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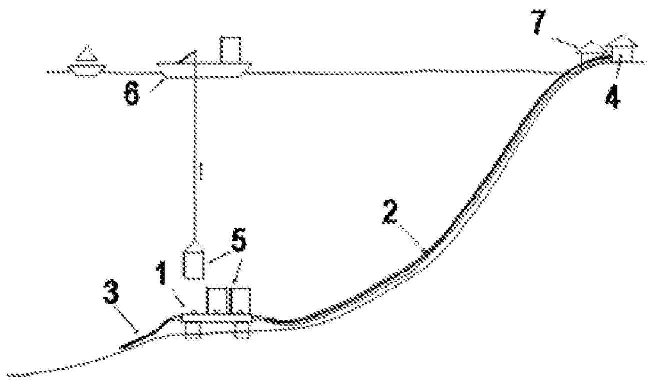
(54)	Title	**Modularized subsea seawater desalination system**
(56)	References Cited:	WO 9733832 A, WO 2012131621 A, US 2016185626 A, WO 2012025656 A1, US 2008190849 A1 EP 0968755 A2
(57)	Abstract	

The present invention relates to a modularized subsea desalination system. A subsea desalination template includes subsea desalination module zones 41 and module couplings 46. A desalinated water outlet 15 is in fluid connection with the module coupling 46 in the subsea desalination module zone. Subsea desalination modules 5 with reverse osmosis cartridges 23 are in fluid connection with a subsea template coupling 47, a seawater inlet section and a concentrated seawater outlet section. A transport pump module for desalinated water 17 with a transport pump is in fluid connection with the subsea desalination template 1 and the desalination modules 5. A water circulation pump 11 is in fluid connection with a seawater side of the at least one reverse osmosis cartridge 23. A desalinated water pipeline extend from the desalinated water transport pump to a location above a sea level. Furthermore, the invention relates to a subsea desalination module 5 and a method exchanging a used subsea desalination module 5.



Modularized subsea seawater desalination system.

The present invention relates to a modular subsea desalination system. The system includes subsea templates with designated modules for desalination, pumping, control, chemical injection and fluid transport. The invention also relates to a subsea RO-module and a method exchanging such modules.

Reverse osmosis (RO) membranes can be placed in seawater at a water depth corresponding to a hydrostatic pressure greater than the osmotic pressure (π). A hydrostatic pressure greater than π can be utilized in a desalination process to push water molecules through RO-membranes without requiring additional pressure.

WO 9733832 discloses modular deep-sea inlet units into which are incorporated flat sheet semi-permeable membranes that produce high quality desalted water using the reverse osmosis process. The modular devices are sunk into the ocean to the appropriate depth anywhere along the continental shelf.

WO 2012/131621 discloses a power-generating device located on an ocean surface coupled to a deeply-submerged tray structure suspended from its underside, which is used to produce desalinated water by reverse osmosis driven by hydrostatic pressure at depth and augmented by power from the device that is delivered to pumps on the tray.

US 2016/0185626 discloses methods and systems for desalinating saltwater. The method includes drawing feed water from a body of saltwater at a given depth below the surface of the body of saltwater; transporting the feed water to one or more reverse osmosis vessels submerged in the body of saltwater. The feed water is desalinated in the one or more reverse osmosis vessels to produce freshwater and brine concentrate such that the salinity of the brine concentrate is substantially the same as the salinity of the saltwater in the body of saltwater.

WO 2012/025656 discloses a seawater desalination unit comprising frames provided with reverse osmosis membranes that are connected to salt water and desalinated water collection circuits inside a submersible chamber joined to a counterweight base including coupling means for immersion and hoisting purposes.

US 2008/0190849 discloses a water treatment system with membrane modules and a collection channel. The membrane modules are submerged at depth and tethered to one or more anchors on the ocean floor. A breathing tube extends between the collection channel and a buoy floating on the surface of the ocean to expose the collection channel to atmospheric pressure.

The present invention is based on the above mentioned principle. The desalination system of the invention is adapted to be placed at a designated water depth on the seabed. The flow of seawater through an array of RO-membranes is driven by a circulation pump. The retentate (concentrated seawater) from the RO-membranes is discharged locally. Permeate (desalinated water) is pumped with a transport pump to receiving facilities. The transport pump generates the necessary differential pressure over the RO-membranes for reverse osmosis to occur. With this setup, seawater can be desalinated using hydrostatic pressure present in the surrounding seawater.

The present invention thus discloses subsea desalination system. The system comprises a subsea desalination template adapted to be located on a seabed with at least one subsea desalination module zone and at least one module coupling. A desalinated water outlet is in fluid connection with the module coupling in the subsea desalination module zone. At least one subsea retrievable desalination module includes a seawater inlet section, a concentrated seawater outlet, and a subsea template coupling adapted to be connected to the at least one module coupling, and at least one reverse osmosis cartridge with a desalinated water outlet is in fluid connection with the subsea template coupling. A retrievable desalinated water transport pump module includes a water inlet, a water outlet and connections adapted to connect the water inlet and the water outlet with template piping of a template with a pump module zone, and a desalinated water transport pump in fluid connection with the subsea desalination template and the at least one a subsea desalination module, and a bottom side forming an interface between the pump module zone of the template with the pump module zone and the pump module. A retrievable water circulation pump is in fluid connection with a seawater side of the at least one reverse osmosis cartridge. A desalinated water pipeline is adapted to convey fluid from the desalinated water transport pump and to a location above a sea level.

The subsea desalination template may include at least one suction anchor.

The template with the pump module zone may be the desalination template.

The desalination may further include at least one control module located in at least one control module zone on the desalination template.

At least one chemical injection module may be located in at least one chemical injection module zone on the desalination template.

The at least one subsea desalination module may include a seawater inlet filter arranged to filter seawater entering the at least one reverse osmosis cartridge.

The seawater inlet filter may be located on top of the at least one subsea desalination module, on an opposite side of the module away from the desalination template.

The template with the pump module zone may be a separate pumping template and a desalinated water flow path may extend between the separate pumping template and the subsea desalination template.

The desalination system may further include a separate filtering and pumping station with a filtering and pumping station template, a filter and a circulation pump in a circulation pump module upstream of the desalination template, pumping seawater through the at least one subsea desalination module.

The separate pumping template with the at least one pumping module may be located on a downstream side of the subsea desalination template and may include a desalinated water inlet and a desalinated water outlet, whereby the separate pumping template with the at least one pumping module conveys water from the desalination template to a topside facility.

The desalination system may include two pumping modules.

Furthermore, the invention relates to at least one subsea desalination module for a desalination system. The subsea desalination module comprises a plurality of reverse osmosis cartridges and a fluid coupling to the subsea template.

Furthermore, a method for replacing subsea modules installed on a subsea desalination system with serviced subsea modules is disclosed. The method includes the steps of:
identifying that the subsea module require service based on pre-defined parameters;
providing a vessel above the subsea desalination system;
lowering a subsea module lifting tool onto the selected subsea module;
lifting the selected subsea module to the vessel;
lowering the serviced subsea module onto subsea template;
securing the serviced subsea module to the subsea template.

The identification may be based on parameters selected from the group of parameters: desalinated water flow rate, water pressure drop over the subsea desalination module, desalinated water salinity and regular time intervals.
securing the subsea desalination module lifting means to the used subsea desalination module, releasing the used subsea desalination module from a subsea desalination means, lifting the subsea desalination module lifting means and the used subsea desalination module on to the vessel, lowering the subsea

desalination module lifting means and the serviced subsea desalination module onto subsea desalination template, securing the serviced subsea desalination module to the subsea desalination template, and releasing the subsea desalination module lifting means from the serviced subsea desalination module.

The lifting means can be a standard lifting frame, a releasing lifting tool, simple wires with eyelets etc.

A clean in place (CIP) system will remove scale, solids, silt, organic matter (etc.) from the internals in the filter and RO desalination modules. The clean in place system consist of chemical supply connection, chemical storage, a dedicated pump, instruments and valves, in order to perform back-flushing of the internals. The CIP is initiated from the control system by certain parameters.
The module subject to cleaning is isolated from the rest of the system that is in normal operation.
The cleaning chemical is back flushed into the internals and retained for some time. Thereafter the cleaning chemicals including the scale (etc) are flushed out. When CIP is completed the filter and/or RO module is put back into operation.

The chemical injection system prevents or remove organic growth in the downstream transport system during operation and/or shut-down.

Short description of the enclosed figures:
Fig. 1 is a schematic representation of a first step of an installation of a part of a subsea desalination system of the invention;
Fig. 2 schematic representation of a second step of the installation of fig. 1;
Fig. 3 is a schematic representation of an installed subsea desalination system of the invention;
Fig. 4 is a schematic representation of a first step of an installation of a complete subsea desalination system of the invention;
Fig. 5 is a schematic representation of a subsea desalination system of the invention with twelve desalination system templates;
Fig. 6 shows a detail of fig. 5 with three templates;

Fig. 7 is schematic representation of an alternative configuration of a desalination system of the invention with a separate pumping template;
Fig. 8 is schematic representation of a desalination system in an alternative embodiment with a floating desalinated water receiving facility;
Fig. 9 shows the embodiment of fig. 8 during a module exchange step;
Fig. 10 shows the embodiment of fig. 8 further including a floating power generation unit;
Fig. 11 shows an alternative embodiment of the invention with a seawater inlet at a remote location relative to a template;
Fig. 12 shows an alternative embodiment of the invention with a seawater inlet at a remote location above a template;
Fig. 13 shows an alternative embodiment of the invention with a seawater inlet at a separate filtering and pumping station;
Fig. 14 shows an alternative embodiment of the invention with a desalinated water transport pump template separate from a water desalination template;
Figs. 15a-15d show details of desalination modules for the desalination system of the invention;
Figs. 16a-16c show details of alternative desalination modules for the desalination system of the invention;
Fig. 17 is a schematic representation of a subsea template in a 3x3 configuration for 9 modules;
Fig. 18 is a schematic representation of a subsea template in a 3x6 configuration for 18 modules; and
Fig. 19 is a schematic representation of a water pump module of the invention.

