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Fitch et al.

[11] **3,750,412**

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[54] **METHOD OF FORMING AND MAINTAINING OFFSHORE ICE STRUCTURES**

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[73] Assignee: **Mobil Oil Corporation,** New York, N.Y.

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[52] **U.S. Cl.** **61/46,** 61/63, 62/1, 62/64, 62/259

[51] **Int. Cl.** **F25c 1/02**

[58] **Field of Search** ..... 62/1, 260, 66, 67, 62/74, 75, 259; 61/36 A, 1, 46, 63

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[57] **ABSTRACT**

The specification discloses a method of constructing and maintaining an ice structure at a desired, frigid, offshore location which can be used for drilling and/or producing oil wells. An ice floe or a part of a fast ice mass forms the base on which ice is accumulated to form the structure. The ice can be accumulated by spraying, flooding, or piling up of ice. The structure may be reinforced and has means to protect it from marginal melting during the "summer" months.

7 Claims, 14 Drawing Figures

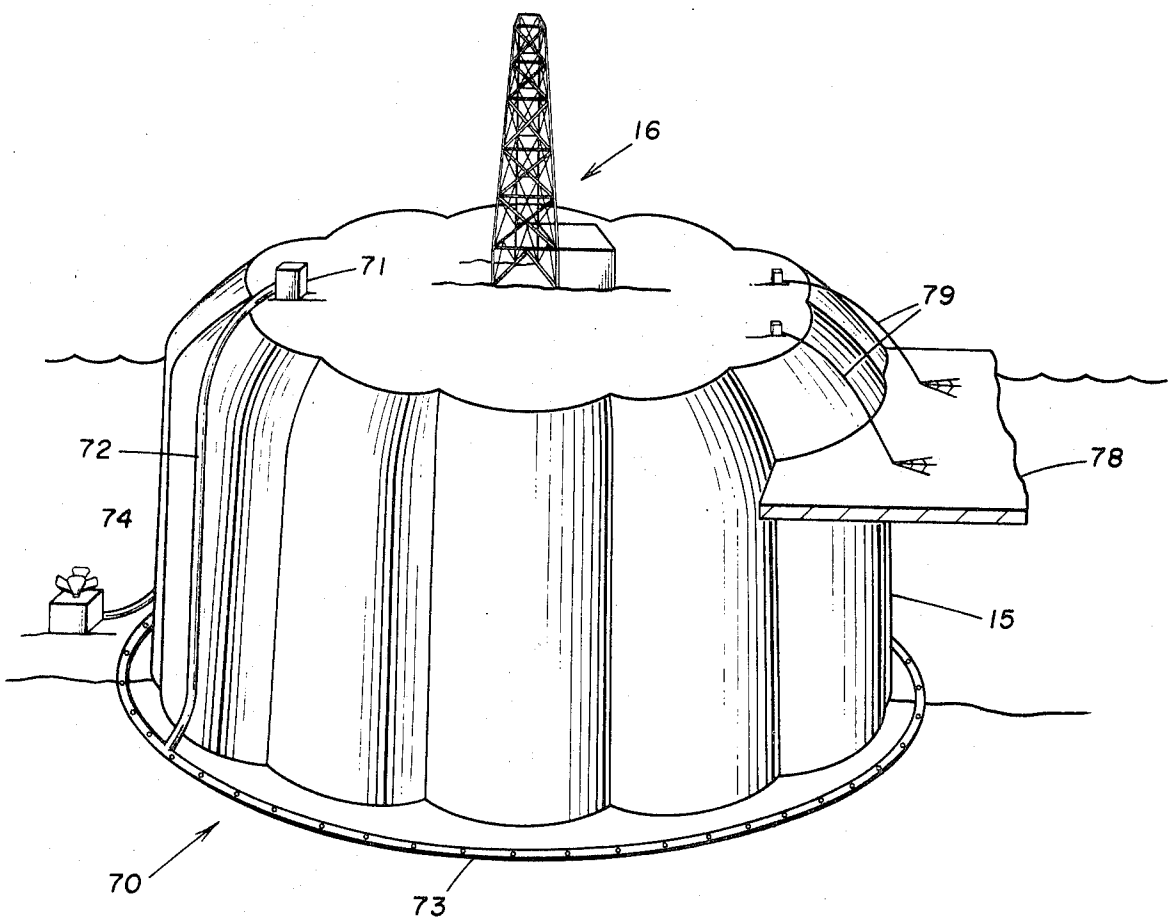


FIG. 4

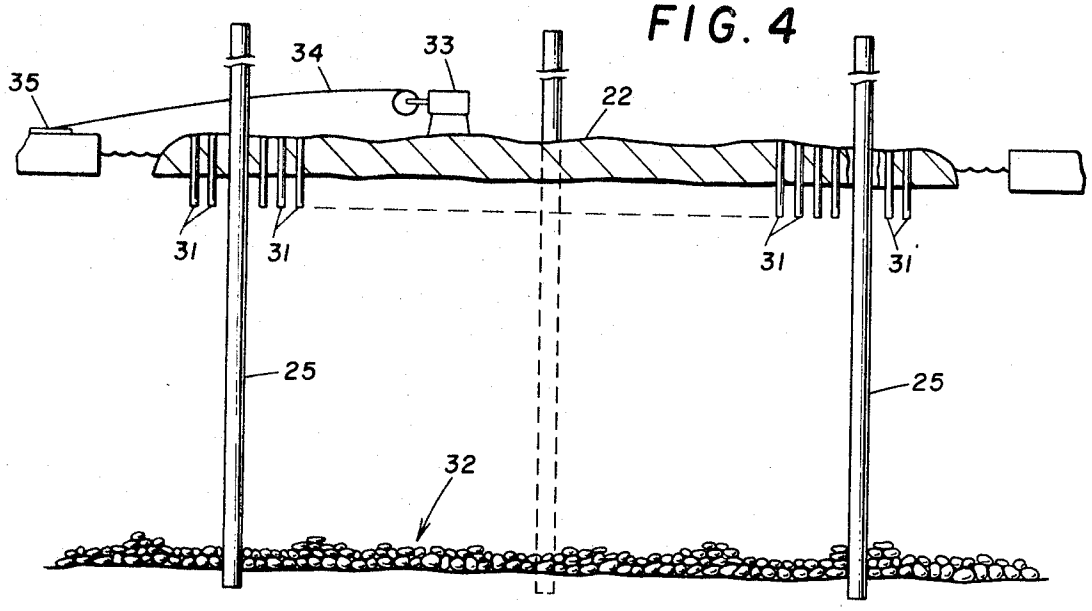
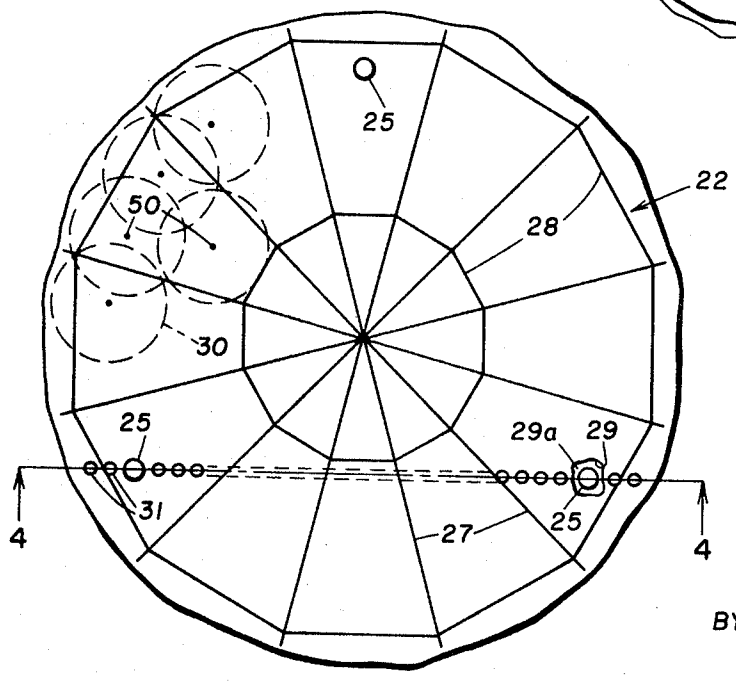


