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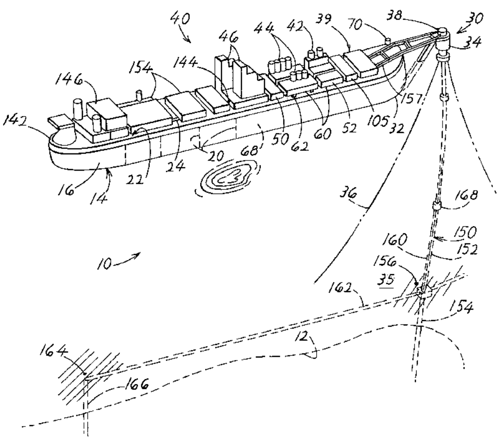
(54) Title: OFFSHORE NITROGEN PRODUCTION AND INJECTION



(57) Abstract: Nitrogen is produced above an offshore hydrocarbon reservoir (12) and injected into the reservoir, by a complex (40) mounted on a previously used vessel hull (16). The vessel weathervanes and the complex includes equipment that takes in ordinary air from a bow end (32) of the vessel, cools the air using sea water pumped into the equipment, and liquefies the oxygen component of air so pure nitrogen remains. The complex also includes injection equipment that heats and pressurizes the pure nitrogen to inject it into the reservoir. The complex is mounted above pipes (24) on the deck (22) of the vessel hull, on spacers (62) so mounting of equipment can be accomplished rapidly and without major alterations to the hull. A riser bundle (150) that extends from the hull to the sea floor, may include both a production riser (152) that carries crude hydrocarbons up to the vessel for storage in hull tanks (20), and an injection riser (160) that carries pressured nitrogen. The lower end of one of the risers is connected to a sea floor pipeline (162) that extends at least 100 meters away from the lower end of the other riser.

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OFFSHORE NITROGEN PRODUCTION AND INJECTION

BACKGROUND OF THE INVENTION

When hydrocarbons are withdrawn from a reservoir that lies under a sea floor, as when liquid and gaseous hydrocarbons are produced from the reservoir, the pressure of the remaining hydrocarbons decreases. To limit pressure reduction, fluid that is liquid or gaseous, and preferably gaseous, may be pumped back into the reservoir. A liquid such as seawater can be injected, but this can create reservoir problems, so a gas often must be used. Produced gaseous hydrocarbons are usually too valuable to use for reinjection. Nitrogen is a suitable gas to inject into the reservoir because nitrogen constitutes 79% of air by volume. Oxygen constitutes 21% of air and must be removed so it does not oxidize hydrocarbons in the reservoir. Carbon dioxide constitutes less than 1% of pure air and is undesirable but acceptable in small quantities. . One way to produce nitrogen without oxygen from air is to burn fuel such as gaseous hydrocarbons that combine with oxygen, but this produces considerable carbon dioxide along with the nitrogen. Large amounts of carbon dioxide tend to contaminate hydrocarbons produced from a reservoir. Another way to produce nitrogen is by liquefaction of air and distillation to separate nitrogen from oxygen and other undesirable constituents. Considerable energy and large equipment is required to provide and inject such nitrogen. A nitrogen production system that provided for injection of highly pure pressurized nitrogen into a subsea reservoir, and that could be constructed rapidly and at moderate cost, would be of value.

SUMMARY OF THE INVENTION

In accordance with one embodiment of the invention, a system is provided for use in an offshore environment to enable the production of pure nitrogen for injection into an offshore hydrocarbon reservoir, which enables low cost and rapid setup of the system. The system includes a vessel hull with a deck and a separation complex mounted on the deck that includes equipment for using sea water as a heat sink to cool air in the liquefaction of its oxygen component so nitrogen can be separated out, and that includes injection equipment for injecting the nitrogen into the reservoir.

An available vessel hull can be obtained, such as one previously used to transport oil. The equipment of the separation system is mounted on the deck of the hull, so the hull does not have to be modified and so the equipment can be readily mounted without having to take it apart to fit it into the hull. The hull usually has pipes on its deck. Spacers are used to mount the equipment of the separation system above the level of the pipes on the deck.

