of pedestal-type multi-tanks (the 3-leg configuration as shown in Figure 23) and C-SPAR type configuration of multi-layer multi-tank (see Figure 25). The protruding skirt-shaped bottom or protruding skirt-shaped lower solid ballast compartment could be used for pedestal-type multi-tank floating platforms. The intrinsic bottom solid ballast compartment or intrinsic lower solid ballast compartment is for a C-SPAR type multi-layer multi-tank floating platform. "The equal mass flow-rate displacement system between ballast seawater and liquid storage compartments with closed, pre -pressurized gas in an inter-connected process" shall be used for the liquid storage system of the floating platforms in the present invention, in which the inside inert gas pressure is lower than the outside seawater hydrostatic pressure. In case of reducing the inside inert gas pressure for safety reasons, the minimum pressure (g) of inert gas in Figure 1 process could be set slightly higher than atmospheric pressure to meet the requirements for the pump suction head height, and for the deep well pumps (their inlets are located in the bottom of the multi-tank), or for the underwater pumps installed outside the multi-tank underwater to be used for seawater offloading pump and liquid storage offloading (export) pump. The floating platforms in the present invention include: single leg pedestal-type floating platforms with underwater storage; multi-leg pedestal-type floating platforms with underwater storage; floating platform of A-type SPAR multi-layer multi-tank; floating platform of B-type SPAR multi-layer multi-tank; floating platform of C-type SPAR multi-layer multi-tank. These floating platforms have following characteristics: deep-draught, multi-tank is placed in the water depth with little impacts from waves; small water plane area and the water plane area shall be as less as possible on the condition that it meets the requirement of the vertical stiffness in heave direction; the COB of the single-leg floating platform above its COG; the natural periods in 6-DOF of the platform are longer than the primary wave periods; the same positioning mooring system as a SPAR platform or semi-submersible platform to be used as floating platforms; the platform draught kept little change to keep the upright floating condition during loading and offloading operations.

Floating Platform's Legs and Topsides Facilities (see Figures 22~25)

As the same as an existing concrete gravity platform, platform legs 38 in concrete cylindrical tube shaped are used for the floating platforms in the present invention,. It could be single leg (see Figures 22, 24), 3-legs or 4-legs (see Figures 23, 25); however, if the stability of the platform mainly relies on the water plane areas of the leg(s), then the configurations with 3-legs or 4-legs are preferred. Conductors, risers and subsea cables could reach to seabed through cylindrical or conical tube shaped legs. Cylindrical leg could have several horizontal separations to make equipment cabin(s) and buoyancy tank(s) (void). The buoyancy tank near water surface could use double-wall configuration to improve safety. Equipment, such as pumps, could be installed in the equipment cabin(s). If single leg is used, the topsides facilities (modules) 36 could be the same as the one for a SPAR. If 3 or 4 leg configurations are used, the topsides facilities could be the same as a semi-submersible platform. In order to ensure the damaged stability, watertight bulkhead structure could be used for the topsides facilities module 36 for all floating platforms mentioned above.

Floating Platform's Mooring and Positioning System

Catenary, taut or semi-taut mooring leg systems, the same as used in a SPAR or a semi-submersible platform, could be used for the floating platforms in the present invention. The fairleads of the mooring legs shall be placed according to the wave and wind loading. It could be placed around the COB of a platform, or moved up to the position close to sea surface. In harsh waters, e.g. with very strong winds and wave, the floating platforms could use two sets of mooring positioning systems, and the fairleads placed in different water depth respectively.

Buoyancy Characteristics of the Floating Platforms

One of the purposes in the overall design of a floater is to reduce as much as possible, the environmental loads, the motion responses induced by the environments, the linear/angular accelerations, the linear/angular velocities and the displacements/angles of the floater, and to balance the buoyancy and floating conditions, stability requirements, sea-keeping and station-keeping requirements of the floater, and to assure the overall performance of the platform. However, some characteristics mentioned above normally are contradictory, especially between the stability and the sea-keeping.

In order to guarantee the buoyancy (variable load and displacement) and floating conditions (plan positions of the COG and the COB), following technical measures will be used in this invention: the buoyancy force of all floating platforms in this invention mainly comes from the displacement of the multi-tanks, only a fraction of the buoyancy force comes from the displacement of the legs. In order to balance out the redundant buoyancy from the multi-tanks, solid ballast could be used. In order to assure the platform stays in a upright floating condition than tipping during operations: 1) its multi-tank is in a configuration with vertical and rotational symmetry in every fixing angle; the COG of the platform structures and facilities on/above the multi-tank, such as legs and topside modules, must be on its central axis. 2) The automatic and equal mass flow-rate displacement process assures the draft of the platform unchanged during loading and offloading operations by firmly conducting the loading and the offloading of the ballast seawater and the stored liquid in a symmetrical way. For instance, for the floating platform with multi-tank of multiple sets of vertical petal-shaped cylindrical storage cells, the two pairs of seawater ballast compartments and liquid storage compartments with central symmetry form a set of storage cell, which will then assure that the platform's COG remains on the central axis under normal or damaged conditions. For a platform with a C-type multi-tank with single wall and multi-sets of vertical honeycomb storage cells in a rotational symmetry to every fixing angle, wherein each storage cell has four honeycomb cells with pipe connections between the top and the bottom of the two cells to store liquid; or uses two identical sets of loading pumps and offloading pumps to load or offload two symmetrical cells with the same flow rate, which will then assure the symmetrically loading and offloading. For a platform with the multi-tank of multi-sets of storage cells shaped like multi-layer tower ladder, one or both of the two methods mentioned above could be adopted depending on the application circumstances. For some of the platforms in the invention, the multi-tanks will automatically meet the requirement of upright floating condition by themselves.

In order to ensure and to give considerations to both stability and sea-keeping for the various floating platforms in this invention, following methods will be used: the same as a SPAR mentioned in the present invention, three solutions will be used to improve the initial GM which is needed by a floating platform's stability. First of all, all single legs' floating platforms in the present invention have their COB above COG, which will cause the "self-righting doll" effect, and most value of the GM comes from the distance between the COB and COG. For pedestal-type floating platforms with 3 or 4 leg configurations, their COG also need to be lower as far as possible, and to achieve this, the intrinsic bottom solid ballast compartment 20-1 as shown in Figure 25, or protruding skirt-shaped bottom solid ballast compartment 20-2 as shown in Figure 23 could be placed in the bottom of the multi-tanks. If these actions mentioned above still could not achieve the goal, protruding skirt-shaped lower solid ballast compartment 20-3 as shown in Figure 22-1, or intrinsic lower solid ballast compartment 20-4 as shown in Figure 24-1 could be used to increase the distance from the solid ballast to the COB and to lower the COG. Another approach is to use heavy concrete for the lower portion of the multi-tank, and light concrete for the leg(s) at the upper portion of the multi-tank. Second, utilizing the effect of air cans inside the moon pool, which keeps tensile force of the risers; the more numbers of the risers, the bigger of the total tensile force with a longer distance from the air cans to the bottom of the platform to create a larger value of the platform GM. Third, for a floating platform with 3 or 4 leg configurations, initial GMs for the stability are mainly from their inertial moments of their water plane areas; although for the platforms with a single leg, the inertial moments of water plane areas is not so much, it still could contribute some restoring moment for the floating platform. The positioning system formed by mooring legs for various floating platforms mentioned in this invention could also provide some restoring moment, and they will reduce the tipping of the platforms caused by the current and the wind. In order to ensure the damaged stability due to a broken tank, following methods will be used: the first and most important one is to prevent tank-broken. For instance, for the places where are vulnerable from being hit by falling objects such as the top of multi-tank, and from impact (column close to the water surface), the concrete wall shall be thickened and enhanced, or with double wall structures. For the multi-tank used for a floating platform, a protecting shield 46 from falling objects (see Figure 22-1) could be used above the top of the multi-tank, which will not only protect the vessel from falling objects, but also increase system damping and added mass. Second, for a floating platform with "tank-in-tank" type of multi-set multi-tanks, since the seawater ballast compartment is outside the vessel and the liquid storage compartment is the inner one, in case of one ballast compartment broken, the automatic control valve will be closed which shall separate the inner and outer tanks to ensure the stored liquid won't leak, and in a normal case, the reduction of buoyancy would be limited; only in the situation when liquid storage compartment is full, sea water ballast compartment has max value of gas inside and the broken place is on the top of compartment, then the buoyancy would reduce the most. However, even in such case, seawater offloading pumps could be used to offload seawater from other tanks which could reduce the platform's total weight. Third, watertight bulkhead structure shall be used at the bottom of floating platform's topsides, and this would provide the last line of defense. These three methods mentioned above not only ensure the damaged stability, but also make the platform standing straight in a damaged case.

In the present invention, three methods will be used to improve the seakeeping performance of floaters. First, try the best to reduce the wave loads on the floaters. Second, adjust the natural period of platform's 6-DOF to improve the motion responses and avoid resonances. Third, increase the system's damping which is helpful particularly in reducing secondary-order motion's responses.

As mentioned above, wave induced force diminishes exponentially with water depth. Although the size of the multi-tank in the present invention is big, the top of system could be in the water depth with little impact from waves, which could then reduce the wave induced force a lot. A floating platform with a deep-draught configuration in the invention is the first approach to reduce the impact from waves to the multi-tank. Even in the situation when the water displacement and the water depth of the multi-tank's top are the same as those in other platforms in the present invention, a floating platform with the multi-tank with multi-sets of storage cells shaped like multi-layer tower ladder has the least impact from waves. On the other hand, a sufficient deep draught for a floater will reduce the first order excited oscillations in platform heave direction, and make the second order responses as the primary part of total heave responses. Indeed, a deep-draught configuration could cause the COB and COG of the system moving down, system GM could be decreased and the moments from the wind-induced force on the structure, above water to the COG, will be increased and so does the wind-induced overturning moment to reduce the platform stability. In survival conditions, wind is a key factor to platform's total pitch and sway motions, and it is especially important in areas like South China Sea and Gulf of Mexico where typhoon and hurricane happen frequently. The second approach: reduce the legs' water plane areas reasonably, and all floating platforms in the present invention have small water plane area to provide a sufficient heave stiffness. As water plane area of floater increases, wave-induced forces on the offshore structure also increase in all heave, pitch and roll directions. In the invention, cylindrical legs of a floating platform to connect the topsides facilities and underwater multi-tank could be single leg configuration as shown in Figures 22-1 and 24-1, and also 3-leg or 4-leg configurations as shown in Figures 23 and 25 respectively. As far as stability concerns, multi-leg configuration is better than the single leg configuration; as far as sea-keeping concerns, single leg configuration is better than multi-leg configurations. In order to reduce the wave-caused force on the platform and improve the wave-keeping, water plane area shall be as small as possible. However, if the water plane area is too small, heave stiffness will become very small also, which will cause a great change in platform draught by a small change in variable load at the topsides during offshore installation and production operations to increase the operational difficulties. Third, proper method is adopted for floating platforms in this present invention to reasonably design the elevation configuration of the underwater structure to reduce its dimensions. Within the range of water depth with wave impact, large area and dimension of the vertical section profile for an offshore platform will lead to large horizontal loads from waves to produce surge and sway motion responses. Legs used in all floating platforms in the present invention are tall and thin cylinder or cone with a small diameter and a simple configuration, and the purpose of that is to reduce the wave loads to the platform and to construct the platform easily at the same time. Besides, according to researches, if an offshore platform has different numbers of legs, but with the same water plane areas and vertical section profile areas, the platform with more legs will receive more wave loads. In order to reduce the wave loads, most of floating platforms in the present invention have a single leg configuration; some of them have 3-leg or 4-leg configurations.

As is well known, floater's natural period in certain DOF is related to its own mass and the stiffness in this certain direction:

$T=2\pi$

In the formula above: M is the mass of floater, which include the added mass; K is the stiffness; T is the period (second).