FIG. 3



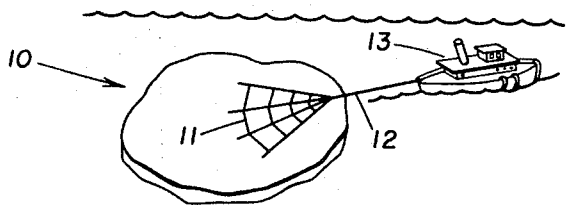


FIG. 1

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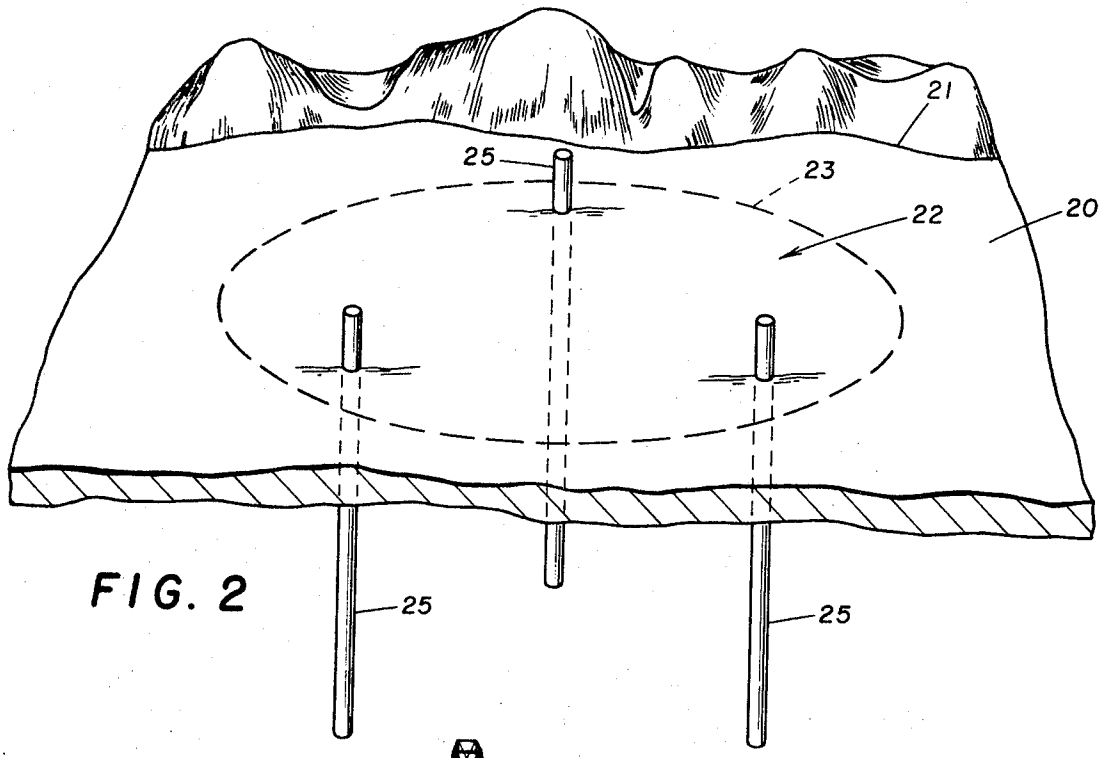