Detailed description of embodiments of the invention with reference to the enclosed drawings:

Fig. 1 shows a first installation step of a subsea desalination system template 1. The template 1 is lowered from an installation vessel 6 towards a seabed.

The template 1 is prefabricated and is installed at a designated water depth. The template is installed as a one-time event by landing it on the predefined location using the installation vessel 6. The template is designed to support the total weight of a system including installation and operational tools and equipment. It contains all required internal piping, cables, valves and connections for water, power, data and chemicals.

The template 1 is a permanent base structure placed at the seabed and provides installation slots/zones for modules and serves as a landing and operation base for modules (including RO-filter modules, pump modules, inlet modules, chemical modules, instrumentation and control modules). It has the required connections, internal piping, cables and valves as well as connections for inlet seawater, discharge concentrated seawater, and desalinated water, chemicals and power. The template 1 is fixed to the seabed by suction anchors. Other fixing mechanisms that may be used (not shown) may include wires, concrete, loads or pillars. A template 1 is usually fixed in place permanently or for a long period such as the operation time or life time of the desalination system. The template 1 in fig 1 is shown installed without the modules.

The template 1 may be elevated from the seabed based on its design and structure. The structure and foundation depends on the actual seabed conditions and requirements. The template is fixed in place using e.g. established methods from the industry.

Subsea templates are installed following established installation procedures, guidelines and equipment e.g. from oil and gas industry. Smaller installations vessels and simpler procedures are continuously under development and can be used whenever available. When subsea structures are installed and fixed at the seabed, transportation pipeline for desalinated water, power and data cables for pumps and subsea equipment and potential chemical/supply lines are installed and connected to the template/s. The desalinated water transportation pipeline together with power and instrumentation cables are laid e.g. using established methods for installation of pipeline and cables. Examples of such methods are:

- Reel-lay
- S-lay

- Tow-out

The method selected for the installation will depend on the length and size of the pipeline and cables, and the available installation vessel 6, infrastructure on location. Pipeline and cables are connected to the subsea templates or manifold using e.g. an ROV with necessary tooling. The connection system is based on existing simplified equipment already in use in industry, e.g. in the subsea oil and gas industry. In some cases, the template may be installed at the seabed with the pipeline and cables (already) connected to it.

Fig. 2 shows the subsea desalination template 1 of fig. 1 installed on a seabed. The template 1 includes suction anchors or other suitable elements forming a foundation for the template. Standardized modules including RO-modules 5 are lowered from the installation vessel 6 and onto the template 1. The stepwise installation eases the requirements of the installation vessel 6. The installation also includes installing a power- and desalinated water pipeline 2 from the template 1 to a land based desalinated water receiving facility 4. A line for cleaning chemicals may also run from the desalinated water receiving facility and to the template 1 along with the power- and desalinated water pipeline 2. The desalinated water receiving facility 4 may include a post treatment and bottling facility if the desalination system shall produce drinking water. Minerals and other additives may also be used to provide a more palatable water. Alternatively, the desalinated water receiving facility 4 could include a pumping station. The system may also include a supply base 7 for offshore operations and for transporting the desalinated water to another location. The desalinated water may be used for other purposes such as agriculture, or industrial applications. A high-concentration salt water tubular 3 from the template leads the high concentration seawater away from the desalination system to prevent an increase of salinity around the desalination system.

The desalinated water receiving facility 4 also provides power and data communication to the template. The data communication may include signals relating to the status of the various components of the template 1, and signals relating to operating parameters of the template 1.

The modules include at least one desalination module 5 with a plurality of RO-filter cartridges and one pumping module with a circulation pump for continuous feeding of seawater to the RO-filter cartridges and a transportation pump pumping desalinated water to the desalinated water receiving facility 4. The modules including the RO-filter module 5 stab into the template 1 with connections e.g. well known from subsea hydrocarbon production facilities. For the desalination modules with RO-filter cartridges, the connections typically include a connection for desalinated water, a connection for high concentrated seawater and connections for transferring signals relating to the status of the module. Connections for cleaning chemicals may also be included.

A ROV is typically used to facilitate the installation and the connection of the modules onto the template 1.

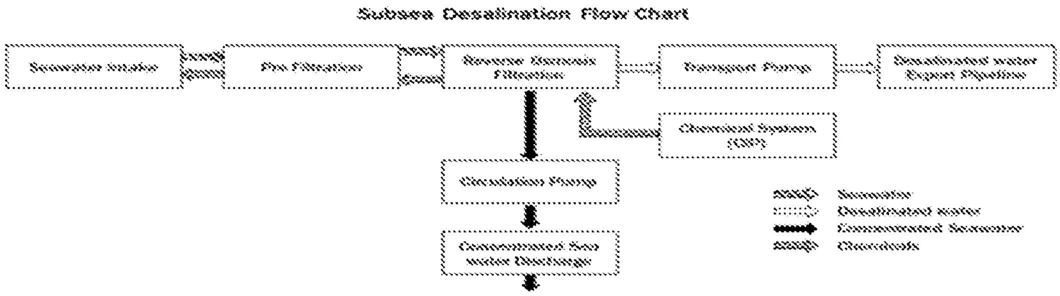
An extended discharge pipeline 3 is installed in conjunction with the templates 1 to lead the high concentrated seawater away from the desalination system. The RO-filter modules 5 and pump, control and chemical modules are installed on the template 1 at the seabed using e.g. the service vessel 6. The service vessel 6 has a crane with necessary lifting capacity to reach the template 1 on the seabed. The service vessel should have sufficient deck capacity to carry several modules in one campaign. The service vessel 6 can be a dedicated vessel, a shared vessel or a vessel of opportunity depending on the availability on the location.
Power to pumps and instruments is supplied either from shore via subsea power cable/s or by local marine power generation e.g. fuel, wind, solar or wave power. Power and instrumentation cables may be built into one cable bundle 2 or laid together. The template 1 may be located on a stand on the foundation to localize the template a certain distance above the seabed to prevent mud and debris from the seabed from being entrained in the water flow to the desalination modules.

Fig. 3 shows a subsea desalination system with the subsea desalination system template 1, and RO-modules 5 and other modules installed on the seabed. The pump in the pump module pumps desalinated water represented by an arrow pointing towards the right along the water transportation lines 2. An arrow pointing towards the left along the connection lines 2 represent electric power to the pumps in the pump modules. Concentrated seawater is expelled through the high concentration seawater tubular 3.

Fig. 4 shows an alternative method, installing a complete subsea desalination system with the template 1 and modules including the RO-modules 5 from a vessel 6 in a single operation. The installation method will for instance depend on the allowable load rating of the installation vessel 6.

Fig. 5 shows a subsea desalination system with twelve desalination plant templates 1 as seen from above. Each template 1 includes nine modules whereof six desalination RO-modules 5, a pump module, a control module and a chemical injection module. The templates 1 are connected to desalinated water branch pipes feeding into a common desalinated water line 2 conveying desalinated water to a desalinated water receiving facility. Each template is also connected to power supply cables and control cables. High concentrated seawater is discharged out of discharge tubulars 3. Each square represents a module. Fig. 5 illustrates that the system is easily scalable to different applications.

Fig. 6 is a detail of fig. 5 showing three templates each including connections for a desalinated water line 2, a power line 14, a chemical line 12, and a discharge line for high concentrated seawater 3. The three crossed out squares of each template represent a transport pump module 17, a seawater circulation pump 11 and a chemical injection module 29. The six open squares represent RO-modules 5. A control system including sensors monitoring pressures, volumetric flows, salinity, power consumption, temperatures etc may be integrated in at least one module. A separate control module is thus not needed.



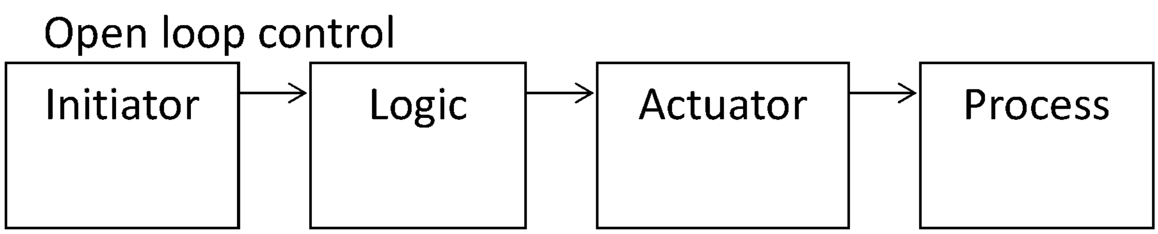
The transport pump module 17 with a transport pump is also included in addition to six desalination modules 5. The pump module 17 is powered by electricity supplied from the receiving facility. The pump module 17 can include both a transport pump transporting desalinated water to the surface and a circulation pump producing a flow of seawater past the RO-filters. The stabbing connections include connections for the desalinated water pump, pump power and signalling. Transport pump module 17 pushes the desalinated water to the receiving surface facilities. By evacuating the desalinated water downstream RO-filter modules the transport pump makes sure that there is no or very little back pressure on the RO-filter cartridges. The transport pump in the pump module 17 provides a pressure difference over the RO-filters that is greater than the reverse osmosis pressure required for RO-desalination.