Regarding the heave natural period of the system, the floating platforms in the present invention belong to the same type as an existing semi-submersible platform and a SPAR: their heave natural period is longer than the primary wave periods, i.e. 12 to 16 seconds in maximum waves. The heave (and other degree of freedom) period of all floating platforms in the present invention are normally longer than 20 seconds. Mooring positioning systems such as mooring legs or tension legs induce impacts on system's stiffness, so that the mooring positioning system could change the natural period, thus affect the floater's motions and dynamic responses. Mooring positioning system could not only reduce the static displacement of a floater directly, but also affect the dynamic responses indirectly. Regarding to the floater's heave stiffness, water plane area and the vertical force from the mooring system play an important role. Catenary mooring positioning system is used in the present invention, which will has a less impact on heave stiffness compared to a tension leg mooring system. Water plane areas of these platform legs relatively small in reducing wave loads on columns, and in turn to limit the heave stiffness to be limited. However, as mentioned above, the heave stiffness of a floating platform could not be too small either, which could cause the response to the platform's variable load too sensitive. Increasing the added mass is also an efficient way to change system's natural period. The approach to increase the added mass sometimes has the same effect as the increase of damping. When to increase the added mass and how to reduce the additional wave loads caused by above mentioned factor should be considered. The multi-tanks used in floating platforms listed in the present invention are placed in a water depth with little wave loads, and therefore the wave loads caused by the increase of added mass shall be very limited as well.

In general, the approaches adopted for the floating platform in the present invention to increase the added mass, system damping and damping moment include the following options: 1) To use protruding skirt-shaped bottom solid ballast compartment 20-2 as shown in Figure 23, protruding skirt-shaped lower solid ballast compartment 20-3 as shown in Figure 22-1, or intrinsic lower solid ballast compartment 20-4 as shown in Figure 24-1. Among these solid ballast compartments, the protruding skirt-shaped types could increase the system radii of gyration better than intrinsic types, which would then increase the moment of inertia. 2) The diameter of the multi-tank top shall be far longer than the one for legs. To emphasize this "small-top, big-bottom" concept, multi-tank with multi-layer ladder configuration shall be used instead of cylindrical multi-tank, e.g. multi-set multi-tank of storage cells like a multi-layer tower ladder configuration (see Figure 22-1). 3) The top of multi-tank and the top of every layer in a multi-layer ladder multi-tank shall have falling-objects protecting shield 46 (see Figure 22, A-A profile) which could also increase the system damping. 4) For a C-type SPAR platform, use level and transverse interconnect heave damping plates 67 (see Figure 25) in a defined water depth to produce little wave loads. Approaches mentioned above will increase the added mass and system damping in each direction of heave, pitch and roll, and also the moments of inertia in each direction of pitch, roll and yaw. It is important to notice that the inner ring of falling-object protecting shields 46 is connected to the multi-tank by a few connection points only and the rest parts could have some arc shaped spaces with the multi-tank. The purpose of this is to ensure transparency between the waters above and below the falling-object protecting shield within the inner ring to reduce the wave loads.

In short, the contradiction in the requirements of floater stability and its sea-keeping ability shall be balanced. To the characteristics of a floater, the floating platforms in the present invention keep the SPAR features and advantages, such as a deep draft configuration with a small water plane area (for the single leg configuration and a SPAR-type platform), the COB above COG, the natural period of the platform longer than the primary periods of 100-year return waves. Meanwhile, the mentioned configurations overcome its drawback of no large volume of oil storage capacity.

Construction and Installation of Floating Platforms

"Dry and wet" two-step construction method could be used for all floating platforms in the present invention. The lower portion of the multi-tank could be constructed in a traditional deep dry dock, then move to a deep water construction site to finish the remaining construction in a floating condition, and finally be wet-towed to field site. Offshore installation method is as the same as that for a semi-submersible and a SPAR. If the lower portion of the multi-tank is constructed in a steel sandwich concrete structure, it could be built in a normal dry-dock or a yard to finish the steel shell construction, and then towed to a deep water construction site to finish the remaining construction work afloat.

REMOVABLE CONCRETE ARTIFICIAL ISLAND

As mentioned above, the removable concrete artificial island in the present invention has two types: fixed one and floating one. Both of them include: a liquid storage system with multi-tank, which forms the body of the artificial island. A topsides facility is installed on the top of the multi-tank. A fixing or mooring positioning system is used to moor the multi-tank at seabed. The common technical characteristics of the two types are: the island body stretches upward piercing water surface to let the island freeboard high enough to reduce or avoid green water over the top of the island; and the gap between the lower deck of the topsides and the top of the multi-tank should be sufficient to assure no water over the lower deck in design sea conditions and with a sufficient safety margin.

"The equal mass flow-rate displacement system between ballast seawater and stored liquids with closed, pre-pressurized gas in an inter-connected process" could be used for the liquid storage system of the removable concrete artificial island in the present invention, in which the inside inert gas pressure lower than the outside seawater hydrostatic pressure. In case of reducing the inside inert gas pressure for safety reasons, the minimum pressure (g) of inert gas in Figure 1 process could be set slightly higher than atmospheric pressure provided it meets the requirement of the pump suction head height. So deep well pumps (the inlets are located in the bottom of the multi-tank), or underwater pumps installed outside the multi-tank underwater could be used for a seawater offloading pump and a liquid offloading (export) pump.

Fixed Artificial Island (see Figure 26)

One of the 9 vertical pedestal type multi-tanks, or one of the 6 types of multi-tanks only used for fixed platforms as mentioned above could be used as the island's body of the fixed artificial island in the present invention. Among these 15 types listed above, the horizontal bamboo raft type multi-tanks are suitable for shallow waters (depth less than 10 meters); the flat box-shaped honeycomb multi-tank is suitable for calm and shallow waters. Since the fixed artificial island stretches upward piercing water surface with the operating weight of the upper portion of the island above water, the whole operating weight of the island could be bigger than its buoyancy without solid ballast, therefore the solid ballast compartment 20 could be cancelled. In short, whether to use or not use a solid ballast compartment on the multi-tank of a fixed artificial island shall be determined based on the different circumstances. Although, the operating weight of the fixed artificial island in the present invention is bigger than its buoyancy, the island still relies on the way of a piled-foundation rather than on the system self-weight to fix the multi-tank at seabed which is the same as the said bottom-supported fixed platform. The way of a piled-foundation could be one of the following 5: 1) an apron pile 31-2, 2) suction piles 31-3, 3) piles 31-1, 4) an apron pile plus with suction piles, 5) an apron pile plus with piles. Among these 5 ways to be used, the selection will depend on the operational requirements of the island, the sea environmental conditions, the seabed geological conditions, the design requirements of towing, and the re-floating requirements during moving and reuse, etc.

The fixed artificial island in the present invention shall follow the following principles in weight control: first, the operating weight during island full-loaded shall be more than or equal to its buoyancy in the design draught at the design high tidal condition. Second, after the stored liquid and sea water inside the multi-tank being drained up (still could be some residue remaining), the light operating weight of the island shall be less than the buoyancy of the island in the design draught at the low tidal condition. The first principle ensures that the problem of an uplifting force on the piled-foundation shall not happen, which is resulted from operating weight less than the total buoyancy. The second principle ensures the buoyancy of the artificial island during construction, installation and towing. More importantly, it shall ensure that the island has ability to re-float for the relocation and the reuse. During re-floating, the first objective is to destroy the suction force between seabed soil and the island's multi-tank bottom. Since a fixed artificial island 49 has a large water plane area, draught change in the island will follow the tidal level change, which could cause a great change of island's buoyancy with an undesirable impact to the piled-foundation. In order to balance the buoyancy change caused by draught variation, ballast water shall be added or reduced accordingly to the tidal change. Therefore, a compensation system is needed, which will add or reduce ballast water automatically during the equal mass flow-rate displacement between ballast seawater and stored liquid. And also, an independent compensation ballast water compartment with an independent compensation system could be used. Both these systems shall be able to add or reduce the ballast water automatically according to the periodical and predictable changes of the tidal levels. During the production operations of the fixed island, great attention shall be paid to scour around the bottom of multi-tank by currents. A method using sand bags around multi-tank bottom could be used to solve this problem.

Floating Artificial Island (see Figure 27)

One of 9 vertical pedestal-types multi-tanks as mentioned above could be used as the body of the floating artificial island 28 in the present invention, which is moored at the seabed by mooring positioning system 34. Since the floating artificial island stretches upward piercing water surface with the constant operating weight of the upper portion of the island above water, it may meet the requirements of buoyancy at design draught without solid ballast. In short, whether to use or not use the solid ballast compartment on the multi-tank of a floating artificial island in the present invention shall be determined based on the different circumstances. The stability of the floating artificial island 28 would mainly rely on the moment of inertia generated by its own large water plane area since its COG is above its COB. Large water plane area causes higher heave stiffness, which will decrease the heave natural period to be closer to primary wave periods, and thus induce resonance motions. It is very important for the floating artificial island in the present invention to rely on skirt-shaped bottom solid ballast compartment, which acts also as a damping plate, to improve the hydrodynamic performance in harsh seas. The effect of a damping plate has been proven by existing SSP platforms. Therefore, no matter solid ballast is needed or not, skirt-shaped bottom solid ballast compartment, which acts also as a damping plate (20-2, 20-3 or 20-5), is a must; the option is, if needed, to add solid ballast inside the tank. Otherwise, it could add sea water inside the tank.

The floating artificial island 28 of the resent invention looks similar to SSP platform, but actually it is not: 1) the storage system is different. In floating artificial island in the present invention, two types of "equal mass flow-rate displacement system between ballast seawater and stored liquid" are used, which will ensure the island's draught remains constant during loading and offloading operations. Because of the displacement system introduced in present invention, neither hydrocarbons-contained gas nor inert gas would be emitted during loading and offloading operation to make the system a green and clean one with energy conservation. The system, without auxiliary equipment for power generation, distribution and inert gas emitting, could be used not only for storing oil, but also for storing various liquids with different characteristic. Therefore, the facilities and systems of the island are simple, with less maintenance and low costs for construction and operation. 2) The structure configuration of the island is different. There are 9 types of concrete multi-tanks used for the floating artificial island in the present invention, which is simple in structural configuration, good in anticorrosion, impact resistance, low cost maintenance, low costs for construction and operation. 3) It has different skirt-shaped bottom damping plate (bottom brim damping plate) configuration. In present invention, if skirt-shaped bottom solid ballast compartment 20-2 is used in a floating artificial island, it has similar hydrodynamic characteristics compared with SSP platform. However, if wheel-shaped ballast compartment 20-5 is used, it could be better than the ones for a SSP platform.

One shall be noted: it is necessary to ensure the geometric symmetry of the structures at water surface and the symmetry during loading/offloading operations for both two types of mentioned islands, and to keep the system COG and COB of the whole island (including the topsides) along a same vertical line during the operations. The objective is to avoid the overturning moment caused by these two centers at two different vertical lines, which could cause piles on one side of a fixed island being pressed and on the other side being pulled, and could also lead to the potential of capsizing the floating artificial island.

Topsides Facilities of Artificial Island

The up-portions of the multi-tank of the two mentioned artificial islands in the present invention pierce out the water surface. The height of the freeboard depends on whether the green water is allowed up to the top of the multi-tank. If not allowed, the freeboard shall be high enough, and wave wall could be set up around the periphery of the island body. If allowed, the legs of topsides 36 must be long enough to avoid green waters reaching the topsides lower deck, and the green water induced loads on the legs and the pedestals shall be taken into consideration during the design and the construction. Similar to a ship-shaped FPSO, the topsides 36 is fixed on the top of multi-tank by several legs. Since there is no apparent sagging and hogging concerns, fixed supporting joints could be used to connect the legs to the top of the island with a local strengthened wall.

The structural configuration of the topsides 36 could be a single-layer deck or a multi-layer deck, and a safety distance, not less than 2.5~3 meters in a normal design, shall be kept between the lower deck of topsides 36 and the top of the multi-tank.

Construction, Installation and Relocation

In present invention, the key to the construction of the artificial island is how to construct its multi-tank. There are three different ways to construct and install the island: build the whole island (including both island-body and topsides facilities) in one-step "dry" construction method, and then wet-towed to the field site for offshore installation. Build the island-body in "dry" method and build topsides facilities separately, and tow it to the field site for offshore installation. Build the island-body using "dry" & "wet" two-step method by building the topsides facilities separately, and towing it to the field site for installation, or installing the topsides facilities on the island-body in a deepwater site, and then wet-towing it to the field site for offshore installation. The relocation of a fixed artificial island is similar to a bottom-supported and fixed platform, and the relocation of a floating artificial is easy and would not be restated here.