FIG. 2

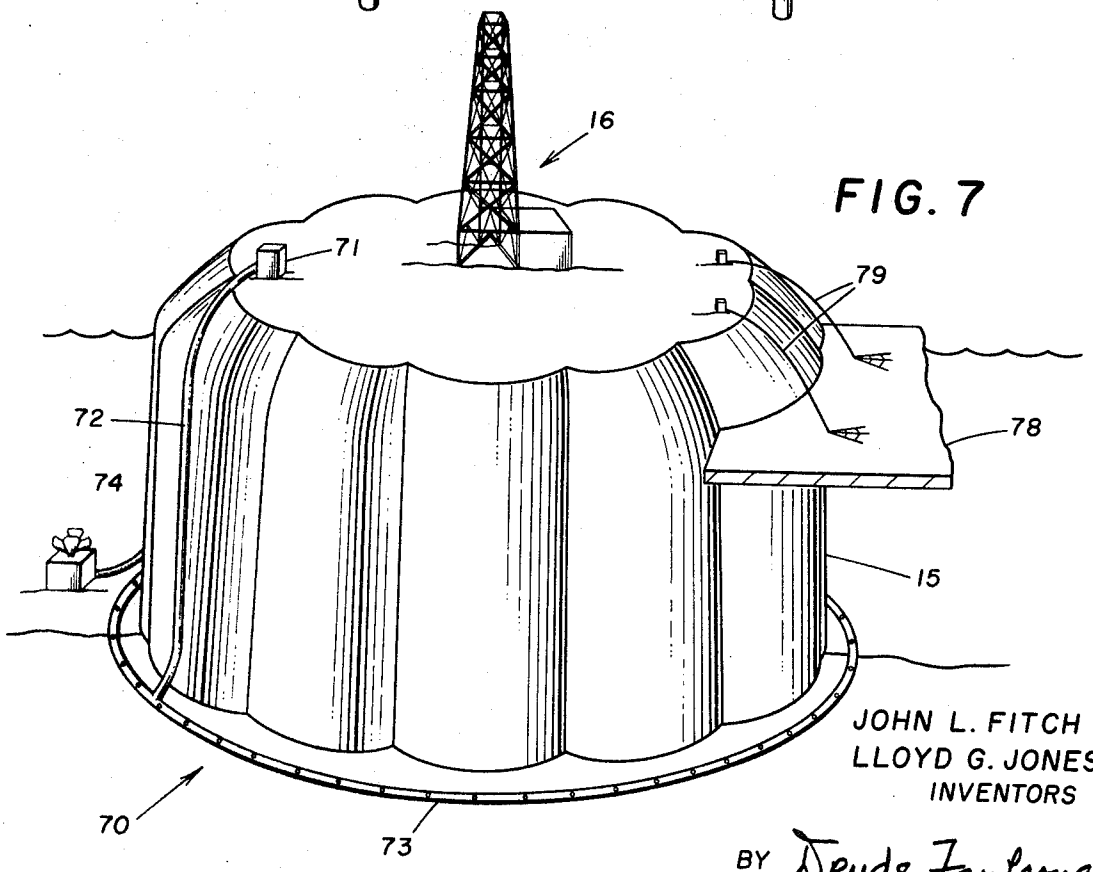


FIG. 7

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FIG. 5

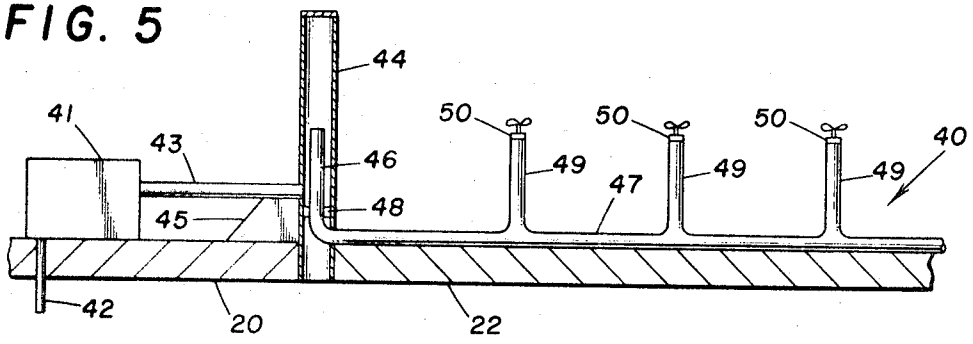
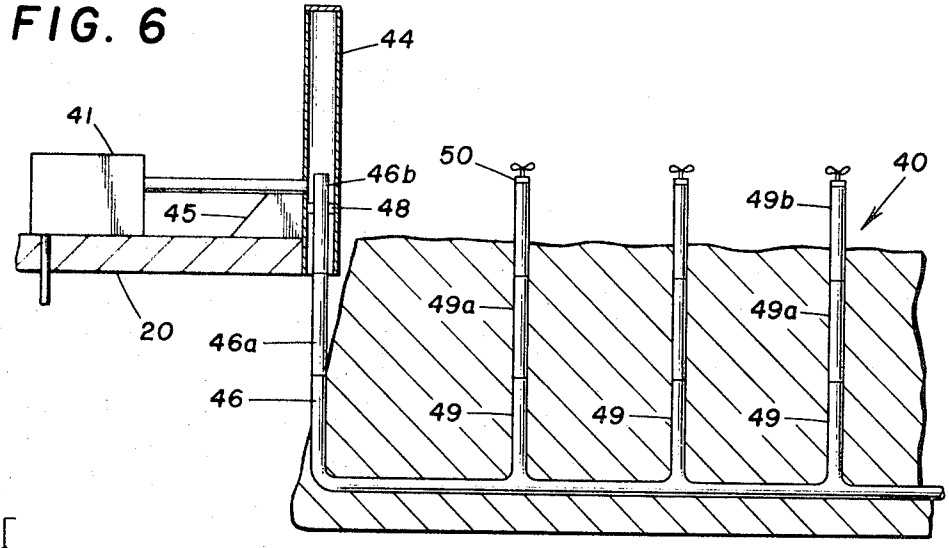