The pump module 17 includes a frame to support the assemblies and components of the pump module. The frame serves as a lifting frame of the module during installation and retrieval and act as a guide and bumper during alignment and landing of the module. The frame protects the more sensitive components in the module. The pump module includes a submergible electric motor and a pump connected by a drive shaft. The pump provides the necessary head in the desalinated water. Power to the electric motor is provided by electric jumpers from a power cable termination. These jumpers can be connected and disconnected by a ROV.

The pump includes a housing with the hydraulic machine that provides the specified head and flow in the fluid. The pump is connected to the template piping with one fluid inlet and one fluid outlet.
The pump module 17 will contain ancillary systems and devices to ensure reliable operation of the pump and motor. E.g. motor cooling system, lubrication system, instrumentation for monitoring and control, valves. Pump modules 17 are retrievable, interchangeable and replaceable. The pump module is placed downstream of the RO-filter modules 5.

In an alternative embodiment, the circulation pump for seawater is placed up-stream of the RO-modules or upstream of the RO-filter module.

The control module 18 includes all the electronic and logic circuits to monitor and control the process system, communicate with the topside control room and execute commands. The control module 18 has electrical connectors to connect to the control cable/s for I/O to the surface and connectors for I/O to sensors and equipment on the template. Each control function, e.g. open and close a valve, will have a dedicated control loop.
This could be a simple open loop control, or a more advanced closed loop control with sensor feedback.



Control functions are usually initiated from the topside control room by a human operator but can alternatively be fully automated and executed by the control system. The control module 18 houses all electronics in one atmosphere pressure vessels, designed to withstand the hydrostatic pressure at the installation depth.

Control modules 18 are retrievable, interchangeable and replaceable.

The base case is chemical supply from land or surface vessel by pipeline.
In some cases, local chemical supply could be an advantage or necessary. In these cases, a chemical injection module 29 contains one or several chemical containers and required pumps, piping, instrumentations and control systems for cleaning, maintenance and disinfection purposes. Chemicals are injected into the desalinated water flow and mixed with it for cleaning, maintenance and disinfection purposes. Different types of chemicals are used in “clean-in-place solution” to backflush RO-modules or pre-filter assemblies. Chemical injection modules 29 are retrievable, interchangeable and replaceable.

Fig. 7 shows an alternative configuration of a desalination system of the invention with a separate pumping template 16 serving several desalination templates 20 without pumps or control modules. The pumping template 16 includes a chemical injection module 29, a transport desalinated water pumping module 17, a seawater circulation pump 11 in a circulation pump module and a control module 18. The seawater circulation pump 11 is shown in a separate circulation pump module, but each desalinated water pumping module 17 could also accommodate the seawater circulation pump 11. In the shown configuration could the pumping template with four zones or slots then accommodate two pumping modules 17 with seawater circulation pumps 11 to provide a failsafe system with built in redundancy allowing components to be exchanged without stopping production. The desalination templates 20 only includes RO-modules 5. Discharge tubulars 3 lead high concentrated seawater away from the system as explained above. A line for electric power 14, a control cable 19 and a line for desalinated water 2 runs to the desalinated water receiving facility on a surface vessel or a topside facility. The pumping template 16 provides a flow path between the seawater inlet 9 and the seawater circulation pump 11. The inlet tubular 8 provides the flowpath for seawater from the separate pumping template 16 and to the desalination templates 20. Seawater is pumped from the seawater inlet 9, through the pumping template 16, through the seawater circulation pump 11, through the pumping template 16, through the inlet tubular 8, through the desalination template 20, through the seawater filter in the desalination module 5, past and partly through the RO-cartridges to be separated into high concentration seawater and desalinated water, whereby the high concentration seawater flows through the template and out of the high concentration seawater outlet 3. The desalinated water flows into the desalination template 20, the line for desalinated water 2, through the pump template 16, through the pump module 17, through the pump template 16, through the desalinated water line 2 and to the desalinated water receiving facility above the water level (not shown in fig. 7).

The chemical injection module 29 includes a tank or several tanks with chemicals for injection into the desalination modules 5, in particular on the seawater side of the cartridges to remove fouling, scaling etc. that reduces or prevents flow of water through the cartridges. The chemicals such as citric acid can also be injected into the desalinated side of the cartridges to flush the cartridges in a reversed flow direction.

In fig. 7, the separate pumping template 16 serve three desalination templates 20 without pumps or control modules, but ha higher or lower number of desalination templates may clearly be served.

Fig. 8 shows the desalination system of the invention in an alternative embodiment with a floating desalinated water receiving facility 10. Desalinated water is pumped to the floating desalinated water receiving facility 10 through desalinated water line 2. Chemical line 12, and power cable 14 and control cable 19 convey the required consumables to the desalination template 1 with the desalination modules 5. The high concentration seawater outlet 3 leads the high concentration seawater a distance away from the desalination template 1 and to a location where the high concentration seawater not will have a negative influence on the local marine life.

Fig. 9 shows the embodiment of fig. 8 and highlights that the floating desalinated water receiving facility 10 also can be used for exchanging the modules such as the desalination modules 5 for service and maintenance. Cleaning chemicals are conveyed through the chemical line 12. The high concentration seawater is led away from the template by discharge tubular 3.

Fig. 10 shows the embodiment of fig. 8 and 9, apart from also showing a separate floating power generation unit 13. The power generation unit 13 can include systems providing renewable energy from waves, sun, or wind. Alternatively, the power generation unit 13 can include a combustion engine and a generator. The power line extends from the floating power generation unit 13 and to the desalination system at the seabed.

Fig. 11 shows an alternative embodiment of the invention with an inlet tubular 8 with a seawater inlet 9 with a remote location relative to the template 1. The inlet tubular 8 may be used to provide the desalination system with seawater with a more favourable quality including lower concentration of pollution, biological material salt, or other unwanted substances.

Fig. 12 shows an alternative embodiment corresponding to the embodiment of fig. 11, but where the inlet tubular 8 with the seawater inlet 9 is elevated from the seabed.

Fig. 13 shows an alternative embodiment corresponding to the embodiment of fig. 11 and 12, but where the inlet tubular 8 with the seawater inlet 9 is connected to a separate filtering and pumping station 21. The filtering and pumping station 21 includes a module with an inlet filter and an upstream seawater pump, feeding seawater through the RO modules from the inlet side. The filtering and pumping station provides an inlet unit 9 on a separate structure or template apart from the production template 1. Seawater flows through the inlet unit 9 for pre-filtration or pre-treatment before it enters the RO-filter modules. An inlet unit 9 contains one or more inlet modules. Each inlet module contains filter assemblies for filtration and pre-treatment of seawater. A filter assembly consist of one or more filters with different properties. Inlet modules are retrievable, interchangeable and replaceable. The inlet unit 9 also includes a feed pump. The feed pump operates as a circulation pump for the desalination system and enables discharge of high concentrated seawater from the desalination system. The feed pump may be built into a retrievable and replaceable feed pump module.

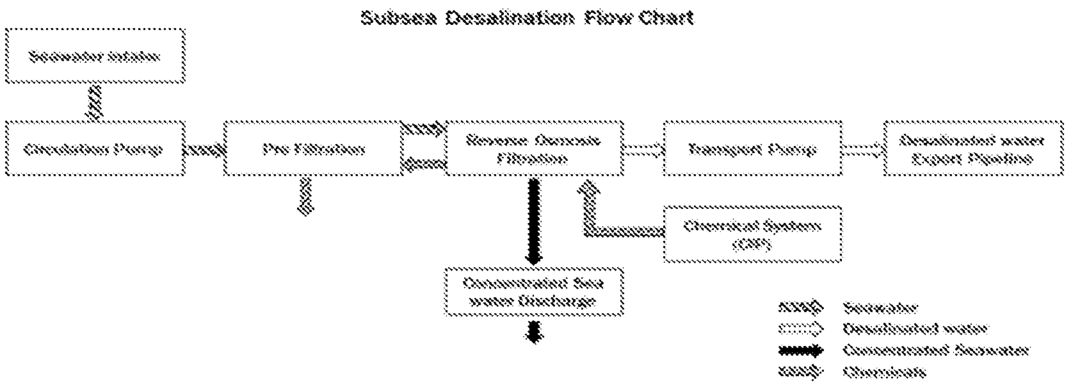


Fig. 14 shows the solution of fig. 7 with a separate pump module template with a desalinated water pump module. The figure also indicates the seabed, the sea surface and the land. This indication is relevant to all the corresponding figures.

Fig. 15 shows details of a desalination module 5 for the desalination system of the invention. The module 5 includes a plurality of RO-cartridges 23 located in an array inside the desalination module 5. Fig 15b shows one cartridge extending the length of the module, and fig 15b shows three RO-cartridges 23 extending the length of the module. The number and size of the cartridges depends on the commercially available RO-cartridges and the design parameters of the module. Bespoke RO-cartridges may also be used. An inlet filter 22 for ambient seawater is located on top of the modules and an inlet grid 26 protects the inlet filter 22 for seawater. The inlet filter 22 is designed to prevent premature clogging of the RO-cartridges. The module 5 includes an outer frame 27 and upper lifting connectors 28 commonly used for subsea modules. An outlet for desalinated water 24 and an outlet for seawater with high salt content 25 are located at the bottom of the module and are adapted for connection with the template.