The vessel can be used to both produce hydrocarbons from the hull and inject nitrogen into the reservoir. A single riser bundle extends from the vessel to the sea floor, and includes both a production riser for carrying hydrocarbons from the reservoir up to the vessel, and an inject riser for carrying pure nitrogen down to the sea floor for injection into the reservoir. A lower end of one of the risers, such as the inject riser, is connected to a pipe that extends along the sea floor by at least 100 meters and that connects to a pipe that extends down into the reservoir thereat.

The vessel hull is moored so its can weathervane, so its bow always faces upwind. An air intake for the separation system is located at the bow of the vessel. This avoids drawing in air that is contaminated by engine exhaust, vapors from hot lubricant and hydrocarbons, etc. that instead pass towards the stern and then away from the vessel.

The novel features of the invention are set forth with particularity in the appended claims. The invention will be best understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an isometric view of a system of the present invention lying over an undersea hydrocarbon reservoir, for producing and injecting nitrogen into the reservoir.

Fig. 2 is a side elevation view of the system of vessel of the system of

Fig. 1.

Fig. 3 is a plan view of the vessel of Fig. 2.

Fig. 4 is a block diagram view of the separation complex of the system of Fig. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 shows a system 10 of the present invention for producing and injecting pure nitrogen gas into an undersea hydrocarbon reservoir, or well 12. The system includes a vessel 14 with a vessel hull 16. The vessel hull is a former tanker hull which has tanks 20 that can store large quantities (millions of gallons) of crude oil and that has a large deck 22. The deck 22 was largely uncluttered when used as a tanker, except for numerous pipes 24 immediately over the deck that were used to transfer oil into, out of, and between tanks. The large deck and the buoyancy of the tanker allows it to be used to hold large and heavy equipment of the present invention.

A turret structure 30 has been mounted on the hull, beyond the hull bow 32 (it could be mounted in a moonpool within the hull). The turret structure includes a turret 34 that is moored to the sea floor 35 by a mooring structure that includes catenary lines 36. The mooring structure allows limited vessel drift (more than 10 meters but no more than one kilometer) and allows vessel weathervaning so the bow is always pointed upwind. Fluid swivels 38 on the turret are connected to crude hydrocarbon processing equipment 39 on the hull that removes sand, etc., and to the undersea hydrocarbon well.

A nitrogen production and injection complex 40 is mounted on the hull. The complex includes an air compressor station 42 where air is compressed in the process of air liquefaction, an absorption station 44 where impurities are removed, and a cryogenic station 46 where air is cooled to a very low temperature in order to liquify oxygen in the air so pure nitrogen can be obtained. The complex reheats nitrogen by passing it back though the cryogenic station 46. The reheated nitrogen passes though a nitrogen compression station 52 where nitrogen is pressurized before it is injected. The pressurized nitrogen passes though one of the fluid swivels to flow down though one of the risers to the reservoir to pressurize the reservoir. An electricity generator and other equipment is shown at 154 and a helicopter pad and crew quarters are shown at 146.

It would be possible to build the vessel by incorporating the various stations of the nitrogen complex in the hull when the hull was built. However, applicant finds that an existing hull, especially that of a tanker which was built with tanks in the hull to carry hydrocarbons, can be economically used instead. Such existing hull can be economically fitted with stations that are placed on the deck (the term “on the deck” is used herein to mean on or above the level of the deck)and secured in place. The figures show modules such as 60 that form all of the stations of the nitrogen production and injection complex, which were separately manufactured and then loaded onto the deck 22 of the hull and secured in place as by welding. The nitrogen complex modules are placed on spacers 62 that space them above the hull deck. This provides room for the pipes 24 that were already present on the tanker or that applicant adds and that lie under the modules.

At least 80%, usually at least 90%, and commonly at least 95% of the volume 68 within the hull is left empty of nitrogen production equipment. The volume 68 can hold produced hydrocarbons (e.g. liquids such as pentane that has a density of 0.63 and hexane that has a density of 0.66). The density of such hydrocarbons is much less than that of water (density of 1.0) so the floating hull still provides sufficient buoyancy to support the nitrogen production equipment of the nitrogen complex that lies above the deck.