FIG. 6



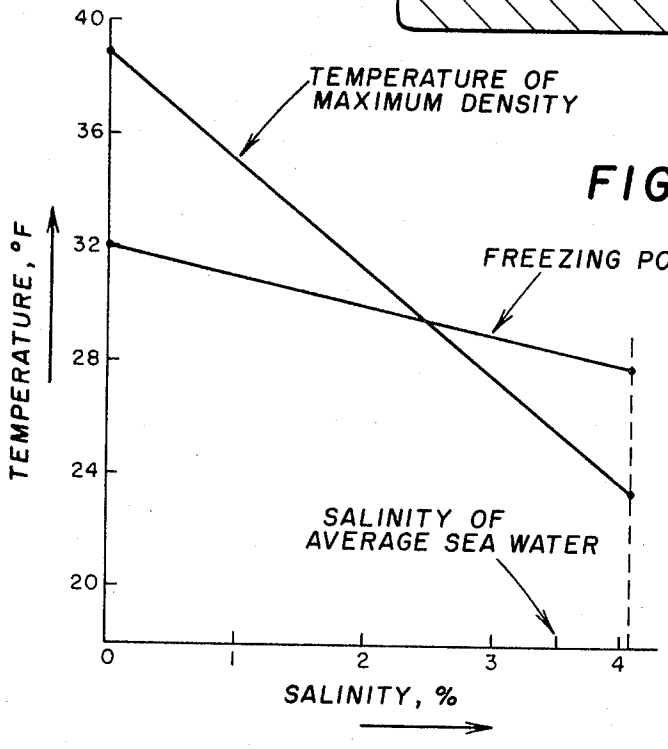


FIG. 11

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FIG. 10A

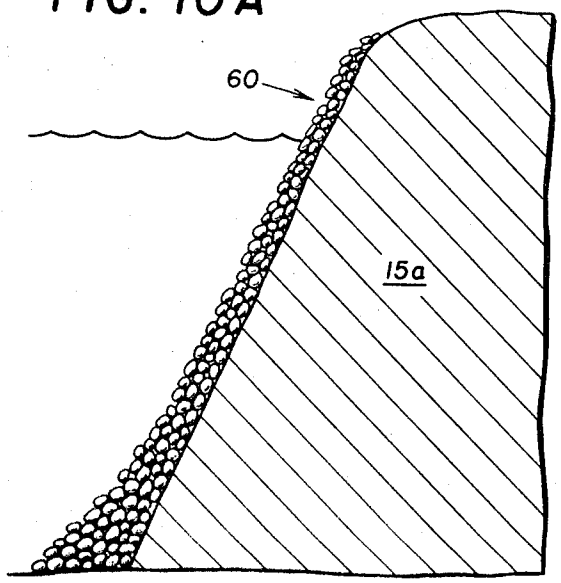


FIG. 10B

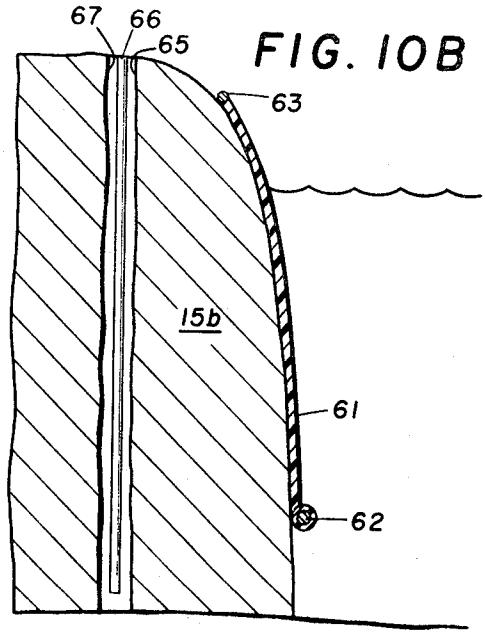


FIG. 13

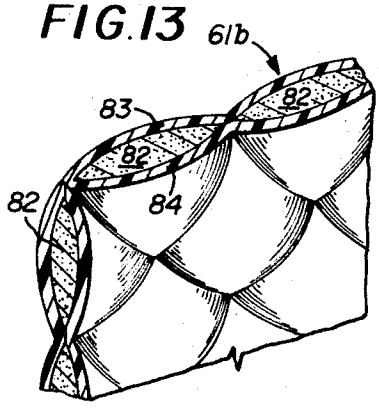


FIG. 8

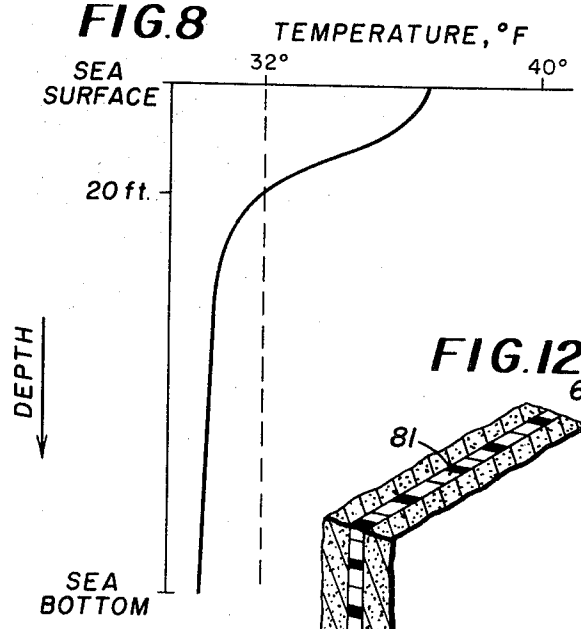
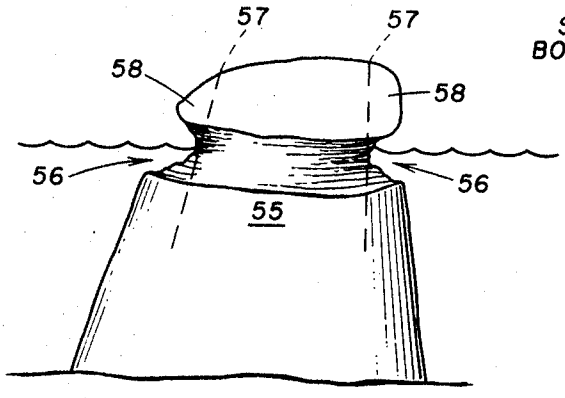


FIG. 12

FIG. 9



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METHOD OF FORMING AND MAINTAINING OFFSHORE ICE STRUCTURES

BACKGROUND OF THE INVENTION

This invention relates to a method of providing a structure in a hostile, frigid environment and more particularly relates to a method of building and maintaining an ice island at a frigid offshore location.

The increasing demand for petroleum products has required the exploitation of many new regions throughout the world. One of the most promising of these regions from the standpoint of potential reserves is that which lies along the Artic shelf which stretches some 3,000 miles from western Alaska to eastern Greenland. While there is little question that vast amounts of petroleum are present in this area, the production of this petroleum presents several new technical and economical problems.

The Artic shelf in many places is broad with a gentle slope. In winter, ice attaches itself to shore and freezes outward as much as fifty miles from shore. This "fast ice" could possibly serve as a temporary, stable platform for drilling or other operations but unfortunately this ice breaks up in the summer and "shore-leads" of open water develop through the ice. Some of these leads may range up to 200 miles in width. While the leads are open, floating drilling operations might be carried out but the risk is great since pack ice frequently moves shoreward under the influence of winds and currents. When this happens, the pack ice can completely close the shore-leads, thereby damaging any equipment within the leads. Further, this pack ice, which may range up to ten feet or more in thickness, can exert massive force which may be too great to be resisted by any practical drilling/production fixed platform of the conventional type. Therefore, to operate successfully in these areas of the Artic shelf, the drilling/production structure must be capable of withstanding or avoiding the force of moving pack ice.

One structure which can successfully resist such forces is an island which extends upward from an anchored position on the marine bottom to a distance above the waterline. Ideally, this island would be a naturally occurring one but unfortunately such islands are not normally present in this area or are located in the wrong places to serve a particular field. It follows that, in most instances, if an island is to be used, it must be of some other form.

Three alternate forms of such islands are as follows: (1) artificial islands built of earth materials and the like; (2) natural ice islands; and (3) artificial ice islands. As to artificial earth islands, the severe shortage or difficulty of obtaining the required materials in the Arctic areas makes their use impractical in most of these areas. The use of natural ice islands in these areas has been investigated as reported in OIL AND GAS JOURNAL, July 28, 1969, pp. 118–119, but these attempts were abandoned due to severe cracking of the islands. A further difficulty is that natural ice islands are unlikely to be present at the desired location and time. This leaves artificial ice islands to which the present invention relates.

There are several important considerations involved in providing an artificial ice island which is capable of serving as a year-round, permanent, or semipermanent offshore structure. First, the base of the island has to be selected and must be properly positioned at a desired location. Second, ice has to be accumulated onto the base to actually form the artificial island. Third, the island must be attached to the sea bottom to a degree sufficient to substantially prevent it from moving laterally under forces imposed by drifting ice, wind, and currents. Fourth, the island must have sufficient mechanical strength to resist major breakup due to forces imposed by ice, wind tides, waves, or other forces. Last, the island has to be maintained during periods when the ambient temperature of the water and/or air rises above the melting point of the ice forming the island so that the island will not melt or break up.

SUMMARY OF THE INVENTION

The present invention provides a method for constructing and maintaining an ice structure at a desired, frigid, offshore location which satisfies the considerations mentioned above.

A base of naturally occurring ice which is normally a relatively flat slab of ice is selected and anchored over the desired location. This base may be an ice floe or it may be part of a fast ice mass normally overlying the desired location. Reinforcing material may be provided on the base to strengthen it and to give it added weight for stability. In one embodiment, piles are passed through the base and into the marine bottom to anchor the base and to aid in construction of the structure.