Similarly with fig. 15, does fig. 16 also show a desalination module. Fig. 16 shows an embodiment with several outlets for desalinated water and seawater with high salt content. Fig. 16 also show an embodiment with a top cap 30 allowing seawater to be pumped into the desalination module instead of pumping desalinated water out of the module.

The RO-filter module 5 includes a plurality of RO-filter cartridges 23 placed in an assembly of conduits arranged in parallel where one (fig 15b) or more (fig. 15c) RO-filter cartridges 23 are placed in each conduit in series. Seawater enters RO-filter module through the pre-filter assembly 22 where seawater is filtered to the desired quality. Then pre-filtered seawater is distributed over the RO assembly where it enters assembly of RO-filter cartridges 23 in the individual conduits. Inside the conduits seawater is separated by RO-filter cartridges 23 into desalinated water (permeate) and high concentrated seawater (retentate). Desalinated water and high concentrated seawater exit conduits in separate outlets 24, 25 respectively where each phase is collected in its own collection piping or manifold system. The RO-filter module 5 is connected to the template via flow connectors.
Desalinated water from the RO-filter modules 5 is collected and pumped to the surface by a transportation pump. A circulation pump makes sure that seawater continuously enters the RO-modules 5 and high concentrated seawater leaves the modules. High concentrated seawater is discharged to the sea.

Flow of seawater through the RO-filter module is enabled by a circulation pump. Seawater is pumped through pre-filter assembly and RO-filter assembly. A circulation pump makes sure that there is sufficient flow of seawater through each RO-filter module and that the high concentrated seawater is transported to a desired location where it is discharged to the sea.

The pre-filters 22 improving the water quality are placed upstream of the RO-filter cartridges 23. The pre-filters 22 are formed as an assembly including one or more filter elements. The shape, size, material composition, number of layers and exact functionality of a pre-filter assembly depends on the local water conditions, operational requirements for RO-filter cartridges and required changing frequency of RO-filter cartridges. The pre-filter assembly is shown as an integrated part of a RO-filter module, but could also constitute a separate pre-filtration assembly. A separate pre-filter assembly could be attached to a filter module or could be located at a different location. As an alternative, the pre-filter assembly could be placed on the same template, at a different structure, at a different template or as a separate unit on its own template.

RO-filter modules placed on a template are retrievable, interchangeable and replaceable. They are “modularized” and can be interchanged by or replaced with RO-filter modules placed on other templates.

Fig. 15d shows an embodiment of the RO-filter module 5 of the invention with a seawater intake 31 in the subsea template coupling 47 to allow seawater from the circulation pump to be pumped into the RO-filter module. Accordingly does this embodiment not include the seawater intake at the top of the RO-module. This module is for instance suitable for the configuration shown in fig. 13 where an external unit includes the circulation pump and inlet pre-filter, pumping the seawater at low pressure (below the osmotic pressure π) into the desalination template and from there into seawater intake 31 in the subsea template coupling 47.

Figs. 17 and 18 show templates 1 with room for nine and eighteen modules respectively. The templates include four suction anchors 40 to secure the templates 1 to the seabed. An outlet 3 for seawater with high salt content is located at one end of the template and an outlet 15 for desalinated water is located at the opposite end of the template along with a connection for a power cable 14 and a connection for a chemical line 12. The squares of the templates represent sockets for modules, allowing one module to be installed in each square. The crossed out squares represent zones with sockets for technical functions and the squares without a cross represents desalination module zone 41. The sockets for technical modules may include a pump module zone 42, a chemical injection module zone 43 and a control module zone 44. Each zone includes at least one module coupling 46 with connections for a module. The module couplings 46 for at least the one or more pump module zones 42 and the one or more desalination module zones 41 include water connections. The one or more pump module zones 42 include module couplings 46 for power and control cables. The control module zone 44 may include connections for various sensor and may also include control hardware for controlling the electric motor in the pump module. The control module also controls valves inside the template for enabling complete cut off of a module connection to allow exchange of modules without seawater leaking into the desalinated water system. The control module also controls valves allowing cleaning fluids into the components, and valves to allow back flushing of the desalination modules to prevent clogging. The control module can also monitor pressure sensors and flow sensors to identify when a desalination module should be flushed or exchanged. The control module can furthermore communicate with salinity sensors to identify unwanted ingress of seawater into the desalinated water circuits.

The templates 1 include all elements required such as piping, valves, systems for connecting process modules, energy supply, cleaning chemicals, monitoring, control and communication. The modules are exchangeable and have a common footprint and connections.

Flexible maintenance and method of installing and exchanging modules is based on the industry practice e.g. from the offshore industry.

The modules can be «cleaned in place» while located on the seabed. A cleaning fluid is pumped into the modules through the template, either from a cleaning module or from a separate cleaning fluid line from the surface. A module can be singled out and cleaned while other modules are in operation.

Fig. 18 additionally shows a socket for a circulation pump module 45 with the circulation pump. The circulation pump module may pump water out of the outlet 3 for seawater with high salt content and thus force seawater to flow past the RO-filters in the RO-filter modules. Alternatively, the circulation pump module could be located upstream of the RO-filters in the RO-filter modules.

Fig. 19 shows a water pump module 17 with a module frame 27, a sealed electric motor 48, a water pump 49 and standardized lifting connections 28. A control connection 50, a water inlet 51 a water outlet 52 and a power connection 53 are located at a bottom side of the water pump module 17. The bottom side and the connections are adapted to the template as the bottom side typically will form the interface between the module zone of the template and the pump module.

Clearly all the components are designed for subsea use with a pressure rating to allow the components to operate reliably at a depth of typically around 300m to provide a hydrostatic pressure of about 30bar that should be sufficient to overcome the osmotic pressure π.

For an environment friendly discharge solution, it is important to distribute the high concentrated seawater uniformly into the sea and away from the desalinated water production system. A solution includes a discharge pipe 3 with multiple outlet or nozzles or a network of discharge pipes and tubes with multiple outlets over a greater area in the sea (not shown). Such discharge units limit or reduce the environmental impact of the concentrated seawater in the more sensitive areas (not shown). A discharge unit has bespoke discharge modules placed on a template to enable a controlled and smooth water discharge. The discharge unit is connected to the desalinated water production unit. The discharge modules are retrievable and replaceable.

The desalination system described above with reference to the enclosed figures is remotely monitored, controlled and operated from an onshore control centre or from an offshore surface vessel. The control centre could be anywhere but connected to the onshore control centre or desalination system e.g. via internet.

The control centre is connected to the subsea system via an offshore data and instrument cable. All pumps, electrical equipment and instrumentation are monitored and controlled from shore via a data and instrumentation cable, or by satellites via a surface buoy. Communication between the surface buoy and satellite could be via e.g. an antenna/sending receiving unit on the sea surface connected to the subsea equipment.

The electrical equipment and the instrumentation may be monitored and controlled from a vessel when the desalination system is operated from such a vessel.

To maintain the subsea system e.g. a service vessel is used. The service vessel commute between an onshore supply base and an offshore field where the subsea desalination system is located. The onshore storage supply base may be located near the subsea desalination system where there are spare RO-filter modules and pump modules ready for shipping. RO-filter modules are replaced on a regular basis or every time there is an issue with a certain module. The service vessel takes one or several RO-filter modules from the onshore supply base to the offshore field where the subsea desalination system is located. One of the selected used RO-filter modules are lifted from the seabed on-board the supply vessel. Then a new ready to operate RO-filter module is lowered into the sea. The new RO-filter module is then installed on the subsea template replacing the old retrieved used RO-filter module. This operation may continue until all used selected subsea modules are replaced with new RO-filter modules. The same operation may take place with the pump, control and chemical modules if needed. The subsea pump, chemical and control modules are lifted onboard the supply vessel before a new pump, chemical or control module is lowered and installed on the subsea template replacing the retrieved pump or control module. All the retrieved modules are taken to the supply base onshore for cleaning, repair and maintenance where they will be made ready for redeployment and replacement of the used modules in operation.

The above embodiments of the invention are described with specific modules and locations. It is however intended that the various solutions can be combined in a system of the invention. For instance, the solution with a line conveying chemicals from the water receiving facility or the solution with a module containing one or several tanks with chemicals at the seabed can be combined with any of the embodiments. Similarly can all the embodiments include a circulation pump in a dedicated module, or in a combined pumping module with both a circulation pump and a transport pump. All the embodiments can be utilized for a floating desalinated water receiving facility or a receiving facility on land etc.

CLAIMS

1. A subsea desalination system comprising:

a subsea desalination template (1) adapted to be located on a seabed, with at least one subsea desalination module zone (41) and at least one module coupling (46), a desalinated water outlet (15) in fluid connection with the module coupling (46) in the subsea desalination module zone (41);

at least one retrievable subsea desalination module (5) with a seawater inlet section, a concentrated seawater outlet, and a subsea template coupling (47) adapted to be connected to the at least one module coupling (46), and at least one reverse osmosis cartridge (23) with a desalinated water outlet in fluid connection with the subsea template coupling (47);

a retrievable desalinated water transport pump module (17) with a water inlet (51), a water outlet (52) and connections adapted to connect the water inlet (51) and the water outlet (52) with template piping of a template with a pump module zone (42), a desalinated water transport pump (49) in fluid connection with the subsea desalination template (1) and the at least one subsea desalination module (5), and a bottom side forming an interface between the pump module zone (42) of the template with the pump module zone and the pump module (17);

a retrievable water circulation pump (11) in fluid connection with a seawater side of the at least one reverse osmosis cartridge (23); and

a desalinated water pipeline (2) adapted to convey fluid from the desalinated water transport pump and to a location above a sea level.