THE APPLICABLE CONDITIONS AND MAJOR ADVANTAGES OF THE BOTTOM-SUPPORTED AND FIXED AND FLOATING PLATFORMS AND THE ARTIFICIAL ISLAND IN THE PRESENT INVENTION

The bottom-supported and fixed platforms and the floating platforms in present invention maintain and carry forward the advantages of existing fixed and floating platforms such as a jacket, a jack-up, a concrete gravity platform, a SPAR, a SEMI without their disadvantages. The present invention solves some problems for the two existing platforms mentioned above, such as the storing of liquid underwater and the heating plus heat insulation of the liquid. The bottom-supported and fixed platforms in the present invention could be used for oil and gas development in both shallow waters and harsh deep waters. Compared with an existing FPSO, which is hard for drilling and using dry-wells, the floating platforms in the present invention provide very good performances in buoyancy, stability and sea-keeping and could be used for drilling and using dry-wells, the same configuration as a SPAR. The mentioned platforms are also suitable for oil and gas development in harsh and deep waters. The artificial island in the present invention has a large water plane area; and therefore it could have relatively large wave loads. However, the fixed artificial island could be utilized in calm and shallow waters only. As for the floating artificial island, because of the damping effect caused by the protruding skirt-shaped structures (20-2, 20-3, 20-5), it provides a very good hydrodynamic performance and could be used in harsh and deep waters. The platforms and artificial islands mentioned in the present invention, coupled with a SPM or a spread mooring system for shuttle tankers, could provide a full platform function such as drilling, production, storage and exporting. The fixed artificial island could also be used as the key component of an offshore quay to berth a shuttle tanker alongside directly (see figure 28). The platforms and artificial islands in the present invention both have following advantages: simple system and structural configuration, easy to construct, short construction period, low capital and operation costs, good anti-corrosive performance, long service life, no waste or emission of oil/gas during loading and offloading operations, little pollution, flexible for installation and relocation, easily removed for reuse after the end of oil field life, and suitable for developing not only a large-sized oil and gas field with a long production life but also for a small-sized oil and gas field with a short production life, especially for a marginal oil and gas field.

EXAMPLES OF APPLICATION

The liquid storage, loading & offloading system and the system-based offshore platforms, artificial islands in the present invention could be widely used for oil industry. The following provides some examples of the applications.

Example 1: NEARSHORE BOTTOM-SUPPORTED AND FIXED UNDERWATER (LIQUID) STORAGE, LOADING & OFFLOADING SYSTEM

As shown in Figure15, this system includes: 1) A bottom-supported and fixed multi-tank 19 with a bottom solid ballast compartment. It could be any one of the 15 types of the above-mentioned multi-tanks among 18 types in a total, except for the three SPAR types of multi-layer multi-tanks (Figure 15 shows the vertical cylinder multi-tank with a single set storage cell only) to be fixed at seabed by a underwater piled-foundation for anti-sliding. As shown in the Figure, several underwater pipe piles 31-1 are driven into the seabed through the protruding skirt-shaped bottom of a solid ballast compartment 20-2 to fix the multi-tank at seabed. Since the multi-tank 19 is constructed of concrete, it is better to use the "equivalent mass flow-rate replacement system between ballast seawater and stored liquid with closed, pre-pressurized gas in an inter-connected process", of which the inside inert gas pressure is lower than the hydrostatic pressure outside. 2) A pump module 4. Figure 15 shows the submersible pump (deep well pump type) and the traditional pump module 4-1 which is installed on an out-of-the-water small platform 30 connected to the top of the multi-tank. Otherwise, a subsea pump module could be used according to the water depth and the sea conditions for the application. If the multi-tank with multi-set storage cells is used and there is only one set of pumps equipped, then a special manifold to switch over the process between the storage cells is needed. 3) A SPM 12. Figure 15 shows a CALM system, and other kinds of SPM such as a SAL, or a spread mooring system could also be utilized. 4) An onshore working station 2 to supply power and to provide remote control for this system. The pump module 4 is connected with the onshore working station 2 via a subsea pipeline 3 and underwater power & control composite cables. The pump module 4 is also connected with the SPM 12 via a subsea pipeline 3 and an underwater flexible riser 11 to export and to receive liquid products.

This system could be suitable for shallow water application in conjunction with a onshore working station 2, transfer the onshore oil products or liquid products through an onshore-subsea pipeline to the underwater multi-tank 19 for storage, and then to a shuttle tanker 15 via SPM 12 for exporting. Thus this system becomes a near shore terminal to store and transport the oil products and liquid products. Moreover, this system could also offload the oil products and liquid products from a shuttle tanker via the SPM 12 to the underwater multi-tank 19 to store, and then to distribute to onshore. Or it could transfer products still via the SPM 12 to other ships to transport. Thus this system becomes a near shore terminal to receive and distribute the oil products and the liquid industrial products. This system has advantages to provide a simple system / facilities, a safe and reliable operation, a short construction period, a low capital / operation cost, and is easy to be removed and reused. This system could act as an oil depot and tank farm to store, receive and transport the oil products and the liquid products.

Example 2: A SUBMERGED FLOATING (LIQUID) STORAGE OFFLOADING SYSTEM SERVING FLOATING OR FIXED OFFSHORE OIL AND GAS PRODUCTION FACILITIES

This system, as shown in Figure 16, includes: 1) A submerged floating multi-tank 19 being moored at seabed by a mooring positioning system 34. It could be any one of the 9 pedestal types of multi-tanks, and the Figure shows the vertical and cylindrical single set multi-tank, of which the protruding skirt-shaped bottom solid ballast compartment 20-2 could provide advantages in adjusting the system weight and COG, increasing the added mass, system damping & damping moment, the moment of inertia in each direction of pitch, roll and yaw, and improving the hydrodynamic performance of the system. Since the multi-tank 19 is constructed of concrete, it is better to use the "equal mass flow-rate displacement system between ballast seawater and stored liquid with closed, pre-pressurized gas in an inter-connected process", of which the inside inert gas pressure is lower than the hydrostatic pressure outside. The mooring positioning system 34 could utilize catenary, taut, or semi-taut system to have the fairlead locates near the buoyancy center of the multi-tank or at the top of the multi-tank 19. The multi-tank is placed in a water depth with little influence from the wave, so that the environmental induced forces at the multi-tank are limited. If a SPM and a multi-tank are separated, a mooring positioning system could be small one because of less mooring force acting on the multi-tank. However, if the SPM and the multi-tank are integrated together, the mooring force from the shuttle tanker must be considered in the mooring positioning system design 34. 2) A pump module. As the Figure shows, it is a underwater pump module 4-2 installed on a small underwater platform 35 connecting to the top of the multi-tank. In calm sea conditions, the traditional pump module could be used as listed in Example 1. If multi-tank with multi-set storage cells is used and there is only one set of pumps equipped, then a special manifold to switch over the process between the storage cells is needed. 3) A SPM system 12. As the Figure shows, it is a SPM similar to a CALM, while other SPM configurations could also be considered. A SALM or SAL could also be considered to be installed on the steel structure of a small underwater platform 35 and above the underwater pump module 4-2. The SPM such as a CALM or a STL could also be used and separated from the multi-tank. 4) A working station 2 to supply power and to provide a remote control operation for this system. It is placed on the system-serving offshore production facilities 48, such as a jacket platform as shown in Figure 16, or a floating platform. The underwater pump module 4-2 is connected with a working station 2 on offshore production facilities 48 via a subsea pipeline 3 and power & control composite cables 1. And it is also connected with a SPM 12 via internal piping. If the SPM is separated from the multi-tank, then the underwater pump module 4-2 is connected with the SPM 12 via a subsea pipeline 3 and an underwater flexible riser 11. The shuttle tanker 15 is moored to SPM 12 via mooring lines 13 and the oil products could be transported out via a floating hose 14. The power for the underwater pump module 4-2 is supplied by offshore production facilities 48 and oil storage and offloading operations could be controlled remotely from offshore production facilities 48.

This system is suitable for deep and harsh water application and supported by an offshore floating or a fixed platform and could store oil products produced by the platform and transfer oil products out at intervals via a shuttle tanker. Compared with a FSO, this system has a desirable anti-harsh-environment characteristic, which could be used for any sea conditions worldwide. It has advantages such as a simple facility, a safe and reliable operation, a short construction period and a low capital / operation cost, easy to be removed and reused. Hence this system could be used for both a large scale offshore oil field development and a marginal oil field development, especially for the marginal oil field in deep water application.

Example 3: THE BOTTOM-SUPPORTED PLATFORM WITH SEABED STARAGE AND CONCRETE (TAPERED) CYLINDRICAL LEG(S) (see Figure 17)

One to four concrete (tapered) cylindrical legs could be utilized for this platform and the Figure shows a single leg platform. All conductors, riser and subsea cables pass through the legs. The multi-tank showed in the Figure is a multi-tank with a vertical and cylindrical single set storage cell. It could be any one of the said 14 types of multi-tanks except for a SPAR multi-layer multi-tank. According to the type of the platform multi-tank, corresponding solid ballast compartments shall be used. The platform is fixed at the seabed by an underwater anti-sliding device of piled-foundation. As the Figure 17 shows, several underwater piles 31-1 are driven into the seabed through the protruding skirt-shaped bottom solid ballast compartment to fix the multi-tank to the seabed. In order to improve the structure strength, the level section area and the underwater profile area of the legs shall be as small as possible to reduce the wave loads, and a single-leg is proposed for the platform with a vertical multi-tank if possible. The configuration of the topsides facilities could be the same as a normal gravity platform. The equal mass flow-rate displacement system between ballast seawater and stored liquids with closed, pre-pressurized gas in an inter-connected process could be used for the liquid storage system. The inert gas inside the system has an inert gas pressure less than the outside seawater hydrostatic pressure. In the operation, the minimum pressure of the inert gas (gauge pressure) could be a little bit higher than the atmosphere pressure, and deep well pumps shall be used for the seawater offloading pump and the liquid offloading (discharging for transportation) pump correspondingly with the inlets to be located at the bottom of the multi-tank.

Different construction methods could be used for the platform in this example according to different types of the multi-tank structures used. For example, the multi-tank and legs, even the whole of the platform with "bamboo raft" multi-tank or flat box-shaped multi-tank, could use the one step dry method for the construction. The dry & wet two step method is normally used for the platform with vertical multi-tank with rotation symmetry in every fixing angle. Towing and offshore installation methods for this platform are similar to or the same as a concrete gravity platform, however, the method to fix the platform at the seabed is different. As described previously, the present invention adopts the underwater anti-sliding fixing device 31 providing piled-foundation to fix the platform at the seabed. This platform could be used in the same environments and water depths as other existing concrete gravity platforms, but it overcomes the disadvantages of existing wet storage method and a gravity-based platform. This platform should be suitable for a water depth up to 350 meters.

Example 4: THE BOTTOM-SUPPORTED PLATFORM WITH SEABED STARAGE AND A CONVENTIONAL JACKET LEG (see Figure 18)

This described platform is, in essence, a conventional steel jacket platform on the top of a multi-tank and it is fixed at the seabed. Hence it has all the advantages of a conventional jacket platform, and solves the problem that a conventional jacket platform could not store oils. In the design of the connection portion between the platform jacket legs 37-2 and the multi-tank 19, both the strengths of the legs and the multi-tank wall shall be taken into account to help the transferring of the loading to the underwater piles 31-1. Besides the underwater anti-sliding fixing device 31 providing piled-foundation, a stayed-cable 43 could also be used to fix the platform, as a backup, at the seabed (see Figure 19). For the platform with a very high multi-tank, one could use conventional jacket legs with underwater skirt piles to fix the platform at the seabed through the multi-tank. The multi-tank with vertical and cylindrical single set storage cell is used for the platform in Figure 18, and one of other 14 types of multi-tanks as described above in this invention could be also used, except for SPAR multi-set multi-tanks. According to the type of a platform multi-tank, corresponding solid ballast compartments could be used. "The equal mass flow-rate displacement system between ballast seawater and stored liquids with closed, pre-pressurized gas in an inter-connected process" could be used for the liquid storage system. The minimum inside inert gas pressure shall be less than the outside seawater hydrostatic pressure. During the operation, the minimum pressure of the inert gas (gauge pressure) could be a little bit higher than the atmosphere pressure, and deep well pumps shall be used as the seawater offloading pump and for the liquid offloading (discharging for transportation) correspondingly with the inlets at the bottom of the multi-tank. Underwater pumps could be installed outside the multi-tank below water surface.