Ice is then accumulated on the base. Accumulation of ice may be by freezing water which is sprayed or flooded onto the base, by distributing crushed ice about the base, or by piling up blocks of ice on the base which are gathered from the surrounding environment. Since construction of the structure takes place in the Arctic winter, no refrigeration equipment is needed to freeze the water. The ice is accumulated so that the sides of the structure are substantially vertical or slope slightly inward. Reinforcement may be added periodically during accumulation of the ice to maintain sound structural integrity of the structure. The base under the added weight of the accumulated ice will begin to sink toward the marine bottom. Accumulation of ice is continued until a structure is formed which reaches from the marine bottom to above the waterline.

The structure is protected from marginal melting during the "summer" months by several different methods. One method provides a thermal barrier about the sides of the structure in the form of insulation. Another method provides a barrier about the structure which traps water from surface melting against the sides of the structure to prevent the surrounding sea water from contacting the structure. Another provides refrigerating the structure to further reduce the temperature of the ice forming the structure. Still another method provides for bringing colder water from its normal depth to the surface adjacent the structure to reduce the temperature of the surface water which contacts the margins of the structure. Also, sacrificial blocks of fast ice or pack ice can be secured to the margins of the structure and allowed to melt as the water temperature rises to keep the temperature of the water reduced near the margins.

The above-mentioned and other advantages of the invention will be more readily appreciated as the invention becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a vessel towing an ice floe to a desired offshore location;

FIG. 2 is a perspective view of an initial stage of construction of the present invention;

FIG. 3 is a plan view of a base of ice utilized in the present invention;

FIG. 4 is a cross-sectional view taken along section line 4—4 of FIG. 3;

FIG. 5 is a cross-sectional view of a sprinkler system utilized in the present invention;

FIG. 6 is a cross-sectional view of the sprinkler system of FIG. 5 at a later stage of the present invention;

FIG. 7 is a perspective view of an ice structure constructed in accordance with the present invention and having marginal protection means associated therewith;

FIG. 8 is a graph displaying the temperature versus depth which is typical in the Beaufort Sea during the summer;

FIG. 9 is a perspective view of an ice mass after partial melting;

FIG. 10A is a cross-sectional view of an ice structure having one form of marginal protection in accordance with the present invention;

FIG. 10B is a cross-sectional view of an ice structure having another form of marginal protection in accordance with the present invention;

FIG. 11 is a graph displaying temperature of maximum density and of freezing point versus salinity of water;

FIG. 12 is a perspective view, partly in section, of one type of insulative barrier which may be used in the present invention; and

FIG. 13 is a perspective view, partly in section, of another type of insulative barrier which may be used in the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In constructing an ice island, a base having the desired surface area, e.g., about one acre or greater, is first selected. This base, which will normally be a relatively flat, thin sheet of ice, e.g., five feet thick, may be an ice floe or it may be part of the fast ice mass. If an ice floe is used, a single floe having the desired surface area is preferred, but if such a floe is unavailable, several floes may be grouped and frozen together to form the base. The floe or floes will likely have to be pushed or towed to the desired location. If towed, a gridlike means **11** (FIG. 1) made of reinforcing steel or the like is positioned on floe **10** and water pumped or sprayed onto floe **10** to freeze means **11** in place. A towline **12** from vessel **13** is connected to means **11** so that floe **10** can be towed to position. The means **11** is preferably left in place to provide reinforcement of the base as will be discussed in more detail below.

When floe **10** is in position, it is anchored to the marine bottom by regular mooring lines having anchors thereon or by other suitable anchoring techniques. One such technique is the same as that shown in FIG. 2 wherein the base is formed from fast ice which overlies the desired location of the island. Referring more particularly to FIG. 2, the desired areal extent of base **22** is first marked off (as represented by dotted line **23**) on fast ice **20** which is frozen to shore **21**. If it is necessary to provide a means for maintaining the island in the desired location during construction, other than that provided by attachment of the ice to the shore, holes are drilled or otherwise provided through base **22** and pilings **25** are passed through these holes and are drilled, driven, or otherwise affixed into the marine bottom. By circulating refrigerant through the piles, they can be frozen into the marine bottom to increase resistance to lateral movement of the structure. Three pilings **25** are illustrated but the actual number required will be determined by engineering considerations, e.g., size and strength of the base, etc. These pilings not only serve to keep the island in place while it is being constructed, but also add additional support to the island once it is completed.

With base **10** or **22** in place, the construction of the island, itself, can commence. In some instances, the base may be strong enough, as is, to allow construction of the island. Preferably, however, reinforcing will be provided for the base to add strength thereto. This reinforcing also provides added weight to the base which aids in preventing the island from tipping during construction. Techniques similar to those employed in reinforcing concrete can be used. A preferred reinforcing arrangement is shown in FIG. 3 wherein lengths **27** of reinforcing steel radiate outward from the center of base **10** or **22** and are connected together by cross lengths **28**. Any reinforcing material, e.g., steel rods, pipe, cable, mesh, fiber, etc., can be used as the situation dictates. Discarded drill pipe is especially attractive and can be assembled to maintain fluid communication between lengths of pipe so a refrigerant can be circulated therethrough, as will be discussed more fully below.

Since ice will normally slip or slide on fine-grained, marine bottom sediments under the influence of pressure from the ice pack or moving floes, it may be necessary to provide some means for preventing the ice island, once formed, from slipping on the bottom, especially if piles **25** are not employed. One such means involves laying a layer of coarse gravel and rock **32** (FIG. 4) on the marine bottom underlying the base **22**. Another means is to implant spaced lengths **31** of pipe (only a few shown in FIG. 4) through base **22** so they extend a substantial distance below the base and will act as "spikes" when the bottom of the island engages the marine bottom. Still another means is to "freeze" the island to the bottom with refrigeration, as will be more fully described below.

With base **10** or **22** completed, ice is next accumulated on the base to actually form the island. In the present invention, it is contemplated that the building of the island will take place during the "winter" season of the year so that ambient temperatures are sufficiently below the freezing point of water. For example, the average mean temperature for areas overlying the Arctic Shelf from around the first of Dec. to the 15th of Mar. is about −15°F., with subfreezing temperature extending from Sept. to June. Construction of the island is carried out during this period so that accumulation of ice will not require refrigeration equipment to freeze ice on the island.

The accumulation of ice can be achieved in several different ways or combinations thereof. Preferably, a sprinkler system is provided to allow water to be sprayed onto the base. By spraying fine drops of water through the frigid air, freezing is significantly enhanced

and rapid accumulation of ice can take place. A typical sprinkler system **40** is illustrated in FIGS. **5** and **6**. Pump **41** is positioned on fast ice **20** and has intake **42** extending through ice **20** to the underlying water. Outlet **43** of pump **41** is connected to the interior of jacket **44** which is anchored in a vertical position on fast ice **20** by support **45**. Jacket **44** is closed at its upper end and open at its lower end. Standpipe **46** extends upward through the lower end of jacket **44** and is connected to a manifold **47** of piping which extends over the surface of base **22**. A seal means **48** is provided in jacket **44** to allow sliding movement between the seal and standpipe **46** while at the same time sealing the lower end of the annulus between jacket **44** and standpipe **46**. A plurality of outlet pipes **49** are connected to manifold **47** and each has a rotating sprinkler head **50** at the upper end thereof. The pipes **49** are strategically spaced on base **22** so that when the sprinkler system is in operation, water will be sprayed in such a manner to provide substantially equal accumulation of ice on the base. A typical pattern is represented by the dotted lines **30** (FIG. **3**). In the sprinkler system illustrated, other connecting means could be used in place of the jacket and sliding seal to connect the pump outlet with the standpipe, e.g., a length of flexible hose.