2. The desalination system of claim 1, wherein the subsea desalination template (1) includes at least one suction anchor (40).

3. The desalination system of claim 1 or 2, wherein the template with a pump module zone (42) is the desalination template (1).

4. The desalination system of claim 1, 2 or 3, further including at least one control module (18) located in at least one control module zone (44) on the desalination template (1).

5. The desalination system of one of claims 1 -4, further including at least one chemical injection module (29) located in at least one chemical injection module zone (43) on the desalination template (1).

6. The desalination system of one of claims 1 -5, wherein the at least one subsea desalination module (5) includes a seawater inlet filter (22) arranged to filter seawater entering the at least one reverse osmosis cartridge (23).

7. The desalination system of claim 1-6, wherein the seawater inlet filter (22) is located on top of the at least one subsea desalination module (5).

8. The desalination system of claim 1, wherein the template with a pump module zone (42) is a separate pumping template (16), and wherein a desalinated water flow path extends between the separate pumping template (16) and the subsea desalination template (1).

9. The desalination system of claim 1, further including a separate filtering and pumping station (21) with a filtering and pumping station template, a filter and a circulation pump in a circulation pump module upstream of the desalination template (1), pumping seawater through the at least one subsea desalination module (5).

10. The desalination system of claim 8, wherein the separate pumping template (16) with the at least one pumping module (17) is located on a downstream side of the subsea desalination template (1) and includes a desalinated water inlet and a desalinated water outlet, whereby the separate pumping template (16) with the at least one pumping module (17) conveys water from the desalination template (1) to a topside facility.

11. The desalination system of claim 8, including a plurality of pumping modules (17).

12. A subsea desalination module (5) for a desalination system of claim 1, comprising a plurality of reverse osmosis cartridges (23) and a plug in connection system providing a template interface to a subsea desalination template (1) with at least one subsea desalination module zone (41).

Patentkrav

1. Avsaltingssystem omfattende:
en avsaltings-havbunnsramme (1) tilpasset for å plasseres på en havbunn, med minst én avsaltingsmodul-sone (41) med minst en modulkobling (46) og et utløp for avsaltet vann (15) i fluidforbindelse med modulkoblingen (46) i avsaltingsmodul-sonen (41);
minst en opphentbar avsaltingsmodul (5) med en innløpsseksjon for sjøvann, et utløp for konsentrert sjøvann og en havbunnsramme-kobling (47) tilpasset for å kobles til den minst ene modulkoblingen (46), og minst en omvendt-osmose innsats (23) med et utløp for avsaltet vann i fluidforbindelse med den undersjøiske havbunnsramme-koblingen (47);
en opphentbar transportpumpemodul (17) for avsaltet vann, med et vanninnløp (51), et vannutløp (52) og tilkoblinger tilpasset for å forbinde vanninnløpet (51) og vannutløpet (52) med havbunnsramme-rørsystem på en havbunnsramme med en pumpemodulsone (42), en transportpumpe (49) for avsaltet vann i fluidforbindelse med avsaltings-havbunnsrammen (1) og den minst ene opphentbare avsaltingsmodulen (5), og en underside som danner et grensesnitt mellom pumpemodulsonen (42) på havbunnsrammen med pumpemodulsone og pumpemodulen (17);
en opphentbar vannsirkulasjonspumpe (11) i fluidforbindelse med en sjøvannsside av den minst ene omvendt-osmose innsatsen (23); og
en vannledning (2) for avsaltet vann tilpasset for å transportere fluid fra transportpumpen for avsaltet vann og til en plassering over havoverflaten.

2. Avsaltingssystem ifølge krav 1, karakterisert ved at avsaltings-havbunnsrammen (1) inkluderer minst ett sugeanker (40).

3. Avsaltingssystem ifølge krav 1 eller 2, hvor havbunnsrammen med en pumpemodul-sone (42) er avsaltingshavbunnsrammen (1).

4. Avsaltingssystem ifølge krav 1, 2 eller 3, videre omfattende minst en kontrollmodul (18) plassert i minst en kontrollmodul-sone (44) på avsaltings-

havbunnsrammen (1).

5. Avsaltingssystem ifølge krav 1-4, videre omfattende minst én kjemikalie-injeksjonsmodul (29) plassert i minst en kjemikalieinjeksjonsmodul-sone (43) på avsaltings-havbunnsrammen (1).

6. Avsaltingssystem ifølge et av kravene 1-5, karakterisert ved at den minst ene opphentbare avsaltingsmodul (5) inkluderer et sjøvanns-innløpsfilter (22) anordnet for å filtrere sjøvann som kommer inn i minst én omvendt-osmose innsats (23).

7. Avsaltingssystem ifølge krav 1-6, hvori sjøvannsinnløps-filteret (22) er plassert på toppen av den minst ene opphentbare avsaltingsmodul (5).

8. Avsaltingssystem ifølge krav 1, hvori havbunnsrammen med en pumpemodul sone (42) er en separat pumpe-havbunnsramme (16), og hvor en strømningsvei for avsaltet vann strekker seg mellom den separate pumpe-havbunnsrammen (16) og avsaltings-havbunnsrammen. (1).

9. Avsaltingssystem ifølge krav 1, videre omfattende en separat filtrerings- og pumpestasjon (21) med en filtrerings- og pumpestasjons-havbunnsramme, et filter og en sirkulasjonspumpe i en sirkulasjonspumpemodul oppstrøms for avsaltings-havbunnsrammen (1) for pumping av sjøvann gjennom den minst ene opphentbare avsaltingsmodul (5).

10. Avsaltingssystem ifølge krav 8, hvori den separate pumpe-havbunnsrammen (16) med den minst ene pumpemodulen (17) er plassert nedstrøms for avsaltings-havbunnsrammen (1) og inkluderer et innløp for avsaltet vann og et utløp for avsaltet vann, idet den separate pumpe-havbunnsrammen (16) med den minst ene pumpemodulen (17) fører vann fra avsaltings-havbunnsrammen (1) til et anlegg over havoverflaten.

11. Avsaltingssystem ifølge krav 8, omfattende flere pumpemoduler (17).

12. Opphentbar avsaltingsmodul (5) for et avsaltingssystem ifølge krav 1, omfattende et antall omvendt-osmose innsatser (23) og et plugg-in forbindelsessystem som tilveiebringer et havbunnsramme-grensesnitt til en avsaltings-havbunnsramme (1) med minst en avsaltingsmodul-sone (41).