The multi-tank in the lower portion of this type platform, with steel jack legs 37-2 in the middle and the topsides facilities 36 above, shall be constructed and towed separately. Based on the configurations of the multi-tank, one step dry construction method or dry & wet two step construction method could be utilized accordingly. The sequence of the offshore installation is to tow the multi-tank 19 to the site first, and then install and fix it at the seabed. The next step of the installation is to connect the conventional jacket legs 37-2 onto the multi-tank 19. The final step is to install the topsides facilities 36 onto the legs. In theory, the economically affordable water depth of a traditional steel jacket platform could reach 300 meters. Considering the height of a multi-tank is about 50 to 100 meters, this described platform could be suitable for a water depth up to 400 meters.

Example 5: THE BOTTOM-SUPPORTED PLATFORM WITH DEEP-WATER COMPLIANT TOWER LEG AND SEABED STARAGE (see Figure 19)

This described platform is, in essence, to install a platform with a compliant tower leg onto a multi-tank fixed at the seabed for deepwater applications. Therefore, it has all the advantages of a platform with a compliant tower leg, and solves the problem that the platform with a compliant tower leg could not provide the oil storage capacity. In the design of the connection portion between the compliant tower legs 37-3 and the multi-tank 19, both the strengths of the legs and the multi-tank walls shall be considered, especially the fatigue, to help transferring the loading to the anti-sliding fixing device with piled foundation. The liquid storage system is the same as the one in Example 4, so there is no need to repeat it here. The construction, transportation and offshore installation are the same as a platform with traditional jacket legs described previously. However, the verticality of compliant tower legs shall be less than 0.1° as required. The sequence is to install and level the leveling template 39 on the top of the multi-tank (which is already installed at the seabed), then install the tower base template 40, tower base section 41 and tower top section 42. In theory, the economically affordable water depth of this platform with a compliant tower leg for a water depth could reach as much as 800 meters. In an existing installed compliant tower, the water depth already reaches 530 meters. Considering that the height of a multi-tank is about 50 to 100 meters, this described platform could be suitable for a water depth up to 1000 meters. The A-type SPAR multi-set multi-tank could be used for the platform in Figure 19 and one of other 17 types of multi-tanks as described above in this invention could be also utilized. According to this type of the multi-tank, corresponding solid ballast compartments shall be used. Besides the underwater anti-sliding fixing device 31 providing piled-foundation to fix the platform at the seabed, a stayed cable 43 could also be used to fix the multi-tank, rather than the compliant tower as a backup for the described platform (see Figure 19). The compliant tower base template 40 could also be equipped with underwater piles being driven into the seabed through the multi-tank.

Example 6: THE BOTTOM-SUPPORTED PLATFORM WITH JACK-UP LEG AND SEABED STARAGE (see Figures 20 & 21)

This described platform is, in essence, to install a jack-up platform with three or four legs, without mats or pile shoes, onto the multi-tank fixed at the seabed. The topsides facilities 36 are constructed with watertight bulkhead compartment 45 which could move up and down along the jack-up legs 37-4 by the rise-and-fall mechanism fixed at a required position with height marks. The liquid storage system is the same as the one in Example 4, so there is no need to repeat it here. The multi-tank 19 at the lower portion of this fixed platform is constructed in a dry dock, while the steel jack-up legs 37-4 at the middle portion and the topsides facilities 36 are constructed onshore. Since this fixed platform has two different installation options, the design and construction are also slightly different for those two options. In the first option, the whole platform is constructed by the one step dry construction method, and then wet-towed to the field site where the topsides facilities 36 will then be lowered down to the lower portions of jack-up legs 37-4. This platform is similar as a jack-up drilling platform with mats. After towing to the oil field, the multi-tank 19 is lowered down a step by a step until touching the seabed and leveled. Then the underwater skirt piles 31-1 are driven to the grade and the topsides facilities 36 is jacketed up to complete the platform installation. In the second option, the multi-tank is constructed by the one step dry or dry & wet two-step method and installed at the seabed in advance at the installation site. The topsides facilities 36 and jack-up legs 37-4 are assembled in a dry dock and then towed to the installation site with sufficient buoyancy from of the watertight bulkhead compartment 45. At the installation site, the jack-up legs 37-4 are lowered down and connected onto the multi-tank with at jack-leg joints 44. Finally, the topsides facility 36 is raised to complete the platform installation. This platform is similar to a jack-up drilling platform with pile shoes; and therefore, a special design is required for the leg-ends and the jack-leg joints 44 at the multi-tank. The water depth of an existing jack-up platform in a practical application already has already reached 150 meters. Considering that the height of a multi-tank is around 50 to 100 meters. Therefore, this platform is suitable for a water depth up to 250 meters. The multi-tank with vertical and cylindrical single set storage cell is utilized for the platform in Figure 20. It could also use any one of the other 8 types of the pedestal-type multi-tanks. According to the type of the platform multi-tank, corresponding solid ballast compartments could be used. The 3 types of "bamboo raft" multi-tank or 3 types of flat box-shaped honeycomb multi-tank could be used for the platform shown in Figure 21. Besides the underwater anti-sliding fixing device 31 with piled-foundation to fix the platform, the underwater piles at the legs could also be driven into the seabed through the multi-tank to fix the platform.

Example 7: THE PEDESTAL-TYPE FLOATING PLATFORM WITH UNDERWATER STARAGE AND A SINGLE LEG (see Figure 22-1)

As Figure 22-1 shows, the multi-tank 19 of this mentioned platform is of a multi-set of storage cell shaped like a multi-layer tower ladder. Any one of other 8 types of the pedestal-type multi-tank could also be utilized. Based on the type of the platform multi-tank, corresponding solid ballast compartments could be used. The liquid storage system is the same as the one in Example 3 and there is no need to repeat here. In order to ensure the system COB of the platform is above its COG, the protruding skirt-shaped bottom solid ballast compartment 20-2, or the protruding skirt-shaped lower solid ballast compartment 20-3 could be used. Moreover, the upper portion, the lower portion of multi-tank and the legs could be constructed with two different types of concrete materials with a high and a low specific gravity respectively to further lower the COG. By adding the falling-object protecting shield 46 on the top of each layer of the multi-tank, it could increase both the added mass and the damping at the same time. The shield outer diameter shall equal to the outer diameter of the layer at the multi-tank and its inner ring fixed on its upper layer of the multi-tank or on the outer wall of the leg. Its outer ring is fixed on the layer of multi-tank by the upholder 47. The top of the multi-tank shall be located in a defined water depth which could greatly reduce the wave loads, e.g. about 40-meter water depth in South China Sea and in GOM. The legs could be shaped in a cylindrical or conical concrete tube. From the design point of view, the conical tube shaped leg is better. However, the construction difficulty could be increased. The leg shall be on/around the central axis of the platform and its water plane area shall be as small as possible providing that the variations of the variable loads satisfy the heave stiffness requirements. There are several horizontal bulkheads inside the cylindrical legs, forming buoyancy tank(s) (void tank) and equipment cabin(s) for facility installation. The buoyancy tank near the water plane could be double-walls or special enhanced configuration. Cylindrical moon pool 27 passes through the leg and the multi-tank along the central axis. The type of the topsides facilities 36 is similar to the type used for a SPAR-type platform and the watertight bulkhead compartment structure could also be utilized. The wellhead area is located on the axis of the platform. The platform in this Example uses the same catenary mooring leg system as for a SPAR-type platform, or a taut mooring system, or a semi-taut mooring system 34. The positions of the fairleads of the mooring legs are decided based on the specific conditions of the platform under current and wind loads. It could be located near the COB of the platform or close to the sea surface. In some areas with very harsh environments, such as the areas with severe winds, waves, current environmental loads, the floating platform in the present invention could be equipped with two sets of mooring positioning systems at the same time. The fairleads shall be located separately at different water depths. This platform has the same characteristics as an existing SPAR with the small water plane area, the deep draught, and the COB above the COG. If only the legs are considered without topsides facilities and the mooring positioning system, this platform almost has no difference with an existing SPAR. However, since there is a multi-tank with large size and mass under the water surface more than 40 to 50 meters, the hydrodynamic performances are better than an existing SPAR.

Example 8: THE PEDESTAL-TYPE FLOATING PLATFORM WITH UNDERWATER STARAGE AND MULTI LEGS (see Figure 23)

This Example includes different 9 types of the floating platforms with multi-leg configuration which are similar to the previous mentioned 9 types of the pedestal-type floating platform with a single leg. The main difference is that the number of legs is changed from one to 3 or 4. Meanwhile, the total water plane areas of the legs shall still be as small as possible. The mooring positioning system in this platform is similar to a SEMI. It could not be necessary that the platform COB is above its COG because several legs could provide the moment of inertia from the water plane areas for the stability of the platform. Compared with one single leg configuration, the other advantages of this type are that the anti-tipping characteristic of the platform is enhanced and the layout in the structural design of the topsides facilities becomes easy to be optimized. However, the disadvantage is that the water hydrodynamic performances are not perfect. The liquid storage system is the same as the one in Example 4 and there is no need to repeat it here. This platform has the same characteristics as a SPAR with a small water plane area and a deep draught. At the same time, it solves the problem in avoiding a large tipping for an existing SPAR. All the legs and the multi-tank of the platform are constructed with the concrete material. The methods of construction, towing and offshore installation are stated in Example 7.

Example 9: THE SPAR-TYPE MULTI-LAYER MULTI-TANK FLOATING PLATFORM WITH UNDERWATER STARAGE (see Figures 24 & 25)

The SPAR type multi-layer multi-tank floating platform with underwater storage in the present invention has two types: the single leg configuration and the 3 or 4 leg configurations. The introverted type bottom or under-bottom solid ballast compartment could be used for both types. The liquid storage system is the same as Example 4 and there is no need to repeat it here. The cylinder single leg platform consists of upper and lower parts: the lower part is A type or B type SPAR multi-layer multi-tanks and the upper part is the cylindrical leg. The water plane area of the leg shall be as small as possible and sufficient enough to provide required vertical stiffness due to the variable load variations by the topsides. There are many horizontal partition plates inside the cylindrical leg, forming the equipment cabin(s) for facilities and the buoyancy tank(s) (void tank). The buoyancy tank near the water plane could be double-wall or special enhanced structures. The length of the leg is calculated according to the buoyancy and stability of the platform requirement. The cylindrical moon pool 27 passes through the leg and the A, B types of multi-tank along the central axis. The leg outer diameter could be equal to or less than the outer diameter of the multi-tank and the hydrodynamic performance of the later is slightly better than that of the former. The multi-tank of the platform with 3 or 4-leg configurations is the C-SPAR multi-layer multi-tank (see Figure 25). It uses the "pipes" within the pipe bundle of the multi-tank as the legs which are stretched out the water surface. Both the multi-tank and the legs take the structural configuration of the 3 pipes or 4 pipes arranged with clearance for a honeycomb shaped configuration with the rotational symmetry in every fixing angle. Normally no horizontal frame 65 is set for the legs above water surface. While a few horizontal frames 65 are set for the legs below water surface. Each layer of the framework consists of 3 or 4 horizontal bars 66for connecting. Some level and transverse heave damping plates 67 in the forms of a triangle or a square are set at a water depth with little wave impact to the bottom of the platform. The heave damping plates 67 together with the horizontal frame 65 make the 3-pipe or 4-pipe configurations as an integral structure. The heave damping plates 67 are very important to improve the hydrodynamic performance of a SPAR type platform and the number of damping plates is determined based on the result of a hydrodynamic analysis. And the number of the layers of the horizontal frame 65 is determined based on the structural design requirements. The topside facilities of the platform in this Example are the same as a SPAR type platform, and the watertight bulkhead compartment structure for the topsides could be utilized. The wellhead area is located on the axis of the platform. The mooring positioning system of the platform in this Example is the same as an existing SPAR or an existing SEMI.