To prevent the water from freezing in the system, the piping is insulated where exposed to subfreezing temperatures, as required. Further, sprinkler heads **50** are preferably coated with or made of nonsticking material, e.g., polytetrafluoroethylene, so that the centrifugal force of the rotating heads will sling off the ice as the water is exposed to the air. Still further, heating means (not shown), e.g., circulating hot fluids or electrical heating, can be provided at each sprinkler head and at jacket **44** to prevent water from freezing prematurely. Further, a small pipe (not shown) is concentrically positioned throughout the piping of the system through which an antifreezing mixture, e.g., methanol-water, may be circulated to prevent freezing or to thaw any ice that may form in the pipes.

In operation, pump **41** pumps water into jacket **44** where it fills the annulus above seal **48** and overflows into standpipe **46**. The water flows from standpipe **46**, into manifold **47**, through outlet pipes **49**, and out sprinkler heads **50**. As the ice formed from the sprayed water accumulates, base **22** will begin to sink under the added weight. Standpipe **46**, being slidable through seal **48**, will allow manifold **47** and outlet pipes **49** to sink with base **22**. When ice nears the top of outlet pipes **49**, pump **41** is stopped and sprinkler heads **50** are removed so new lengths of pipe **46***a*, **46***b*, **49***a*, **49***b*, can be added. Heads **50** are replaced and operation is resumed. Just before pumping is ceased, all water may be pumped out of the system to prevent freezing while the lengths of pipe are added. When ice floe **10** is used as the base, pump **41** would be mounted adjacent the floe on an anchored barge or the like.

Another accumulation technique is merely flooding the base with water and allowing it to freeze. It must be remembered, however, that there is a great deal of localized brine concentration when salt water is frozen. This leads to brine inclusions and weakness in the ice, plus a tendency for the ice to melt at a slightly lower temperature than fresh water ice. In accumulating large quantities of ice by flooding or by spraying sea water through the air, the concentrated brine produced by the freezing process cannot escape downward to the sea in the normal fashion since the existing ice layers block rapid migration of brine. Therefore, in order to produce ice with low salt content, some means of producing brine flow from the accumulated ice must be provided.

Much of the excess brine can be removed from the ice by occasionally flooding the new ice with an excess of sea water. The sea water is about 3.5 per cent salt while the locally concentrated brine will be at much higher levels of salt content. Therefore, by flooding with an excess of sea water, the localized brine concentration in the new ice can be lowered to approximately 3.5 per cent, leaving the overall salt content of the accumulated ice at a level considerably below 3.5 per cent. In the flooding process of ice accumulation, the excess sea water is added periodically, e.g., every hour or so, allowing the concentrated brine to spill out onto the ice pack surrounding the island. In the spraying process of ice accumulation, the excess sea water is added (sprayed) periodically, e.g., every day or two, or more often if necessary.

Another useful method for inducing brine flow is to adjust the spraying rate so that all of the water does not freeze, leaving a small amount to run off into the sea. The granular accumulation of ice pellets is porous enough to allow the excess sea water to flow down through the top of the island and out at the sides onto the surrounding ice pack or into the sea water by gravity drainage, forcing out before it the concentrated brine located internally in the island structure as a result of the freezing process.

Although sea water will likely have to be used due to availability, it should be recognized that fresh water is preferred since it has a higher freezing/melting point than salt water and forms stronger ice.

In some instances, the depth of water may be too great to allow an ice island having the necessary height to be formed by means of spraying or flooding during the time available. In these instances, ice, itself, may be accumulated rather than freezing water to form the ice. This can be carried out in several ways. One way utilizes an ice crusher which is mounted on a barge if base **10** is surrounded by open water or on a mobile carrier if base **22** is surrounded by fast ice. Ice floes or pack ice is fed to the crusher (not shown) from which it is broken up and blown or otherwise spread onto base **10** or **22**.

Another way to accumulate ice is to pull ice floes or blocks of ice **35** which have been "mined" from surrounding sea surface onto the base. A winch **33** (FIG. **4**) which is repositioned during accumulation is mounted on the base for this purpose. A gridlike anchor, such as means **11** in FIG. **1**, is frozen into each floe or block to secure winch line **34** thereto. The added ice is distributed on base **10** or **22** in such a way as to prevent the base from breaking up. A somewhat higher, uniform loading is normally provided near the edge of base **10** or **22** than that in the middle. Water is periodically flooded into the cracks between blocks of ice and allowed to freeze to "weld" the blocks together. Also, reinforcing material may overlap adjacent blocks for added strength.

Further, it is desirable to distribute the ice during accumulation in such a way as to provide the island with sloping sides (FIG. **5**). Sprinkler heads **50** can be adjusted during accumulation to achieve this result if a sprinkler system is used. This is done in order to pre-

vent tensile forces from developing in the ice mass. If the part of the ice above the waterline is allowed to project (overhang) beyond the lower part of the ice mass, there will be a tendency for this part of the ice to crack and fall off (spall off) into the sea. Thus, it is desirable for the ice above the waterline to slope inward. Also, if the ice below the waterline is allowed to project for a substantial distance beyond the average profile, buoyant forces, due to the density difference between ice and water, will tend to cause tensile cracks to develop in the lower parts of the mass with resulting breakage of the mass and floating of the broken blocks to the surface. Thus, it is desirable that the ice below the waterline have a substantially vertical profile or a gentle inward slope. In some instances, however, it may be permissible for the sides to slope either slightly inward or outward by an amount dependent on the length of the slope and the combined strength of the natural ice mass plus that provided by any reinforcing material which may have been added. As mentioned above, reinforcing material can be used with any of the accumulation techniques and can be added periodically in any necessary pattern to the island as it is being formed.

As ice is added to base **10** or **22**, it will begin to sink under the added weight. Where base **22** is formed from the pack ice, it may be necessary to cut or notch the ice about the periphery at the beginning of the accumulation process. If piles **25** are used, it will be necessary to prevent the sides of the openings through base **10** or **22** from freezing thereto. This may be done in several ways. One way is to heat the piles, e.g., circulate warm water therethrough. Another way is to coat the piles with a nonsticking substance, e.g., polytetrafluoroethylene, prior to positioning them into the marine bottom. Still another, is to use enlarged openings **29** (FIGS. 3 and 4) about each pile and fill the annulus **29***a* between the opening and pile with a nonsticking, nonfreezing substance, e.g., oil, methanol, etc. For this purpose, the organic substances, e.g., oil, are preferable since they continue to float and, by periodically filling the annulus, continuous nonfreezing protection is provided around the piles as the island is being formed. If it becomes desirable to freeze the piles to the island after it is complete, this substance can easily be pumped out and replaced with water.