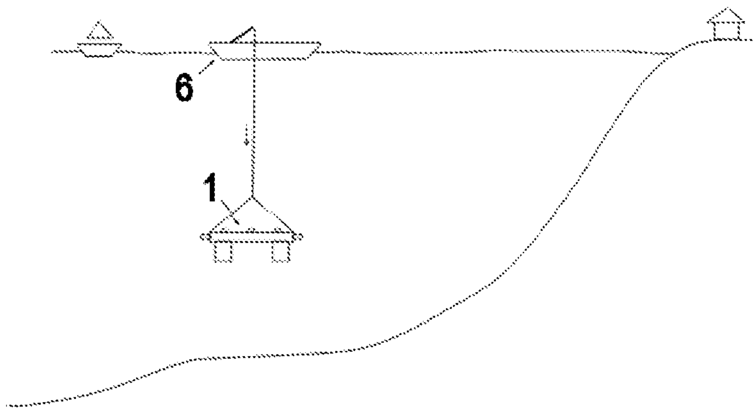


Fig. 1

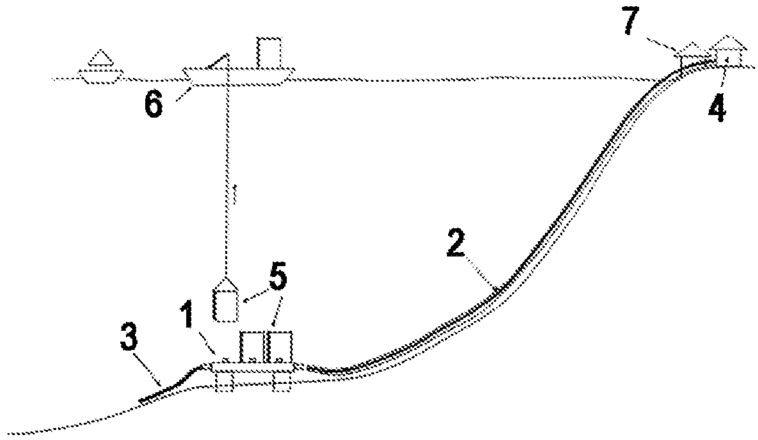


Fig. 2

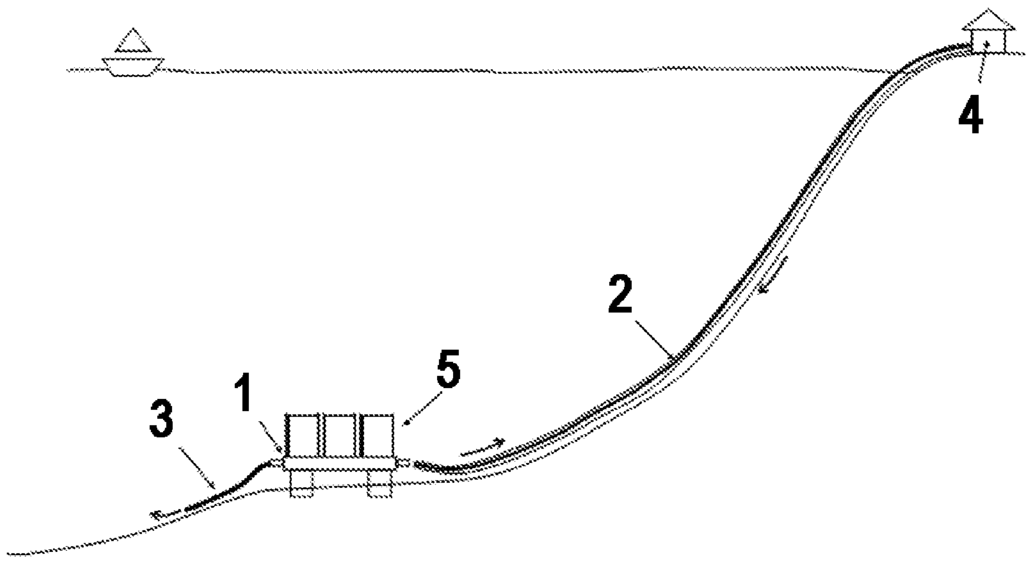


Fig. 3

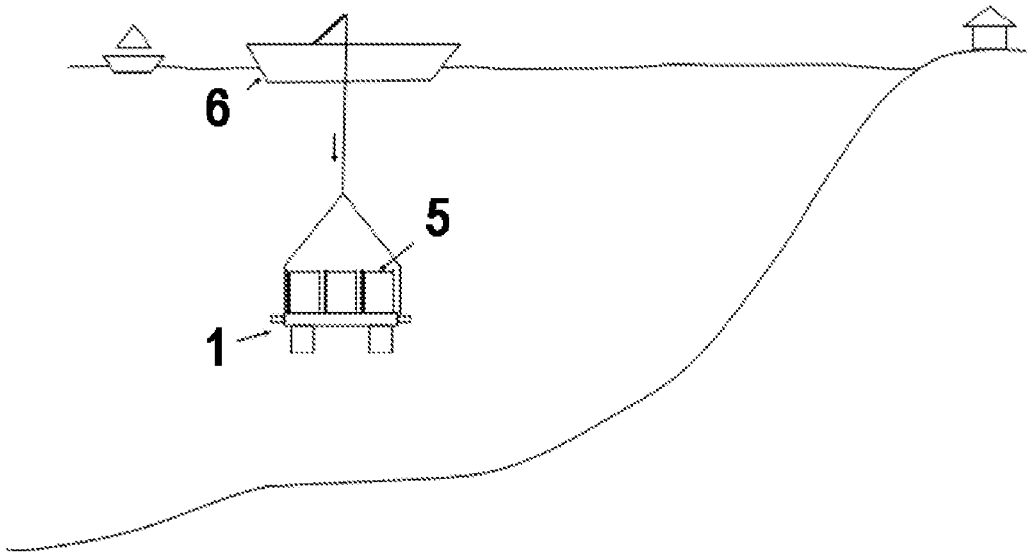


Fig. 4

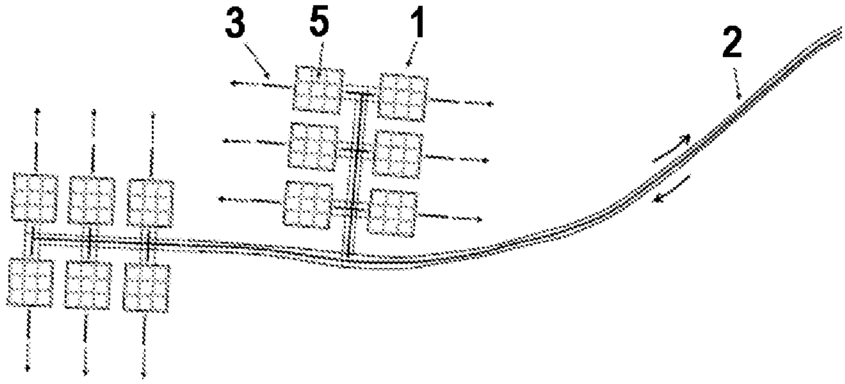


Fig. 5

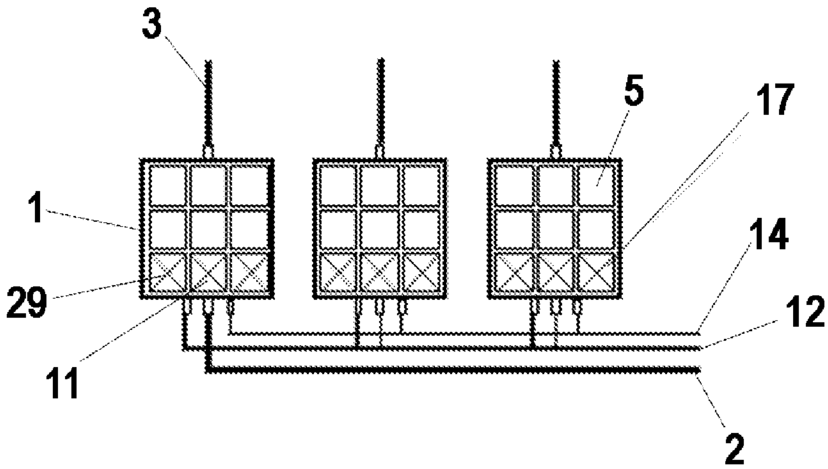


Fig. 6

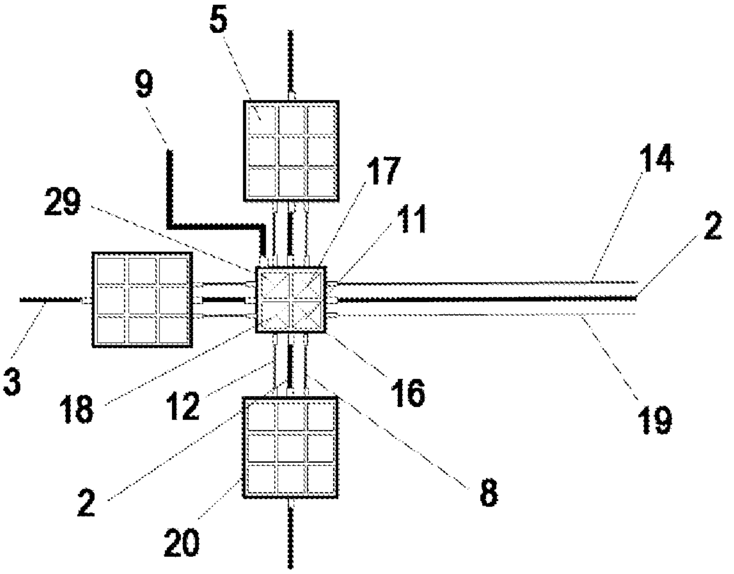


Fig. 7