The multi-tank and the legs of the platform in this Example are constructed with the concrete material. The construction method is the same as in Example 7 and a vertical or horizontal wet-tow method could be used for installation. The methods of positioning, upending and installation of the platform in this Example are the same or similar to the one for a SPAR. This platform has the same characteristics as a SPAR with a small water plane area, a deep draught and the COB of the single leg platform above its COG, and a better hydrodynamic performance as the same or better than an existing SPAR. Meanwhile the 3 or 4 leg configuration for the platform solves the large tipping issue for an existing SPAR and its difficult problem in oil storage capacity.

Example 10: SURFACE FACILITIES WITH MULTI-FUCTION OF DRILLING & PRODUCTION FOR OIL & GAS DEVELOPMENT IN SHALLOW WATERS (see Figure 28)

This specified surface facility (or named as "the overall design plan of the surface facilities for oil and gas development") includes: a fixed concrete artificial island with multi-function of drilling, production, storage and offloading 49-1; a fixed concrete artificial island with multi-function of storage, utilities and accommodation 49-2. Two such islands could be together with one of the previous 9 types of pedestal concrete multi-tank and another being the 6 types of the horizontal multi-tank. These two islands 49-1 and 49-2 are adjacent to each other and connected by a trestle 61, which acts as berthing platform for a shuttle tanker 15. On each side of the two islands, there is a small platform for mooring dolphin 60 (two in total) to fasten the bow hawser and the mooring line 13 of a tanker or a transportation ship. The equal mass flow-rate displacement system between ballast seawater and stored liquids with closed, pre-pressurized gas in an inter-connected process could be used for the liquid storage system for storing, loading, and offloading oils. This is the same as described in Example 3 and there is no need to repeat it here. In order to balance the buoyancy change with the change of the draught, an automatic compensation system to increase/decrease ballast seawater shall be added into the automatic replacement system. The utility systems such as a power supply system for the overall facilities are needed from the second artificial island 49-2. The produced oily water is treated by the first island 49-1, and then discharged or injected back into the ground after meeting the discharge requirement. All production operations could be controlled centrally. The surface facility specified in this Example could be used for the development of oil fields in shallow waters with calm environmental conditions and it could be removed and reused for other field developments. For a development plan requiring a large capability of oil storage, it could propose the adding of extra facilities to increase the liquid storage capability. For example, another bottom-supported and fixed multi-tank, like a bamboo raft multi-tank or a flat box-shaped honeycomb multi-tank with large plane area for oil storage (see the multi-tank number 62 shown with a dashed line in Figure 28) could be installed at the seabed close to the artificial island. One of the biggest advantages of the concrete artificial island in the present invention is the flexibility. The concrete artificial island could add or remove different facilities based on the requirements of different oil & gas development plans to have different kinds of surface facilities. Since the artificial island in the present invention is very easy to be removed and re-installed, it could create a kind of "honey bee type (like a bee to get honey from one flow to another)" platforms including drilling, production, storage and transportation. This type platform is especially suitable for a continuing development of multiple marginal oil & gas fields in shallow waters.

Example 11: A FIXED ARTIFICAIL ISLAND OF STEEL MULTI-TANK COATED WITH CONCRETE (B-TYPE VERTICAL SINGLE-LAYER HONEYCOMB MULTI-TANK LIQUID STORAGE WITH MULTIPLE SETS OF ROTATIONAL SYMMETRIC STORAGE CELLS)

This application Example, considering that China has little experience in design and construction of offshore concrete storage tank nowadays, proposes the option of a steel storage multi-tank with protection concrete coating. This Example is used for small size oil fields in Bohai Bay, China, of which the facilities could be repeatedly used for many times. The specified facilities include: an artificial island for oil / gas / water production, utility and accommodation modules with oil storage capability less than 10000 cubic meters, a simple small platform or a protection framework for well-conductors to install the wellheads to be near the artificial island connected between the platform and the island by a trestle, a berthing platform and two small platforms to be used for shuttle tankers to berth alongside mooring dolphins for loading / offloading operations.

The multi-tank in the island (see Figure 13) is the B-type vertical single-layer honeycomb multi-tank of with multi-sets of rotational symmetric storage cells. Its main body consists of 7 steel vertical and cylindrical internal pressure storage vessels (honeycomb cell 52) and each vessel is in up and down arrangement of vertical storage cell with a downward arched-shaped end seal plate (partition plate 57) in the middle to divide the vessel into two parts. The upper part becomes the oil storage compartment and the lower part is the seawater ballast compartment. Exactly seven identical cells 52 are connected and welded together to form a whole multi-tank by 6 vertical arc-shaped connecting plates 54, 24 vertical interconnecting plates 53, 3 flat seal plates 56 installed at the top, middle and bottom respectively. The geometric figure of the vertical sections of the multi-tank (the thickness of the steel plates is simplified into “full line” or “full curve”) is specified as: The circle centers of the 6 perimeter cells 52 are located on the 6 vertices of a regular hexagon, of which the hexagon side is a little bit longer than the outer diameter of the cylinder (the cell), and the difference between them is a gap between those two cylinders. The central cell 52 is located on the center of the regular hexagon. The arc connecting plates 54 connect every two neighboring perimeter cells. The arc radius is equal to the radius of the cell 52 and the arc tangents to the common tangent line of the two connected circles form a regular hexagon with 6 arcs-formed “vertices”. The vertical interconnecting plates 53 are parallel to the connecting line between the two circle centers of every two neighboring cells and locate on the two sides of the connecting line. The width of the interconnecting plate 53 is a little bit larger than the gap between cylinders and the length of the plate 53 is the same as that of the arc-shaped connecting plates 54 which is the total height of the vessel minus the height of the arched head of the vessel. There are round holes at the top, the bottom and the middle of the interconnecting plates 53 for the interconnection of the liquid and gas on different sides of the plates. Flat seal plates 56, the flat and arc-shaped connecting plates (53 and 54), the arched heads and the cylinders are watertight-welded together to form two up-down closed spaces among the 7 cells 52 which could be used for an oily water settling tank and a solid ballast water tank. The bottom of flat-shaped end seal plate is the contacting surface with the seabed. All the walls of the multi-tank which contact the liquid shall be painted with corrosion preventive coating. Reinforced concrete outer protection and weight coating of steel tank 55 with certain thickness are needed to cover the outer surface of the steel multi-tank to function as a balance weight and a protection against corrosion and collision. The parameters of the main structure are determined as per the following: whether the 7 cells could offer sufficient tank capability for liquid storage; whether the draught, the displacement, and the water plane area of the island body meet the requirements of buoyancy and stability during the wet-tow; and whether the operating weight is larger than the buoyancy during operation after adding ballast water into empty tanks.

The topside facilities have a 6-leg structure (Figure 13 doesn't show it). The equal mass flow-rate displacement system between ballast seawater and stored liquids with closed, pre –pressurized gas in an inter-connected process shall be used for the liquid storage system. The inside inert gas pressure (gauge pressure) at the top of seawater ballast compartment 5 and liquid storage compartment 6 is larger than 0 and less than 2.5 times of the atmosphere pressure. The seawater loading pump and the liquid offloading pump shall be deep well pumps which are installed inside the island body. Otherwise, one could use normal centrifugal pumps to be installed on the topsides facilities or on the top of the island.

Fixing the Island at the seabed

Based on the soil conditions at the site, a steel anti-sliding apron pile 31-2, with height (the depth into the soil) no less than 4 to 5 meters, could be utilized. The pile is passed downward extending through the perimeter arc vertical-outer-wall plates of the multi-tank (Figure 13-3). The apron pile is driven into the seabed by the gravity of the island with all tanks filled with water. If suction piles are adopted, preferably 3 or 6, they are formed by downwards extending through the vertical steel cylindrical walls at the island (the thickness of the steel walls shall be increased, Figure 13-4). If the piles are used, the amount of piles could be 6, 8 or 12. And matching amount of the steel pile sleeves are required, which pass through and welded on the top and the bottom heads of the island (does not show in Figure 13). The steel piles pass through the sleeves. These piles are driven into the seabed and then fixed together with their sleeves.

It is to be noted that, throughout the description and claims of this specification the word "comprise" and variations of the word, such as "comprising" and "comprises" is not intended to exclude other additives, components, integers or steps.

The claims defining the invention are as follows:

1. A liquid storage, loading and offloading system comprising:

a storage tank comprising at least one water ballast compartment to store water and at least one liquid storage compartment to store a liquid;

a volume of inert gas disposed in upper ends of the water ballast compartment and the liquid storage compartment;

wherein the upper ends of the water ballast compartment and the liquid storage compartment are fluidly coupled to each other to form an inert-gas-pressurized closed interconnected system; and

wherein the structure of the storage tank is configured symmetrically.

2. The liquid storage, loading and offloading system according to claim 1 further comprising a valve connected to the water ballast compartment and to the liquid storage compartment; wherein the valve opens under a first condition and therefore the water ballast compartment and the liquid storage compartment become a pressurized-equalized closed interconnected system; and wherein the valve closes under a second condition and therefore the water ballast compartment and the liquid storage compartment become two separate systems not fluidly connected.

3. The liquid storage, loading and offloading system according to claim 1 or claim 2, further comprising a pump module coupled to the storage tank; wherein the pump module comprising at least one pair of loading pumps and at least one pair of offloading pumps; wherein the pair of loading pumps including a liquid loading pump to load the liquid into the liquid storage compartment and a water offloading pump to offload the water out of the water ballast compartment; and wherein the pair of offloading pumps including a water loading pump to load the water into the water ballast compartment and a liquid offloading pump to offload the liquid out of the liquid storage compartment.

4. The liquid storage, loading and offloading system according to claim 3, further comprising an equal mass flow rate displacement system to keep a

2009229435 04 Mar 2013

constant operating weight such that the pair of loading pumps operate substantially at equal mass flow rate to displace the water with the liquid; and also such that the pair of offloading pumps operate substantially at equal mass flow rate to displace the liquid with the water.

5. The liquid storage, loading and offloading system according to claim 3 or claim 4, wherein the water offloading pump or the liquid offloading pump is replaced by a pressure energy of the inert gas in the water ballast compartment or the liquid storage compartment such that the pressure energy offloads the water or the liquid out.

6. The liquid storage, loading and offloading system according to any preceding claim, further comprising a shuttle tank to receive an offloaded liquid from the storage tank or transmitting the liquid to the storage tank; and wherein the shuttle tank is coupled to the storage tank by a riser.

7. The liquid storage, loading and offloading system according to any preceding claim, further comprising a working station for providing power and control; and wherein the working station is coupled to the storage tank by a cable.

8. The liquid storage, loading and offloading system according to any preceding claim, further comprising a hydrocarbon production facility coupled to the storage tank by a pipeline.

9. The liquid storage, loading and offloading system according to any preceding claim, further comprising a fixing device attached to the storage tank for fixing the storage tank on a seabed and wherein an operating weight of the system is equal to or larger than a buoyancy of the system.

10. The liquid storage, loading and offloading system according to any preceding claim further comprising a mooring positioning system attached to the storage tank for mooring the storage tank on a seabed in a floating condition.

11. The liquid storage, loading and offloading system according to any preceding claim, further comprising a solid ballast disposed adjacent to the storage tank to increase weights and damping and lower a center of gravity;

and wherein a diameter of the solid ballast is equal to or larger than the diameter of the storage tank.

12. The liquid storage, loading and offloading system according to any preceding claim, wherein the liquid storage compartment is located inside of the water ballast compartment to form a tank-in-tank type of construction; wherein the liquid storage compartment and the water ballast compartment share a central axis; and wherein if a plurality of storage tanks exist, the plurality of storage tanks are arranged in symmetry and the plurality of storage tanks as a whole share the same central axis.