The island **15** (FIG. 7) will slowly take shape as more and more ice is added to the top until base **10** or **22** contacts the marine bottom. In order to insure that there is sufficient weight to overcome buoyancy factors and resist forces imposed by wind, waves, and drifting ice packs, the island should substantially extend above the waterline. It has been determined that the distance above the waterline should be approximately 10 per cent or more of that distance from the waterline to the marine bottom, depending on the overall density of the island which includes any reinforcing material or materials, e.g., sand, gravel, etc., added for stability. In any case, the island should extend far enough above the waterline to protect any drilling/production equipment **16** mounted thereon from damage by waves or ice and to allow for any surface melting that might occur in the summer.

The temperature of most of the water mass in the Arctic seas is near the freezing point the year round. In midsummer, however, the surface waters are warmed by the sun. A typical Aug. temperature profile in open water in the Beaufort Sea is shown in FIG. 8. In Sept., surface cooling begins, causing thermal convection to occur and the entire water mass approaches the freezing point temperature. At this time, new ice begins to form on the sea surface. Thus, protection from melting is required only during the brief summer period.

Melting may be conveniently considered in three zones: (1) in the subaerial zone (above the water), where heating is mainly due to direct absorption of radiant energy from the sun, (2) in the sub-marine zone (water-ice contact area) where heat is transferred from the water to the ice, and (3) in the bottom contact zone where heat is transferred from the sea floor to the ice.

Subaerial melting can be controlled or prevented by various well-known methods. One is by simply shading the surface from the sun. Another is to cover the surface with a layer of insulating (and reflecting) material such as polyurethane foam, commercial building insulation, etc. A third is to prevent accumulation of water on the surface. It is well known that surface melting of ice in the Arctic is very slow if a layer of water is not present. This is due to the fact that an ice surface reflects most of the sun's energy and very little heat is absorbed.

Sub-marine marginal melting or that melting of the island's perimeters due to heat transfer from the sea water is critical and must be controlled if the island is to be maintained for an extended period through the summer. The melting and consequential breakup of an ice island is similar to that of an iceberg and is illustrated in FIG. **9**. The perimeter of ice mass **55** will melt or erode as represented by cavities **56** due to heat transfer and action of the surrounding sea water. When tension cracks (dotted lines **57**) occur in ice mass **55**, large chunks **58** of ice will break away. If the island is to serve only as a temporary structure, e.g., for drilling a wildcat well, it may be preferable to simply build an island large enough to serve its purpose before it is finally consumed. However, when the island is to be of a permanent nature, some means must be provided to prevent melting and breakup of the island during the "summer" period. As will be discussed below, there are several methods or techniques of protecting the island.

One method of preventing marginal melting involves providing a layer of thermal insulating material extending from above the point of vigorous wave action to a depth where the water temperature is substantially at the melting point of the ice or to the marine bottom, if desired. It is only necessary that the insulation layer provide a sufficient thermal barrier. This is easily achieved because only a small temperature differential exists between ice and the water, e.g., about 5°F., and because most of the heat transfer is due to water motion past the ice surface induced by waves and currents which create a very thin boundary layer through which heat transfers rapidly. Thus, any barrier which restricts water motion near the ice, thus thickening the boundary layer, will greatly retard melting.

One such barrier consists of a layer of rocks **60** placed about the island as shown in FIG. **10A**. As set out above, the sides of the island **15A** may be shaped, as the island is being constructed, so that they normally slope inwardly from the bottom toward the center of the island. The layer of rock is deposited on this slope all the way around the island. The thickness of the rock layer and its angle of inclination is such that the inward stress component of the rock layer will equal or exceed the net horizontal stress in the main ice mass of the is-

land. This prevents radial creep of the ice and reduces the tendency of the island to crack and break up.

Another typical barrier means 61*a* (FIG. 12) consists of a layer of plastic foam **80**, e.g., one-quarter inch of polyurethane supported on one or both sides by tough plastic sheet material **81**, such as polyethylene or Mylar. The foamed insulating material is preferably of the "closed pore" type which retains its insulating properties when exposed to water.

Still another insulative barrier 61*b* (FIG. 13) is one of a "quilted" sandwich construction wherein foamed insulation **82** is trapped between two plastic sheets **83**, **84** which in turn are joined in a quilted pattern. The water-impervious, plastic sheet on both sides adds strength and protects the insulation from water. If holes develop in the plastic sheet only the cells with holes lose their insulating properties, the others remaining undamaged.

Where the barrier is a sheet of insulative material as described above, it may be positioned from a vessel sailing around the island in a manner similar to that used by commercial vessels in laying fish nets or it may be placed from the island by merely sliding it over the side. As shown in FIG. **10B**, sheet **61** of insulation is positioned about the sides of island **15B**. An anchoring or weight means **62**, e.g., chain, is provided at the lower end of sheet **61** to hold it in place while a "pucker" string **63** or cable is used at the upper end of the sheet to hold sheet **61** to the island. Since melting must be protected against only in the "summer," sheet **61** can be removed and repaired during the winter months.

Because the sea water temperature in some locations, even at the surface during summer, is generally only a few degrees above the ice melting point (see FIG. **8**), melting may be greatly inhibited by simply preventing access of sea water to the island mass. This may be accomplished by means of a plastic barrier similar to sheet **61** in FIG. **10B** except that insulation is not required. The plastic barrier, being impervious to water, prevents contact of the saline sea water with the ice. Melting of the surface of the island, a moderate amount of which is desirable in this case, produces relatively fresh water which drains off the island behind the barrier and flows out at the bottom, thereby preventing encroachment of the sea water behind the barrier from below. As noted from chart in FIG. **11**, the density of sea water is greater at temperatures below the freezing point, which gives the temperature of the Arctic seas a tendency to be at or near the freezing point at all depths. Also, since the sea surface temperature for most of the time is approximately 30°F., the ice behind the barrier in contact with "fresh" water will not melt, whereas it would melt if the barrier were not present.

Another method of preventing marginal melting of the island is to utilize the naturally occurring environmental conditions of the frigid sea. Since the Arctic sea water temperature at depths greater than about 20 feet is always at approximately the freezing point (FIG. **8**), melting of the island margin will be greatly inhibited if deep water is brought to the surface near the island. This is done by means of a bubbler system **70** (FIG. **7**) wherein air is pumped from air source **71** through line **72** into submerged pipe **73** which surrounds the structure. Pipe **73** is perforated to permit formation of bubbles which causes the density of water to decrease and allows the colder water to rise. Such bubbler systems have been used in more temperate environments to circulate "warm" water to the surface to prevent freezing around dam and bridge supports. Another system which may be used to circulate cold water to the surface is one which utilizes one or more large, electrically or hydraulically driven impellers **74** mounted on or near the marine bottom to "churn" the water around the island, thereby causing the cold water to rise.