Fig. 4 shows details of the complex 40 that produces and injects nitrogen. The complex includes an air inlet 70 that receives ambient air and that pipes the air though a filter and into a compressor 72. A turbine 74 receives combustion gases produced by burning natural gas (produced by the reservoir, or well) in a combustion chamber 76. The gas expansion turbine 74 turns an electric generator 80 that provides electricity to power the compressors and other equipment.

Large volumes of compressed air exit the compressor 72, at a pressure such as 7.5 bars (about 7.5 times atmospheric, or about 108 psi) and a temperature of about 110° C. The hot compressed air passes through a cooler 82 that uses cooling water to cool the large amounts of hot compressed air to a temperature such as 40° C. The cooling water is cooled using seawater that is pumped through a seawater cooler heat exchanger 84. The sea water is pumped to pass up from the sea through a pipe 85, through the seawater cooler heat exchanger 84 where the cooling water is cooled, and through another pipe 87 back to the sea.

The compressed air from compressor 72 that has been cooled in cooler 82, is cooled by an electrically powered refrigeration system 88 that cools the compressed air to a temperature such as 4° C. The compressed and moderately cooled air then flows through a molecular sieve system 86 to remove water, carbon dioxide, and other gases that might harm the distillation process. It is essential to remove water, carbon dioxide and such other gases because their freezing points are far above oxygen liquefaction temperatures, and frozen water and carbon dioxide would plug downstream equipment. Light hydrocarbons (less that 6 carbon atoms per molecule) such as methane and ethane will pass through the molecular sieve system, but if they freeze and accumulate, then they have to be removed periodically.

The cooled and compressed air (e.g. at 4°C and 6 bars) from the molecular sieve system 86 is split into two streams 90, 92. Stream 92 of air flows into a main heat exchanger 94 where the air is cooled to a temperature such as -40° C. This is accomplished by heat exchange in heat exchanger 94 with a returning cold nitrogen stream 100 and a cold oxygen stream 102 (and a reflux condenser 103) each passing through heat exchanger 94. The cold and compressed air from the heat exchanger 94 then flows along path 104 to a turbo expander 106. The output of the turbo expander is air at a temperature of -175°C, at which the air (the oxygen in the compressed air) is partially liquified. The very cold air moves along path 110 to a distillation column 112. A stream 90 of air from the molecular sieve system 86 and the heat exchanger 94, has been cooled by gaseous oxygen to -175°C and passes along path 114 to the distillation column. In the distillation column 112, the gaseous component, which is nitrogen at -175°C, is removed through outlet 120, while the liquid oxygen component is removed through outlet 122. Each passes through different inlets of the heat exchanger 94. Nitrogen passes along cold path 100 and path 130 to a motor driven compressor 132. The compressor compresses the nitrogen to a pressure such as 110 bars and routes it through one of the fluid swivels and one of the risers to flow into the subsea well. The pure nitrogen gas produced in this way contains over 99.9% nitrogen.

To prevent contaminants from entering the air separation system, the air compressor intakes where ambient air is taken in for the process, is located as far upwind as is practical, which is a location closest to the bow of the vessel or even upwind therefrom. The location, shown at 70 in Fig. 1 is closer to the bow 32 than to the stern 142 and is closer to the bow than a vessel midpoint 144. Since the vessel is freely weathervaning around the turret, the vessel bow will be upwind most of the time. Fig. 1 shows the clean air inlet 70 at the bow.

In a system that applicant has designed, a vessel hull 14 was used that had a length of 316 meters, a 260,000 tons deadweight, and a cargo tank capacity of 306,000 cubic meters. The nitrogen complex was designed to use 47,200 cubic meters (at 1 bar) of natural gas per hour and produce 531,000 standard (at 101.3 μPa and 15.6°C) cubic meters per hour of 99.9% pure nitrogen, which was pressurized at 110 bars.