13. The liquid storage, loading and offloading system according to any preceding claim, wherein the liquid storage compartment is adjacent to the water ballast compartment, either horizontally or vertically, to form a not tank-in-tank type of the storage tank; wherein if a plurality of storage tanks exist, the plurality of storage tanks are arranged in symmetry and positioned apart from one another or positioned head-to-tail vertically or horizontally; and wherein a vertically positioned lower storage tank has a higher pressure of inert gas inside, than a vertically positioned higher storage tank.

14. The liquid storage, loading and offloading system according to claim 13, wherein if a plurality of water ballast compartments or liquid storage compartments exist, the plurality of water ballast compartments or liquid storage compartments are interconnected by a conduit respectively to become one water ballast compartment or one liquid storage compartment in substance.

15. The liquid storage, loading and offloading system according to any preceding claim, wherein the storage tank is formed as a foundation of a bottom-supported platform.

16. The liquid storage, loading and offloading system according to claim 15, further comprising a topside facility to produce hydrocarbon, and a platform leg; wherein the platform leg is attached to the top of the storage tank; wherein the topside facility is connected to the platform leg; and wherein the hydrocarbon generated by the topside facility is stored directly

04 Mar 2013 2009229435

in the storage tank.

17. The liquid storage, loading and offloading system according to claim 16, further comprising a moon pool for a riser or a conductor extending from an underground oil well to the topside facility.

18. The liquid storage, loading and offloading system according to claim 16 or claim 17, further comprising a fixing device to fix the bottom-supported platform on a seabed to form a bottom-supported and fixed platform; wherein a weight of the bottom-supported and fixed platform at a high water level is equal to or larger than a buoyancy of the bottom-supported and fixed platform, and therefore no heavy weight of the bottom-supported and fixed platform is required for stability; and wherein while the liquid inside the bottom-supported and fixed platform is drained, the weight of the bottom-supported and fixed platform is lighter than the buoyancy to help remove and relocate the platform.

19. The liquid storage, loading and offloading system according to claim 18, wherein the storage tank of the bottom-supported and fixed platform is sufficiently tall to pierce the water surface, and becomes a fixed artificial island.

20. The liquid storage, loading and offloading system according to any one of claims 16 to 19, further comprising a mooring positioning system to moor the bottom-supported platform on the seabed in a floating condition to form a bottom-supported and floating platform; wherein a heaving period of the bottom-supported and floating platform is equal to or larger than 20 seconds to keep a constant operating weight.

21. The liquid storage, loading and offloading system according to claim 20, wherein the storage tank of the bottom-supported and floating platform is sufficiently tall to pierce the water surface, and becomes a floating artificial island.

22. The liquid storage, loading offloading system according to claim 20 or claim 21, further comprising a solid ballast disposed adjacent to the artificial island to increase damping and to improve a hydrodynamic performance;

and wherein a diameter of the solid ballast is equal to or larger than a diameter of the storage tank.

23. The liquid storage, loading offloading system according to claim 22, wherein the solid ballast is selected from the group consisting of a protruding skirt-shaped bottom solid ballast compartment, a protruding skirt-shaped lower solid ballast compartment, and a wheel-shaped solid ballast compartment.

24. A process of a loading and offloading system with equal mass flow rate displacement system comprising:

transporting a stored liquid or water from a bottom of a liquid storage compartment or a water ballast compartment to an inlet of a liquid offloading pump or a water offloading pump by a pressure energy of an inert gas;

offloading the stored liquid or water by the respective offloading pump or only by the pressure energy of the inert gas;

supplying the inert gas to maintain pressure of the inert gas of the liquid storage compartment or the water ballast compartment;

and wherein the supplied inert gas is from the water ballast compartment which is loaded with water at the same mass flow rate as the offloaded liquid, or from the liquid storage compartment which is loaded with liquid at the same mass flow rate as the offloaded water.