Another method to protect the margins of the structure is to "capture" blocks of ice from pack ice or fast ice and secure them about the margins of the structure, e.g., block **78** (FIG. **7**) which is secured to structure **15** by cables **79**. This ice is allowed to melt as the temperature of the water rises but substantially delays contact of the water with the structure.

Still another method of preventing melting and breakup of the island is to refrigerate the island so the ice mass is always below freezing. This is done by converting the sprinkler system, if one is used to construct the island, into a refrigeration system. To convert system **40** to a refrigeration system, all water is pumped out of the system and sprinkler heads **50** are removed. Ambient air (during periods when the air is below the freezing temperature) is pumped through jacket **44**, standpipe **46**, and out pipes **49**. Heat of compression of this air is removed, if required by use of an after-cooler, using ambient air for cooling. If a positive refrigerant is circulated through the system, the outlets of pipes **49** are manifolded together (not shown) to provide a closed system for the refrigerant.

Further, holes **65** (only one shown in FIG. **10B**) can be drilled in the island after it is complete, and refrigeration pipes **66** installer therein. Frigid air or another refrigerant is circulated down inner pipe **66** and up the annulus **67** between pipe **66** and either cased or open hole **65**. The amount of cooling required to lower the temperature of the ice mass a few degrees is relatively low. Further, since the cooling need only be carried out a short period during the year and ambient air can be used as a refrigerant, the cost is relatively low. In addition to providing protection from melting, an important added advantage results from refrigeration. By maintaining the island temperature slightly below freezing, the island will be self-healing. That is, if any cracks occur in the island, upon being filled with water the cracks will quickly refreeze. This is due to the fact that the heat capacity of the large colder ice mass will easily supply the necessary sink for the small amount of heat which must be removed for the water in the crack to freeze.

No protection of the ice island from melting at the bottom is needed. A small amount of melting will normally occur soon after the island contacts the marine bottom but after steady-state conditions are reached, little melting will occur. Also, if refrigeration is used, such as pipes **66** in FIG. **10B**, the island can be frozen to the marine bottom which further prevents bottom melting.

It should be recognized that one or more of the above methods can be used singly or in combination to construct a particular ice island and to prevent marginal melting thereof.

It should also be recognized that, although this description of the invention applies to marine construction, parts of the invention may be practiced at onshore locations. For example, in drilling for petroleum in onshore Arctic areas, it is necessary to protect the soil permafrost from melting in the vicinity of the drill site.

This is commonly accomplished by providing a thick pad of gravel in the area to be protected. A much less expensive method of providing such protection from melting is to accumulate a pad of ice by the methods cited herein.

Still further, although the present invention illustrates the structure as being primarily for drilling and/or production of oil, it should be realized that structures constructed and maintained in accordance with the present invention may be put to other uses, e.g., docking facilities, storage areas, airstrips, etc.

What is claimed is:

1. The method of providing protection from marginal melting for an ice structure when the ambient temperature of the water surrounding said structure rises above the melting point of the ice forming said structure, said method comprising:

providing an insulative barrier around said structure to prevent contact of said water with said structure, said barrier extending from above the waterline to at least the depth at which the temperature of the water surrounding said structure is at or near the melting point of said ice forming said structure, said barrier comprising a sheet of plastic material having polyurethane foam on both sides thereof.

2. The method of providing protection from marginal melting for an ice structure when the ambient temperature of the water surrounding said structure rises above the melting point of the ice forming said structure, said method comprising:

positioning a sheet of water-impermeable material about said structure, said sheet extending from above the waterline to at least the depth at which the temperature of the water surrounding said structure is at or near the melting point of the ice forming said structure; and

allowing water resulting from the melting of the surface of said structure to flow from said surface in between said sheet and said structure.

3. The method of providing protection from marginal melting for an ice structure when the ambient temperature of the water surrounding said structure rises above the melting point of the ice forming said structure, said method comprising:

providing an insulative barrier around said structure to prevent contact of said water with said structure, said barrier extending from above the waterline to at least the depth at which the temperature of the water surrounding said structure is at or near the melting point of said ice forming said structure, said barrier comprising foamed insulation trapped between two plastic sheets joined together in a quilted pattern.

4. A method of constructing an ice structure at a desired offshore location in a frigid environment wherein a base of naturally occurring ice overlies said desired location, said method comprising:

accumulating ice on said base by spraying water onto said base and the subsequently formed ice whereby said base moves downward under the added weight of the accumulated ice;

periodically spraying water at a rate in excess to the amount that will freeze;

allowing the excess water to drain from the structure to aid in reducing the salinity of the ice;

continuing to accumulate ice on said base by spraying water thereon until sufficient ice has been accumulated on said base to form a structure which extends from the marine bottom to above the waterline; and

providing protection from marginal melting of said structure when the ambient temperature of the water surrounding said structure rises above the melting point of the ice forming said structure by placing a sheet of water-impermeable material around the periphery of said structure where said structure contacts the water.

5. A method of constructing an ice structure at a desired offshore location in a frigid environment wherein a base of naturally occurring ice overlies said desired location, said method comprising:

accumulating ice on said base by spraying water onto said base and the subsequently formed ice whereby said base moves downward under the added weight of the accumulated ice;

continuing to accumulate ice on said base by spraying water thereon until sufficient ice has been accumulated on said base to form a structure which extends from the marine bottom to above the waterline;

providing protection from marginal melting of said structure when the ambient temperature of the water surrounding said structure rises above the melting point of the ice forming said structure by placing a sheet of water-impermeable material about the sides of the structure; and

allowing water resulting from the melting of the surface of said structure to flow from said surface in between said sides of said structure and said sheet.

6. A method of constructing an ice structure at a desired offshore location in a frigid environment wherein a base of naturally occurring ice overlies said desired location, said method comprising:

accumulating ice on said base by spraying water onto said base and the subsequently formed ice whereby said base moved downward under the added weight of the accumulated ice;

continuing to accumulate ice on said base by spraying water thereon until sufficient ice has been accumulated on said base to form a structure which extends from the marine bottom to above the waterline; and

providing protection from marginal melting of said structure when the ambient temperature of the water surrounding said structure rises above the melting point of the ice forming said structure by placing a sheet of plastic material having polyurethane foam on both sides thereof around the periphery of said structure where said structure contacts the water.

7. A method of constructing an ice structure at a desired offshore location in a frigid environment wherein a base of naturally occurring ice overlies said desired location, said method comprising:

accumulating ice on said base by spraying water onto said base and the subsequently formed ice whereby said base moves downward under the added weight of the accumulated ice;

continuing to accumulate ice on said base by spraying water thereon until sufficient ice has been accumulated on said base to form a structure which extends from the marine bottom to above the waterline; and

providing protection from marginal melting of said structure when the ambient temperature of the water surrounding said structure rises above the melting point of the ice forming said structure by placing a sheet of water-impermeable material around the periphery of said structure where said structure contacts the water, said sheet of water-impermeable material being comprised of foam insulation trapped between two plastic sheets joined together in a quilted pattern.

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