The vessel 14 of Fig. 1 passes fluids to the hydrocarbon well 12 and receives fluids from the well, though a riser bundle, or assembly 150 and the fluid swivel assembly 38. A first one 152 of the risers connects to a pipe 154 at a first location 156 that extends down to the hydrocarbon well 12 to carry hydrocarbons up to the vessel. The produced hydrocarbons pass from the crude riser upper end along a pipe 157 to the crude processor 39. The hydrocarbons not used to energize the complex 40 are stored in the vessel tanks and offloaded perhaps every week to a tanker that takes the hydrocarbons to a far away port. A second one 160 of the risers connects to a pipe 162 that extends along the sea floor to a location 164 where a pipe 166 extends down to the hydrocarbon well. The pipe 166 carries pressured nitrogen for injection into the well. The locations 156 and 164 on the sea floor and corresponding locations in the well, are horizontally spaced apart by more than 100 meters. Such spacing is necessary to assure that the injected nitrogen does not find its way to the pipe and riser that produce hydrocarbons from the well. The riser bundle includes means 168 that holds the risers close together (preferably less than 2 meters spacing).

In a large hydrocarbon production field, the nitrogen producing vessel may be used only to produce and inject nitrogen. Other vessels may be used to produce all hydrocarbons from the undersea well. Another alternative is that the nitrogen producing and injection vessel may be used alone to pressurize a well from which hydrocarbons later will be produced.

Thus, the invention provides a system for producing nitrogen and injecting nitrogen into a hydrocarbon well that lies under a sea. The system includes a seaworthy vessel hull that is preferably one that was previously used as a tanker. A nitrogen production and injection system is installed on top of the deck of the vessel hull, with spacers to allow pipes on the deck. The nitrogen production complex produces nitrogen by liquefaction of oxygen to remove it from the air and leave nitrogen. The vessel is moored so it weathervanes, and the air intake for the nitrogen production complex lies at the bow of the vessel to minimize the intake of contaminants. The vessel usually is also used to produce hydrocarbons from the well into which nitrogen is injected. A riser bundle extends from a turret that is mounted on the vessel to a platform on the sea floor. The riser bundle includes a first riser that carries hydrocarbons up to the vessel and a second riser that carries pressured nitrogen down to the sea floor for injection. One of the risers has a lower end that is connected by a primarily vertical pipe to the well, or reservoir. The other riser is connected to a seafloor conduit that extends at least 100 meters along the sea floor to a location where the conduit connects to a primarily vertical pipe that extends down to the well.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur to those skilled in the art, and consequently, it is intended that the claims be interpreted to cover such modifications and equivalents.

WHAT IS CLAIMED IS

1. Apparatus for injecting gas into an undersea hydrocarbon reservoir (12) that lies under the sea floor (35) of a sea, comprising:

a seaworthy vessel hull (16) that has a deck (22) and that is moored to the sea floor;

a nitrogen production complex (40) that has an air intake (70) for receiving environmental air, equipment (46, 82, 88, 94, 112) for cooling the air and separating out nitrogen in the air from other components in the air, and equipment (42, 132) for pressurizing the nitrogen to inject it into the reservoir;

most of the volume of said nitrogen production complex being mounted on top of said deck of said vessel hull, with at least 80% of the volume inside the vessel hull being left unoccupied by the nitrogen production complex to provide buoyancy for the nitrogen production complex.

2. The apparatus described in claim 1 including:

hydrocarbon processing equipment (39) mounted on said vessel hull;

a riser bundle (150) that extends from said vessel to the sea floor and that includes a crude oil riser (152) and an injection riser (160);

said crude oil riser that has a crude riser lower end connected to a first production location (156) in said reservoir to carry crude hydrocarbons up to said vessel hull, and a crude riser upper end connected to said hydrocarbon processing equipment;

said injection riser has an upper end connected to said equipment for receiving pressurized nitrogen and a lower end connected to a second injection location (164) in said reservoir to inject nitrogen therein;

said second injection location (164) being horizontally spaced by at least 100 meters from said first injection location (156).

3. The apparatus described in claim 2 wherein:

said nitrogen production complex is energized by some of the crude hydrocarbons carried up to said vessel hull through said crude oil riser and processed by said hydrocarbon processing equipment, and said vessel hull has tanks (20) built into the hull that contain hydrocarbons processed by said hydrocarbon processing equipment.