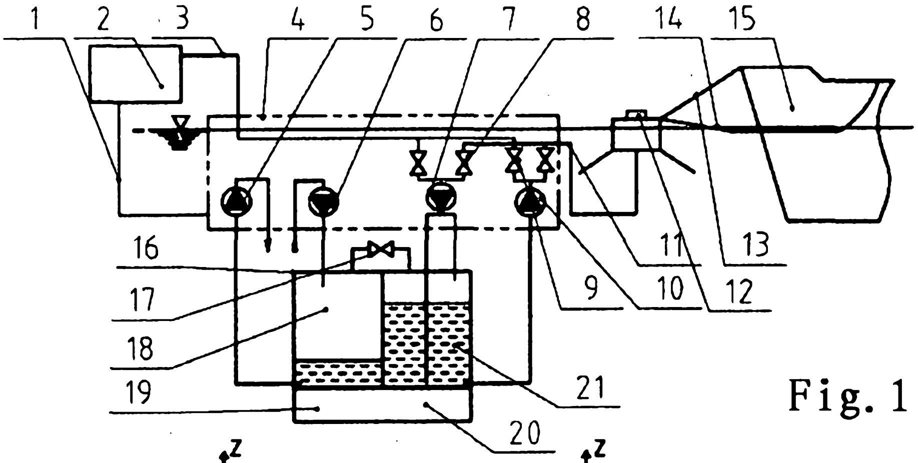

Fig. 1

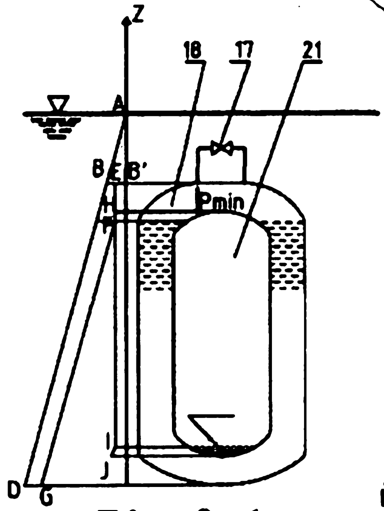

Fig. 2-1

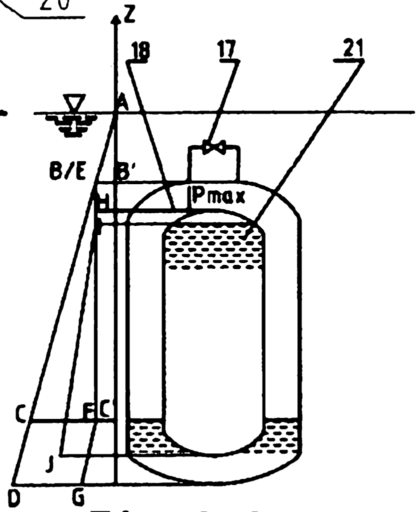

Fig. 2-2

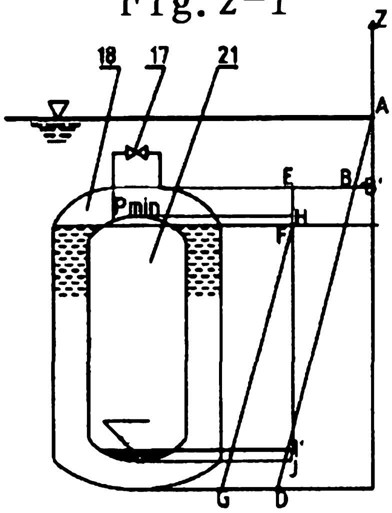

Fig. 2-3

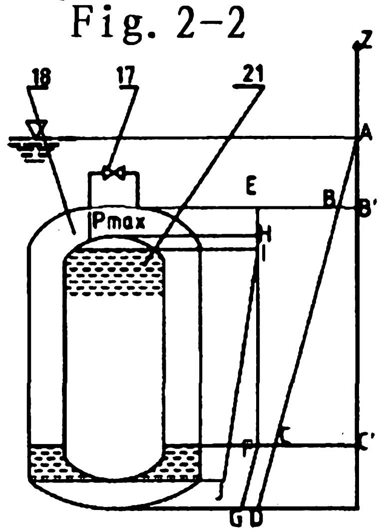

Fig. 2-4

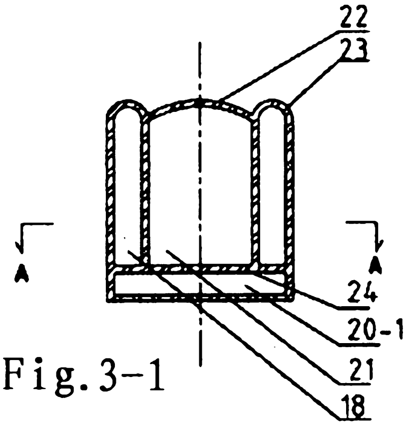

Fig.3-1

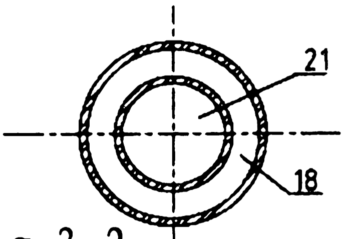

Fig.3-2

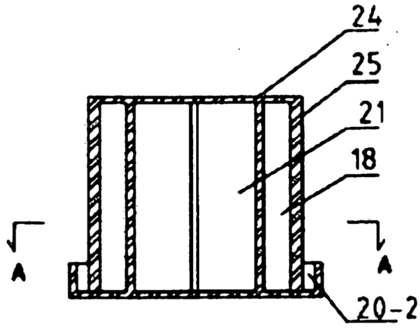

Fig.4-1

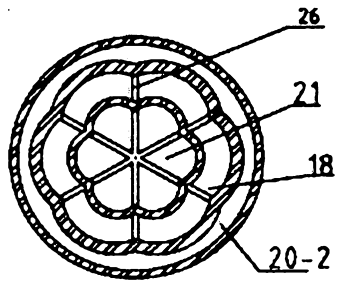

Fig.4-2

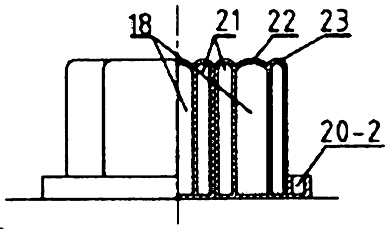

Fig.5-1

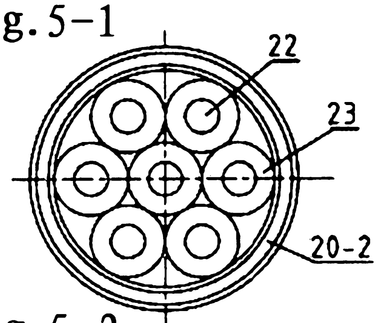

Fig.5-2

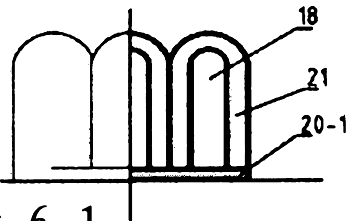

Fig.6-1

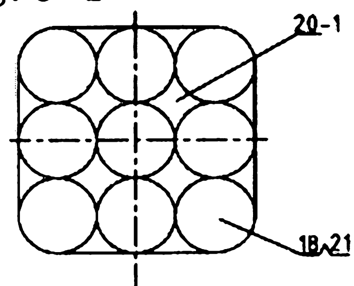

Fig.6-2

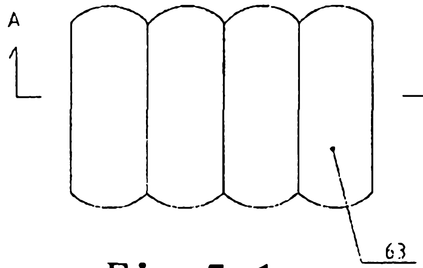

Fig. 7-1

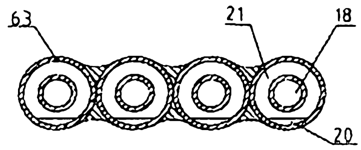

Fig. 7-2

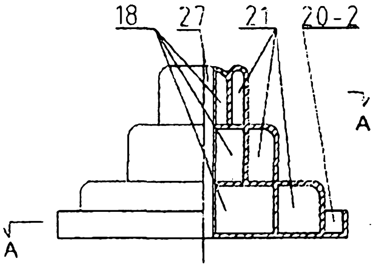

Fig.8-1

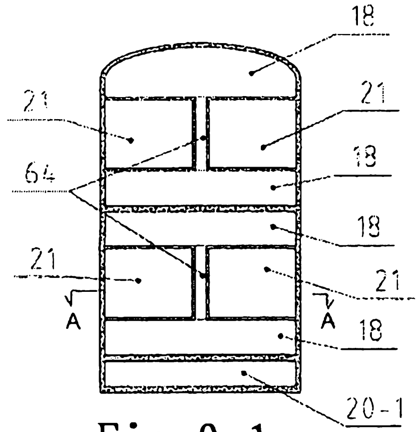

Fig. 9-1

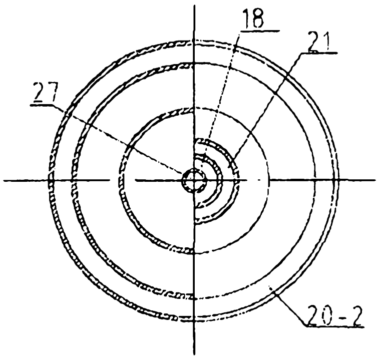

Fig.8-2

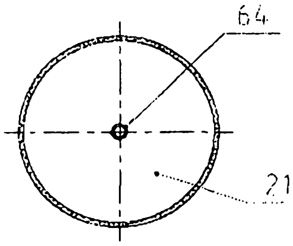

Fig. 9-2

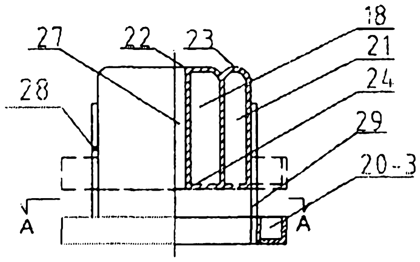

Fig. 10-1

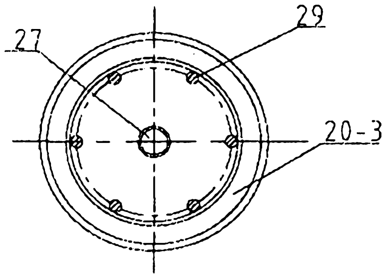

Fig. 10-2

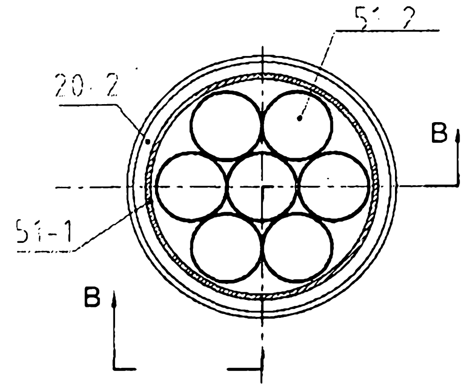

Fig.11-1

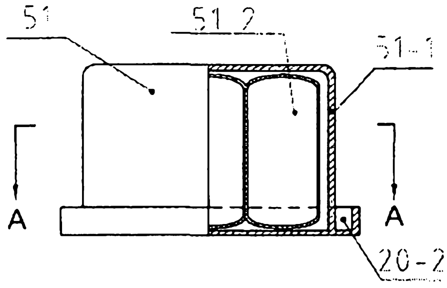

Fig.11-2

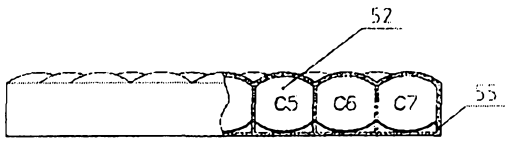

Fig.12-1

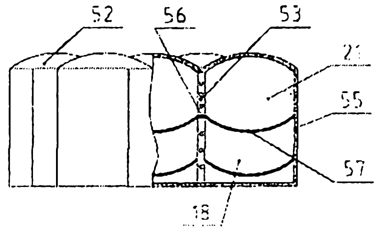

Fig.13-1

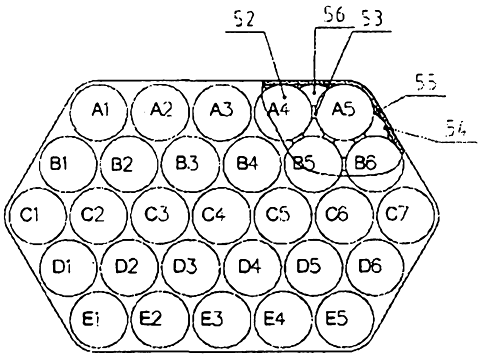

Fig.12-2