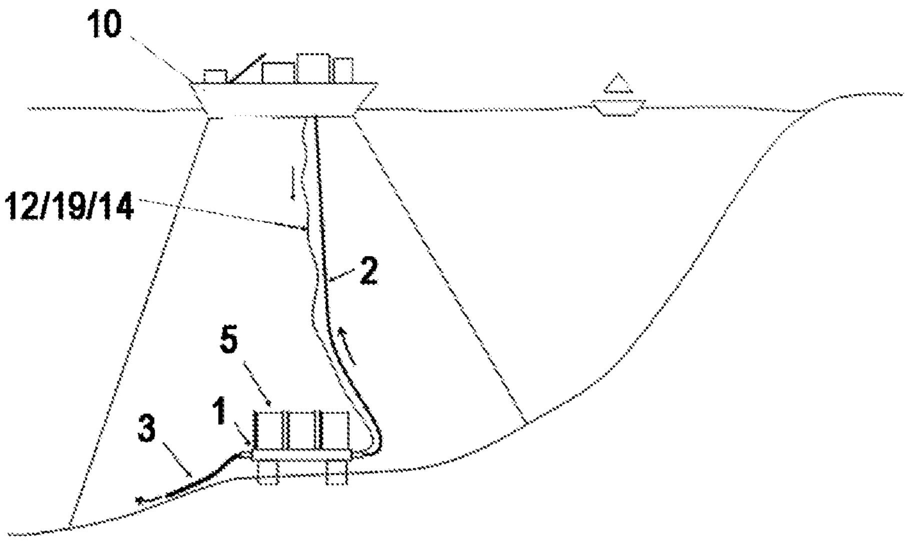


Fig. 8

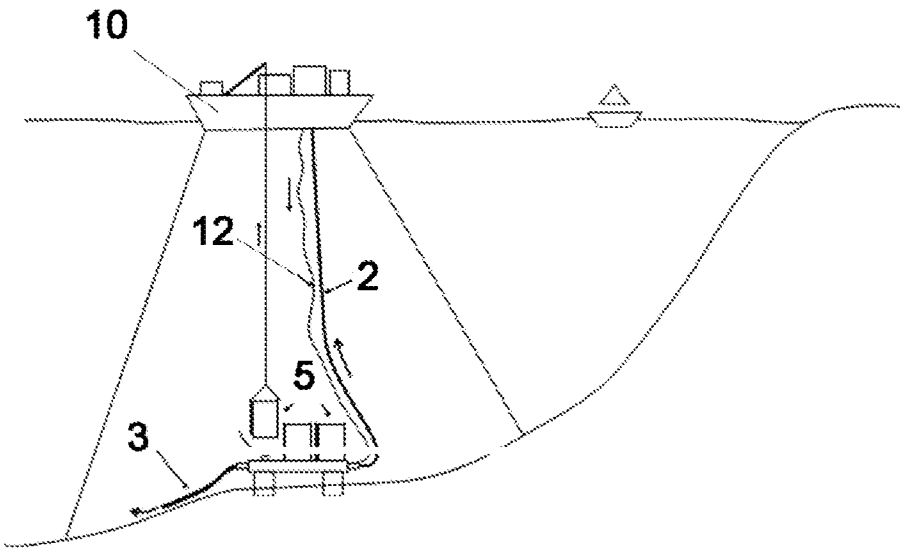


Fig. 9

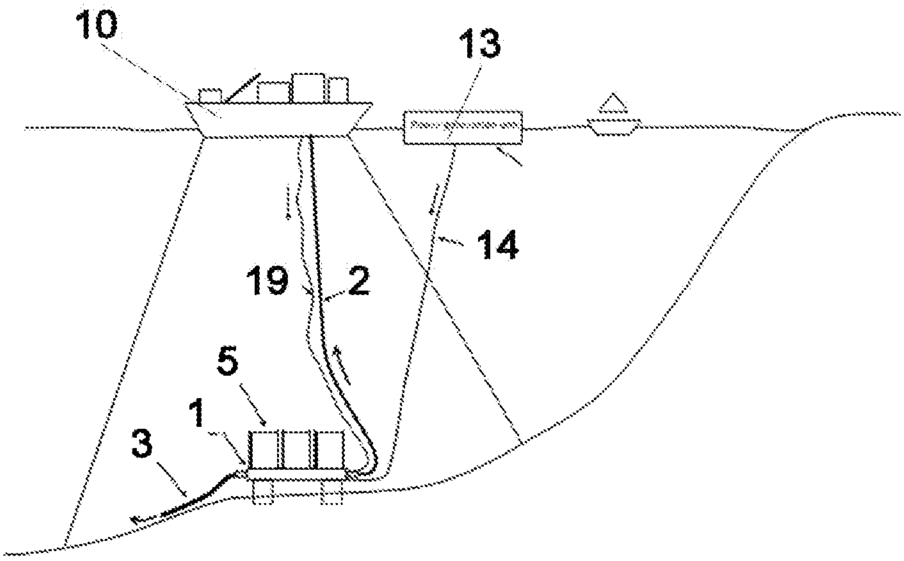


Fig. 10

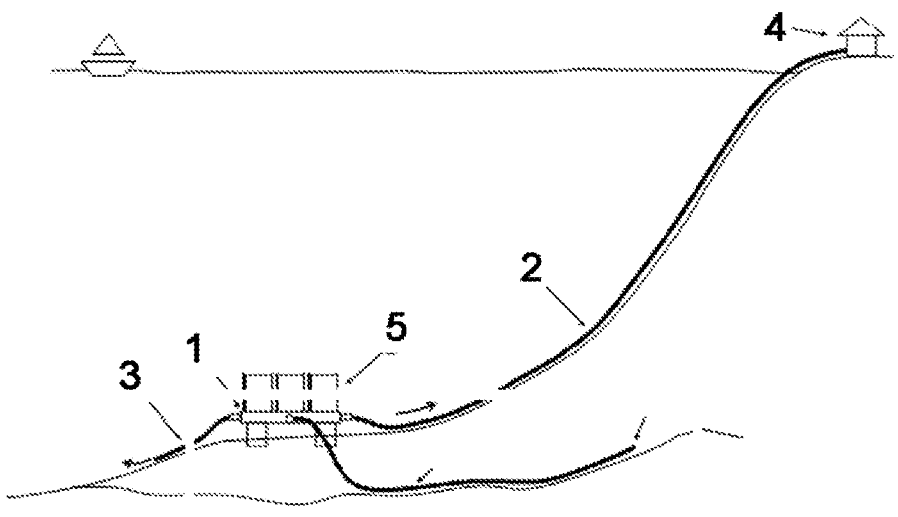


Fig. 11

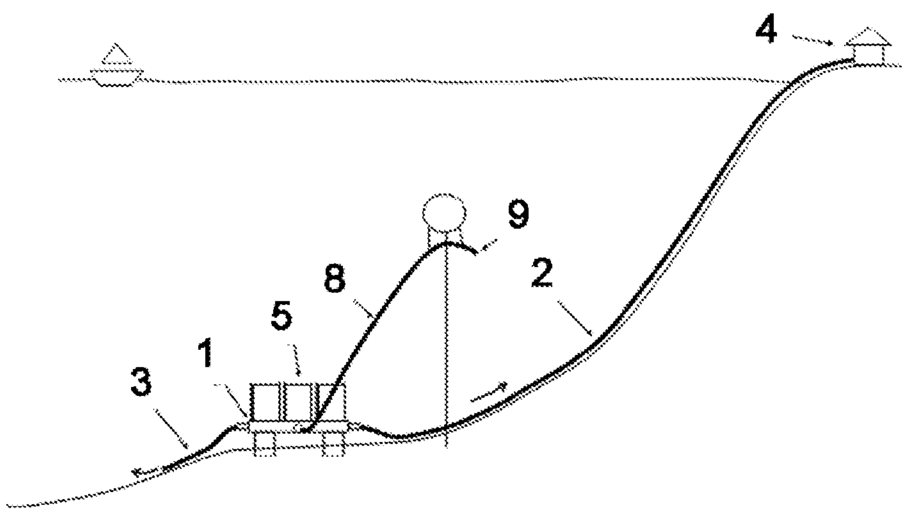


Fig. 12

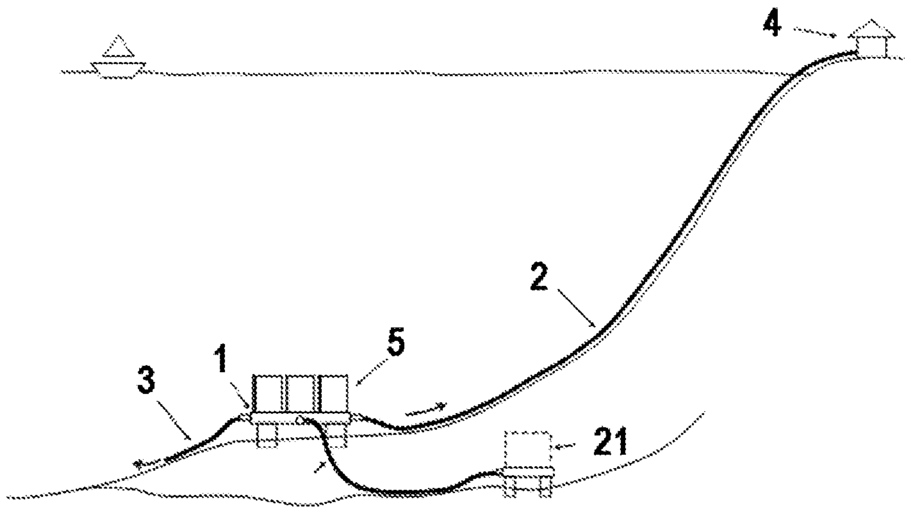


Fig. 13

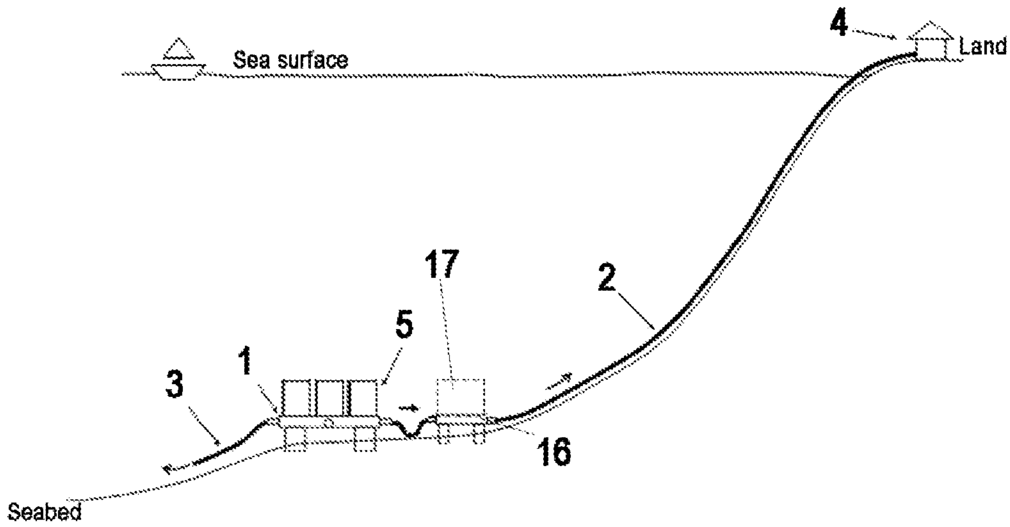


Fig. 14

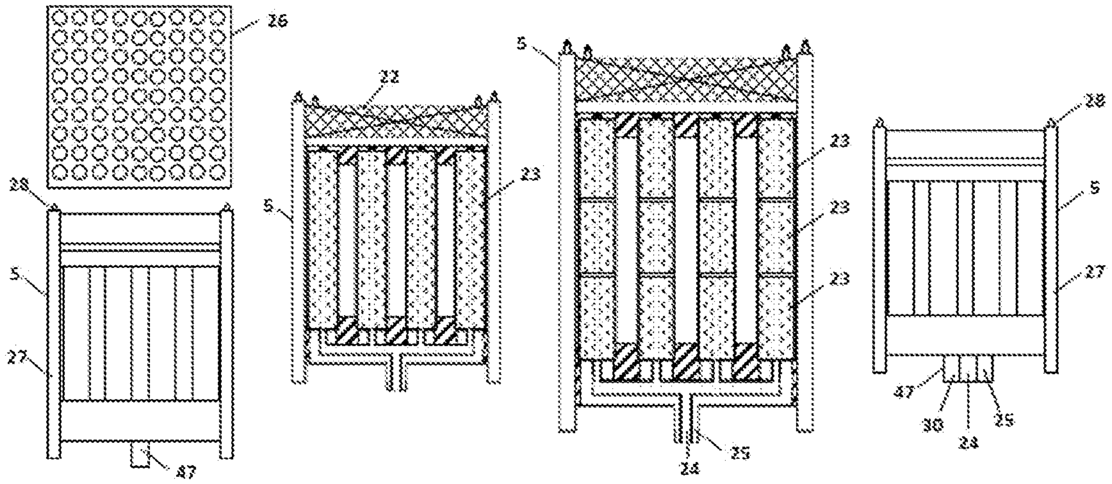