4. The apparatus described in claim 1 wherein the mooring of said vessel hull to the sea floor allows said vessel hull to weathervane so a bow end (32) of said vessel lies upwind of a stern (142) of said vessel, and wherein;

said air intake (70) lies closer to said bow end than to a midpoint (144) of said vessel that lies halfway between the vessel bow and stern, to thereby avoid the intake of vapors originating on the vessel.

5. The apparatus described in claim 1 wherein:

said vessel hull is a previously used hull with a deck (22) and with a plurality of on-deck pipes (24) lying closely over said deck, and including a plurality of spacers (62) that mount said equipment of said complex above said on-deck pipes.

6. Apparatus for injecting gas into an undersea hydrocarbon reservoir to pressurize it, comprising:

a seaworthy vessel hull (16) that has a bow (32) and stern (142);

a separation system that has an air intake (70) for receiving environmental air, equipment (46, 82, 88, 94, 112) for cooling the air and separating out nitrogen in the air from other components in the air, and equipment (42, 132) for pressurizing the separated-out nitrogen to pump it into the reservoir;

a mooring system (34, 36) that limits hull drift while allowing the hull to weathervane so its stern points in changing directions away from its bow with changing winds, waves and currents;

said air intake (70) is closer to the bow (32) than to the stern (142) of the hull.

7. The apparatus described in claim 6 wherein:

said vessel hull has a deck (32);

at least 90% of the volume of said equipment for cooling and separating and said equipment for pressurizing, lies on top of said deck.

8. The apparatus described in claim 7 including:

a plurality of pipes (24) lying closely over said deck, said equipment for cooling and separating lying on said spacers and above said pipes.

9. A method for pressurizing an undersea hydrocarbon reservoir comprising;

mounting a separation system (40) on a deck of a vessel hull and mooring the hull to the sea floor;

drawing ambient air into the separation system and operating the separation system including cooling the drawn-in air using sea water pumped in from the sea as a heat sink and further cooling the air and separating out the nitrogen from the oxygen;

operating the separation system to heat the separated-out nitrogen, and pump the separated-out and heated nitrogen into a first location (164) in the undersea hydrocarbon reservoir.

10. The method described in claim 9 including:

producing hydrocarbons from said undersea reservoir, from a second location (35) that is spaced at least 100 meters from said first location, and using some of said produced hydrocarbons to energize said separation system.

11. The method described in claim 9 wherein:

said step of mounting a separation system comprises mounting at least 90% of said volume of said separation system above the deck of said vessel hull.