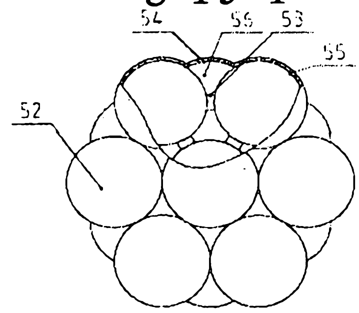

Fig.13-2

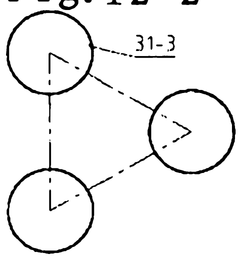

Fig.13-4

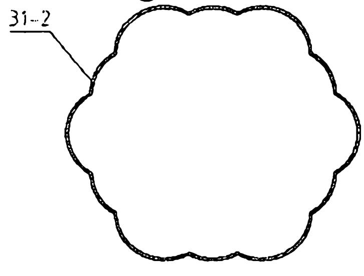

Fig.13-3

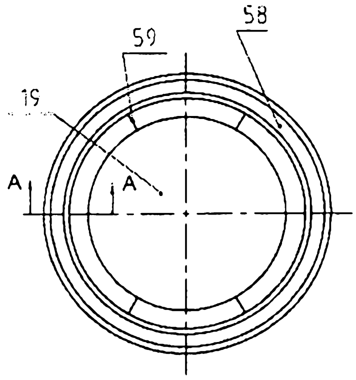

Fig.14-1

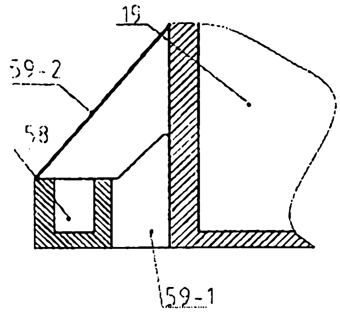

Fig.14-2

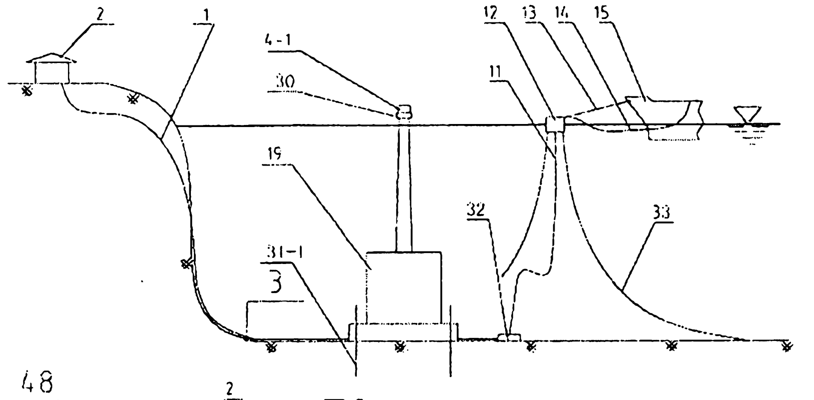

Fig.15

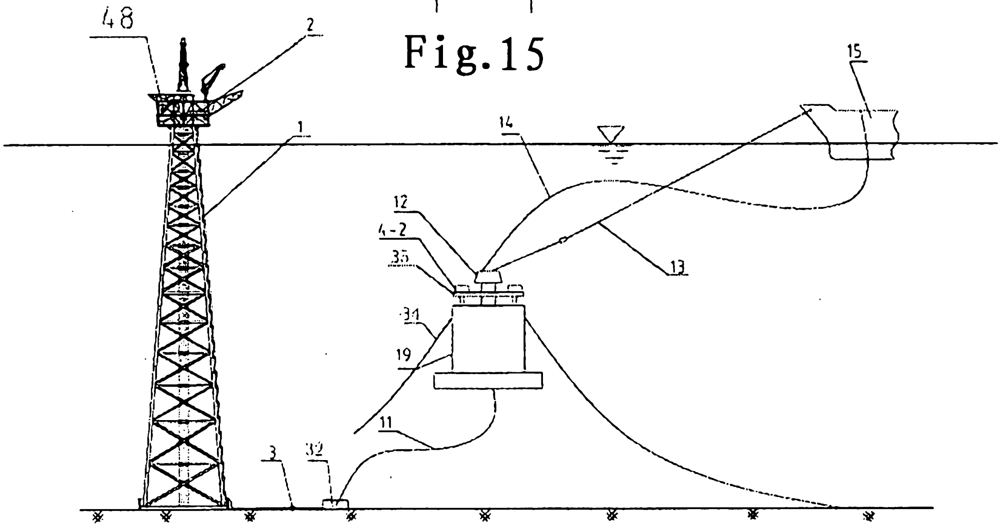

Fig. 16

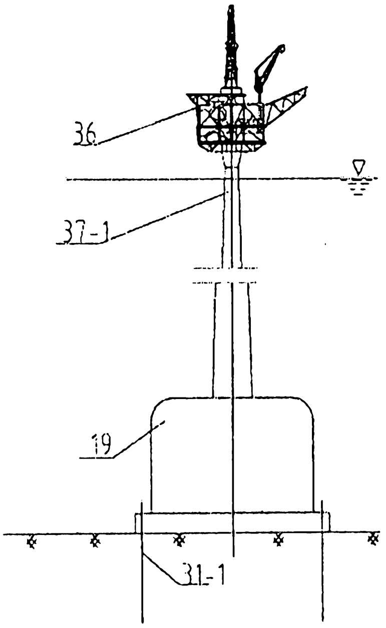

Fig.17

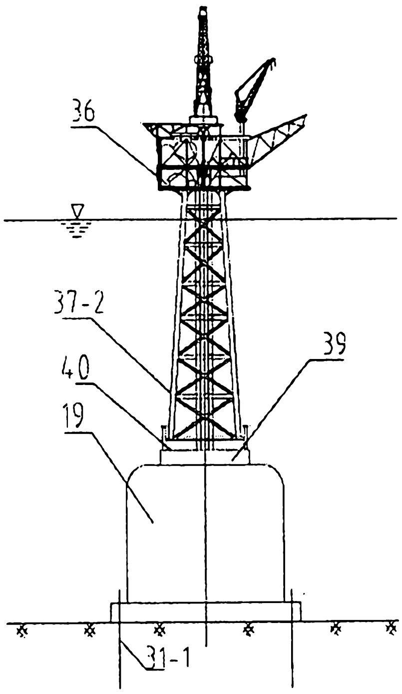

Fig.18

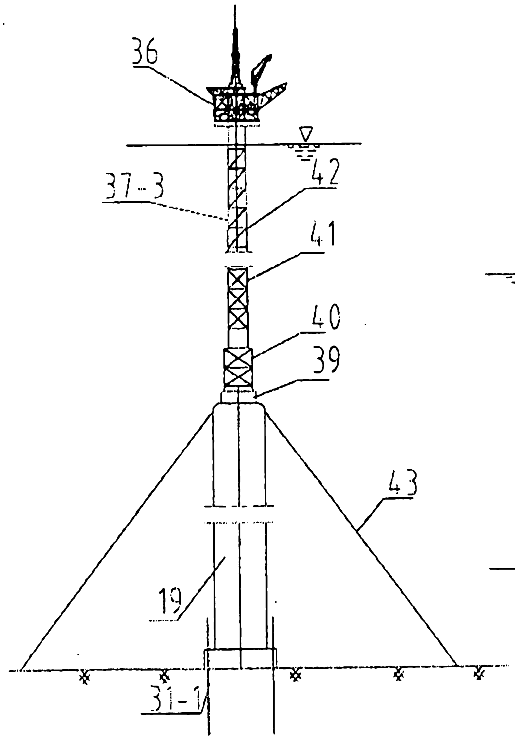

Fig.19

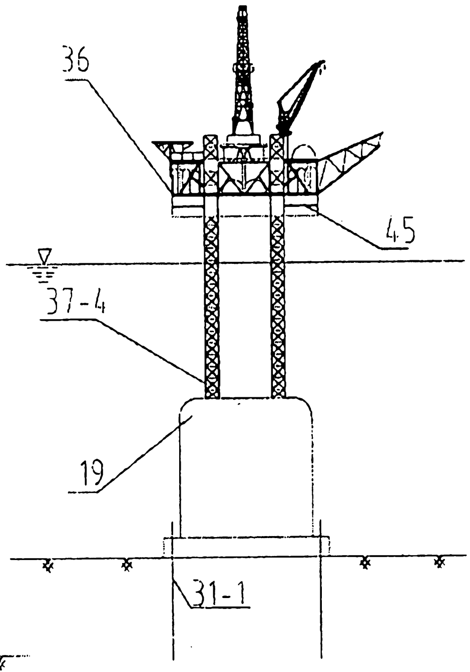

Fig.20

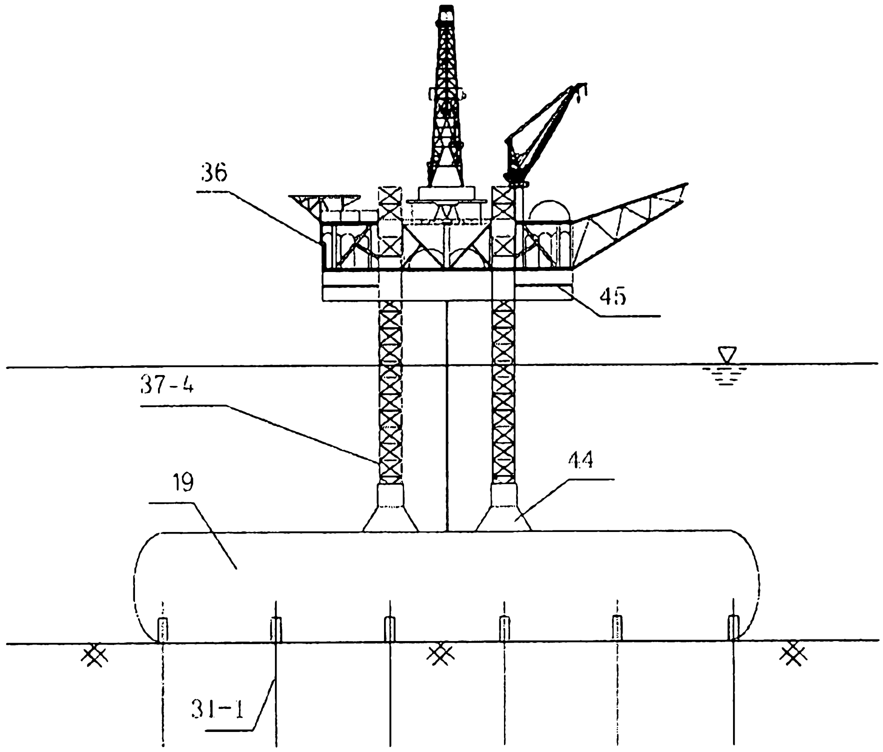

Fig. 21

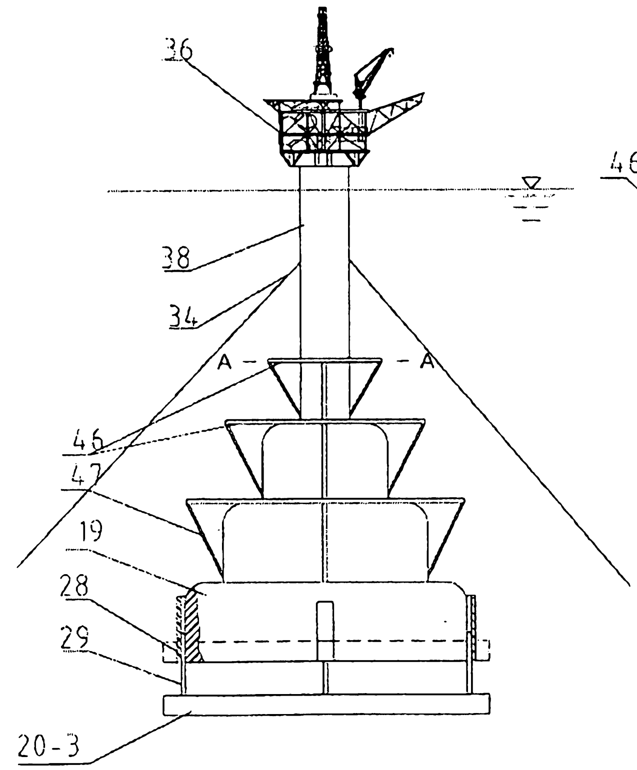

Fig. 22-1

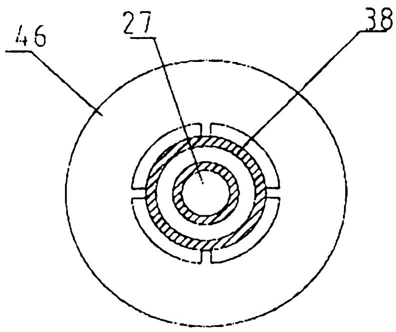

Fig. 22-2

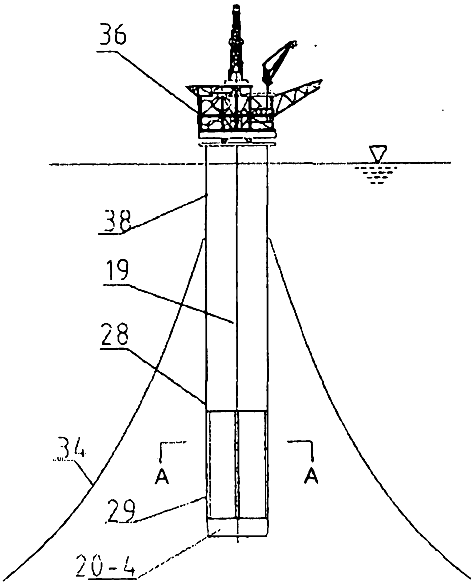

Fig. 24-1

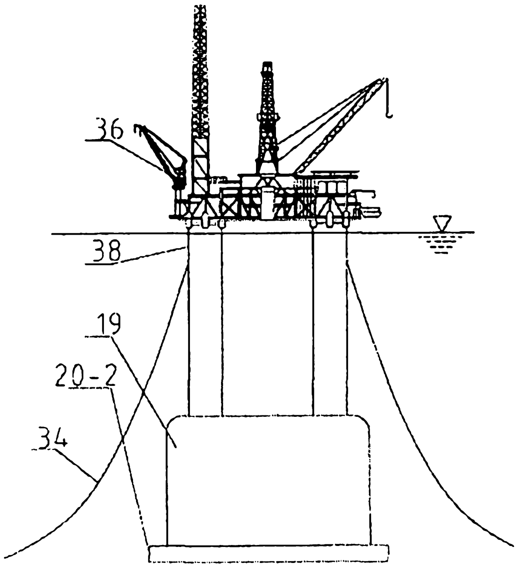

Fig. 23

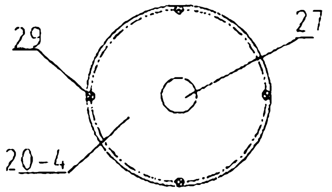

Fig. 24-2

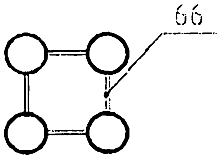

Fig. 25-2

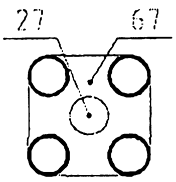

Fig. 25-3

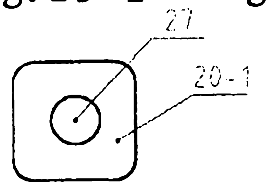

Fig. 25-4

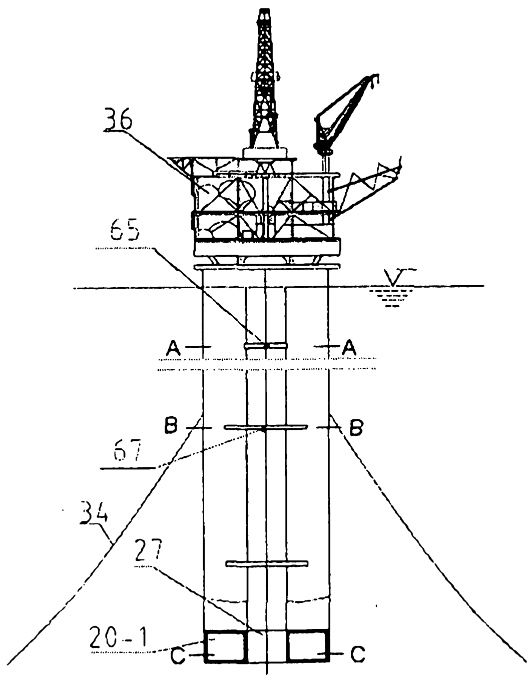

Fig. 25-1

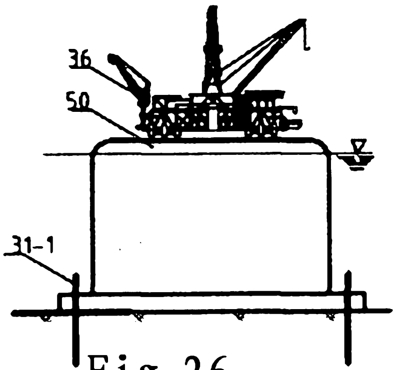

Fig. 26

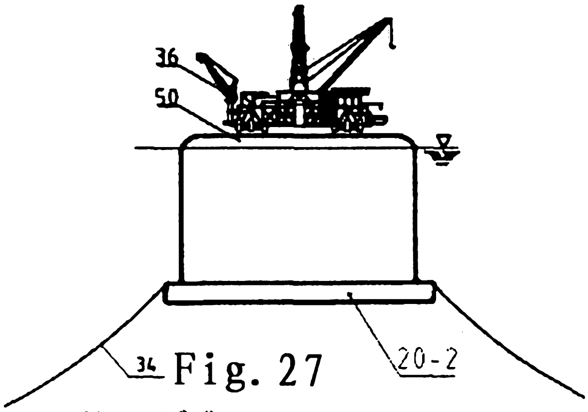

Fig. 27

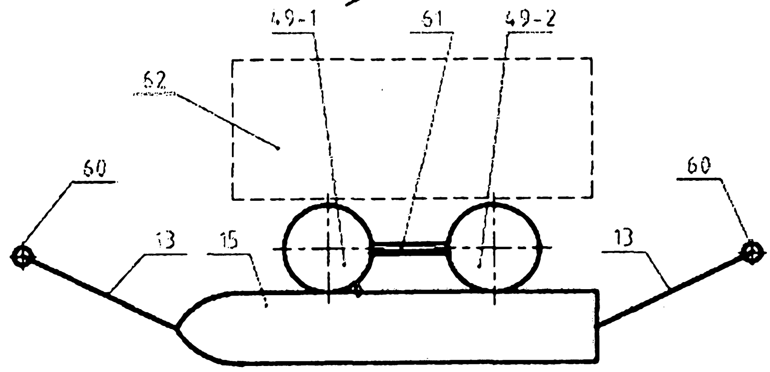

Fig. 28

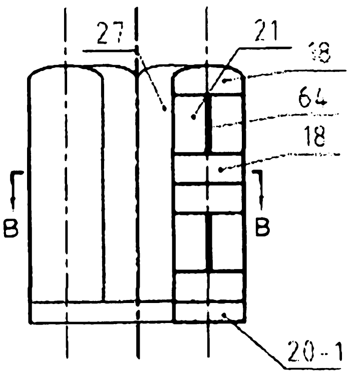

Fig. 29-1

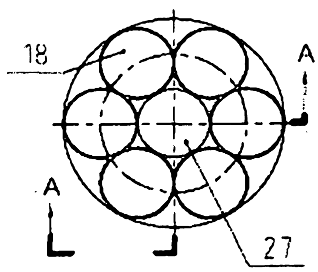

Fig. 29-2