Fig. 15

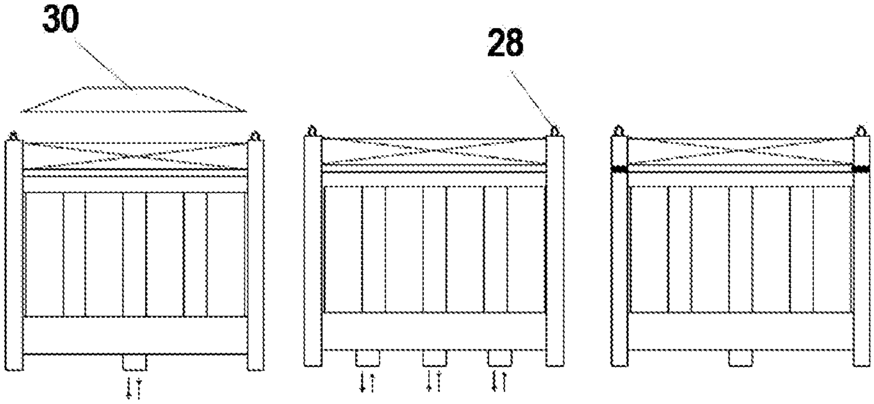
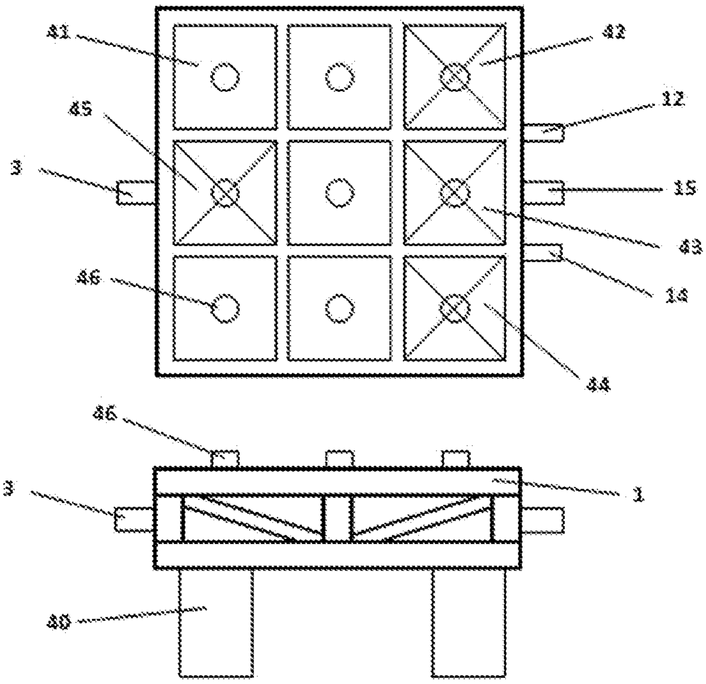


Fig. 16


41
42
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12
3
15
43
46
14
44
46
3
1
40

Fig. 17

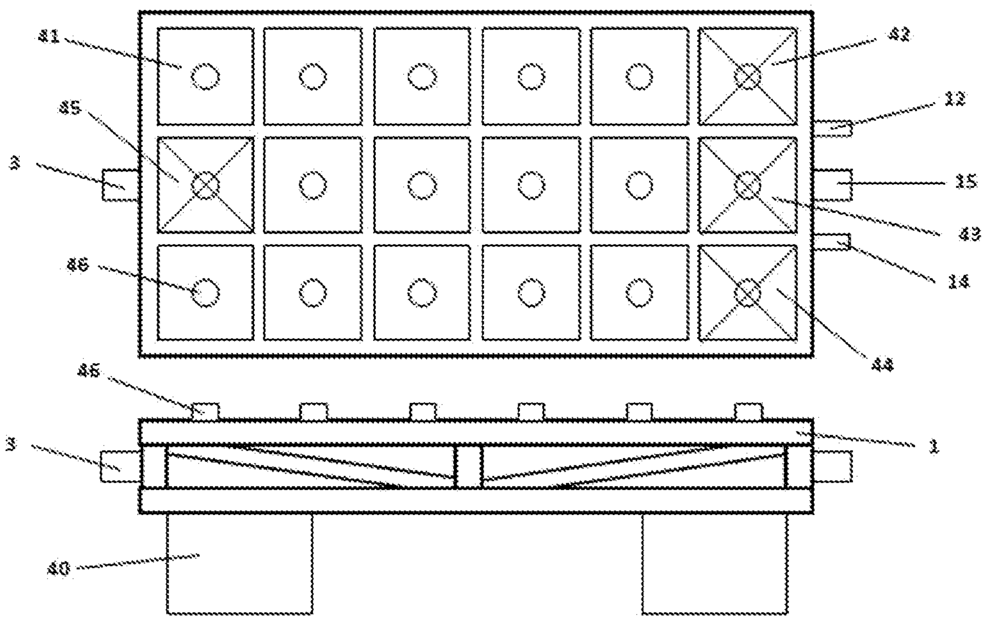
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Fig. 18

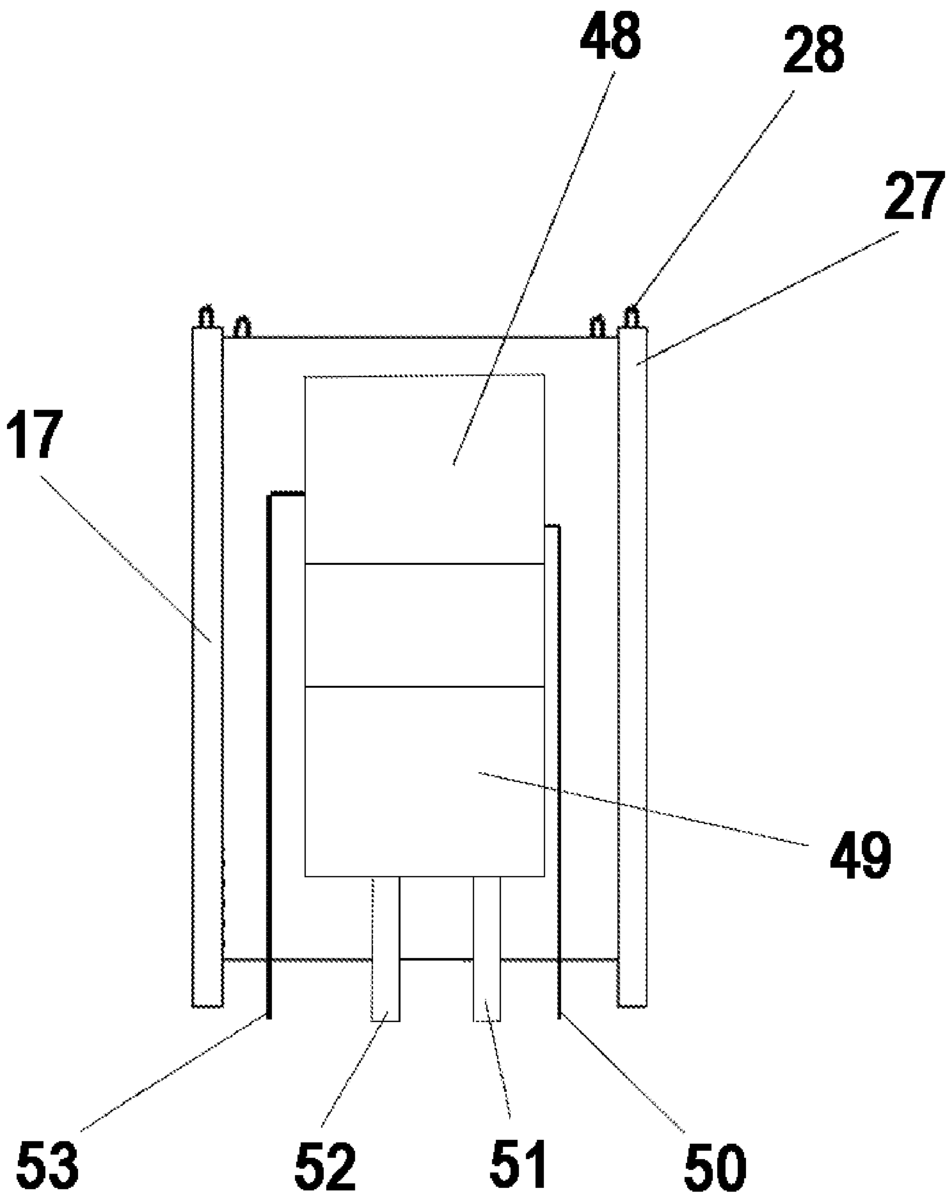

Fig. 19