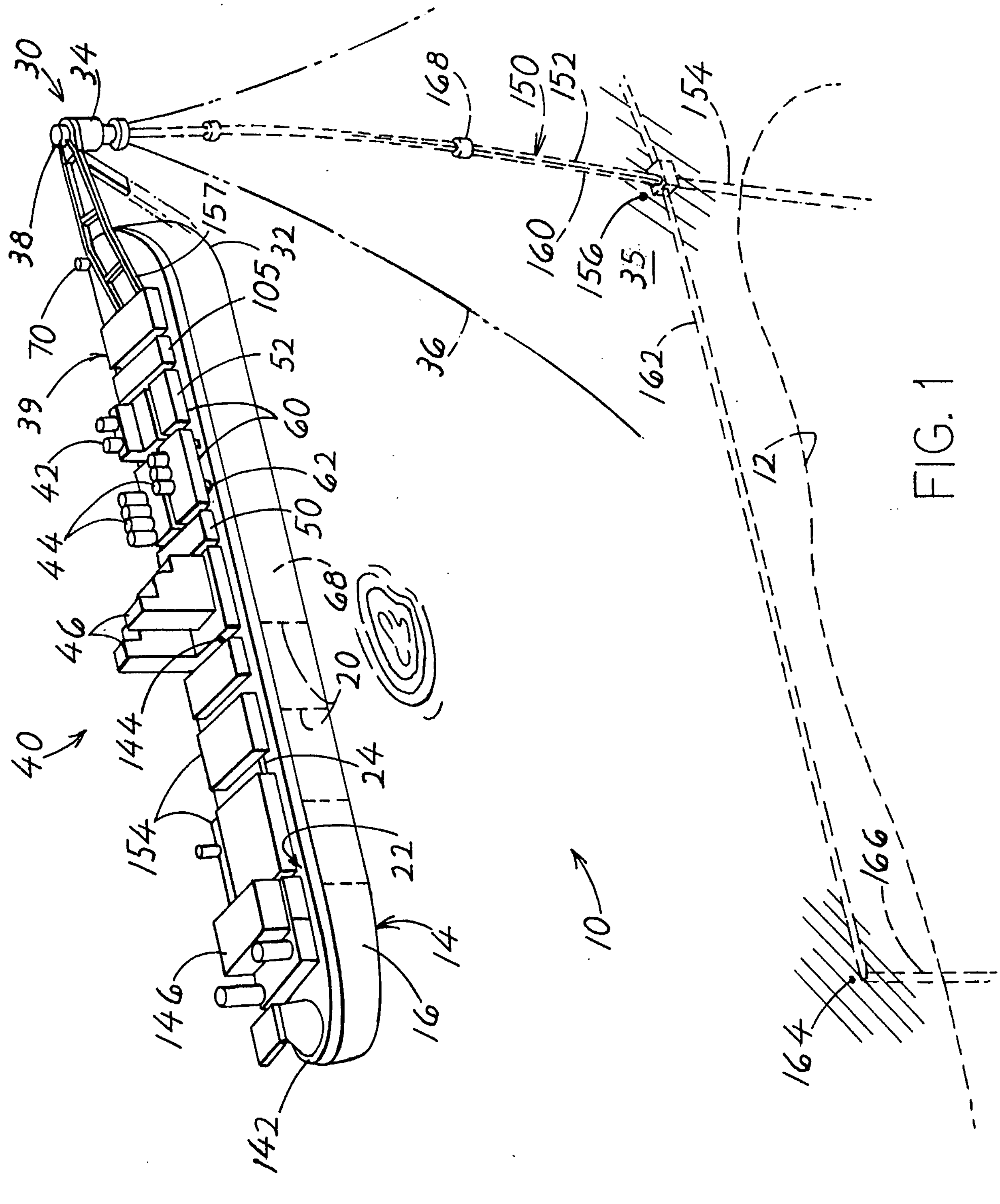
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FIG. 1

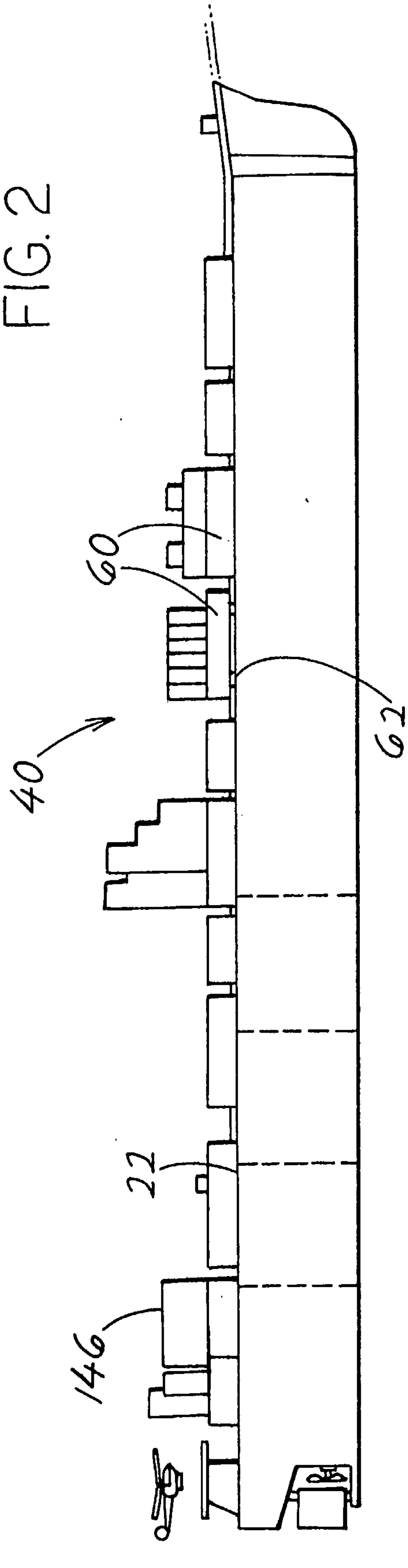


FIG. 2

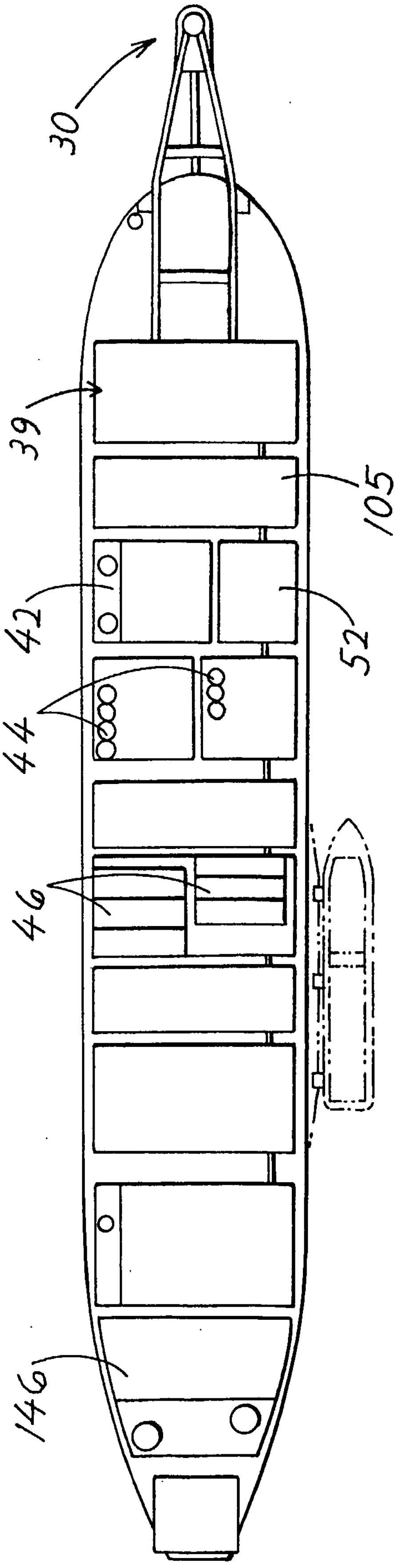
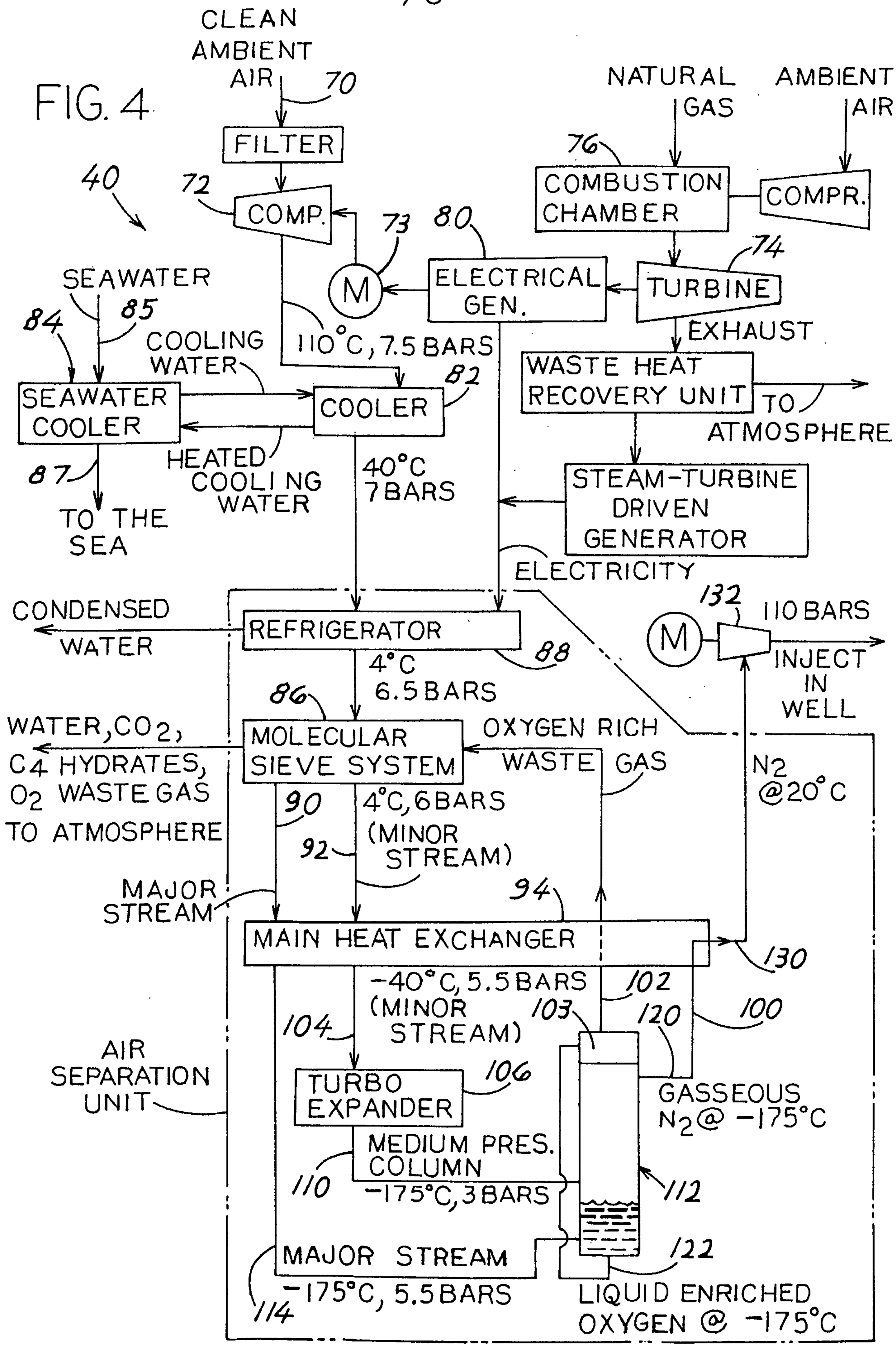


FIG. 3

FIG. 4


CLEAN AMBIENT AIR
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FILTER
72
COMP.
73
M
NATURAL GAS
AMBIENT AIR
76
COMBUSTION CHAMBER
COMPR.
74
TURBINE
80
ELECTRICAL GEN.
EXHAUST
40
WASTE HEAT RECOVERY UNIT
TO ATMOSPHERE
SEAWATER
84
85
COOLING WATER
110°C, 7.5 BARS
82
SEAWATER COOLER
COOLER
HEATED COOLING WATER
87
TO THE SEA
40°C 7 BARS
STEAM-TURBINE DRIVEN GENERATOR
ELECTRICITY
CONDENSED WATER
REFRIGERATOR
88
132
110 BARS
M
INJECT IN WELL
4°C 6.5 BARS
86
WATER, CO2, C4 HYDRATES, O2 WASTE GAS TO ATMOSPHERE
MOLECULAR SIEVE SYSTEM
OXYGEN RICH WASTE GAS
N2 @20°C
90
4°C, 6 BARS
92
(MINOR STREAM)
MAJOR STREAM
94
MAIN HEAT EXCHANGER
130
-40°C, 5.5 BARS (MINOR STREAM)
102
103
120
100
104
TURBO EXPANDER
106
AIR SEPARATION UNIT
GASSEOUS N2 @ -175°C
MEDIUM PRES. COLUMN
110
-175°C, 3 BARS
112
MAJOR STREAM
122
114
-175°C, 5.5 BARS
LIQUID ENRICHED OXYGEN @ -175°C