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Backstrom

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[54] **STORING OF GAS UNDER PRESSURE**

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[58] **Field of Search** 60/.5, 39.02

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[57] **ABSTRACT**

A method of storing gas under pressure in a reservoir comprises applying a pressure of the gas in the reservoir to a surface of a body of liquid outside the reservoir so as to resist leakage of gas from the reservoir. The reservoir may be constituted by an underground cavity, a cavity near the ground or by a container within such a cavity. In one application use is made of a second cavity above the reservoir and a connection from the reservoir opening into the second cavity above an intermediate level, liquid being supplied to the second cavity up to the intermediate level. In another application the reservoir acts as the storage chamber of a compressed air power storage system connected to a water supply. In a third application especially intended for LPG or LNG the reservoir is constituted by a container within a cavity near or below the earth, the container having walls which are separated from the sides of the cavity by a space, the method including introducing a body of liquid comprising a material remaining plastic or liquid at the temperature of the gas to the said space. Also disclosed is apparatus for storing gas under pressure.

14 Claims, 4 Drawing Figures

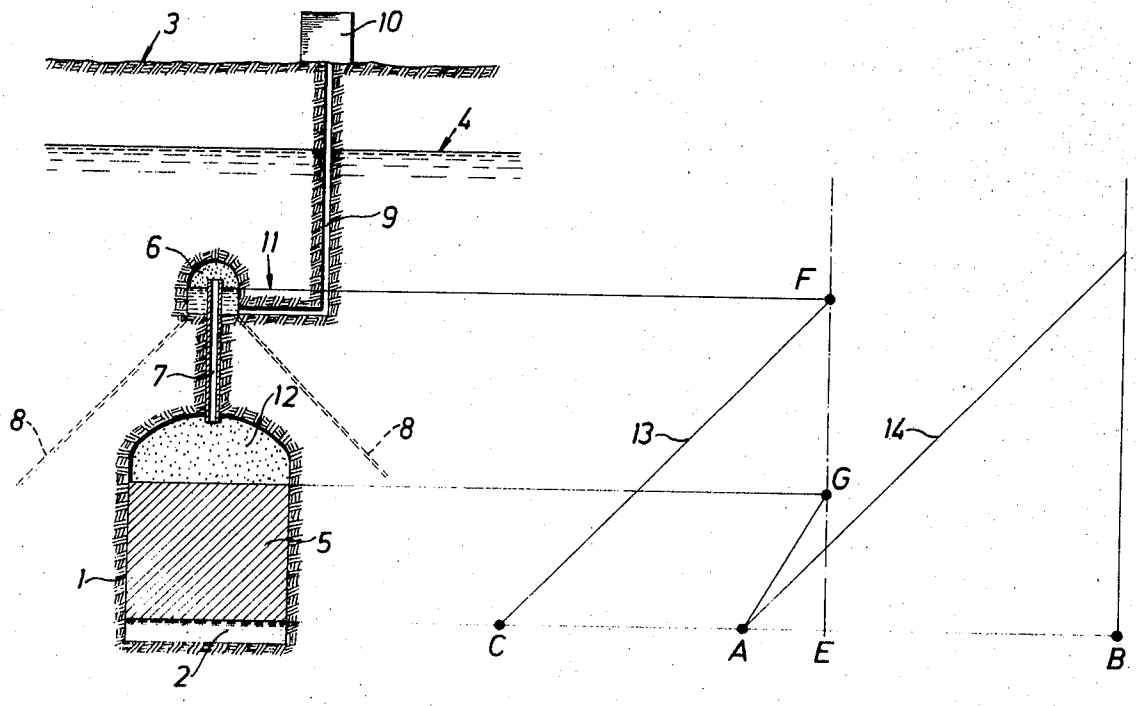


Fig. 1

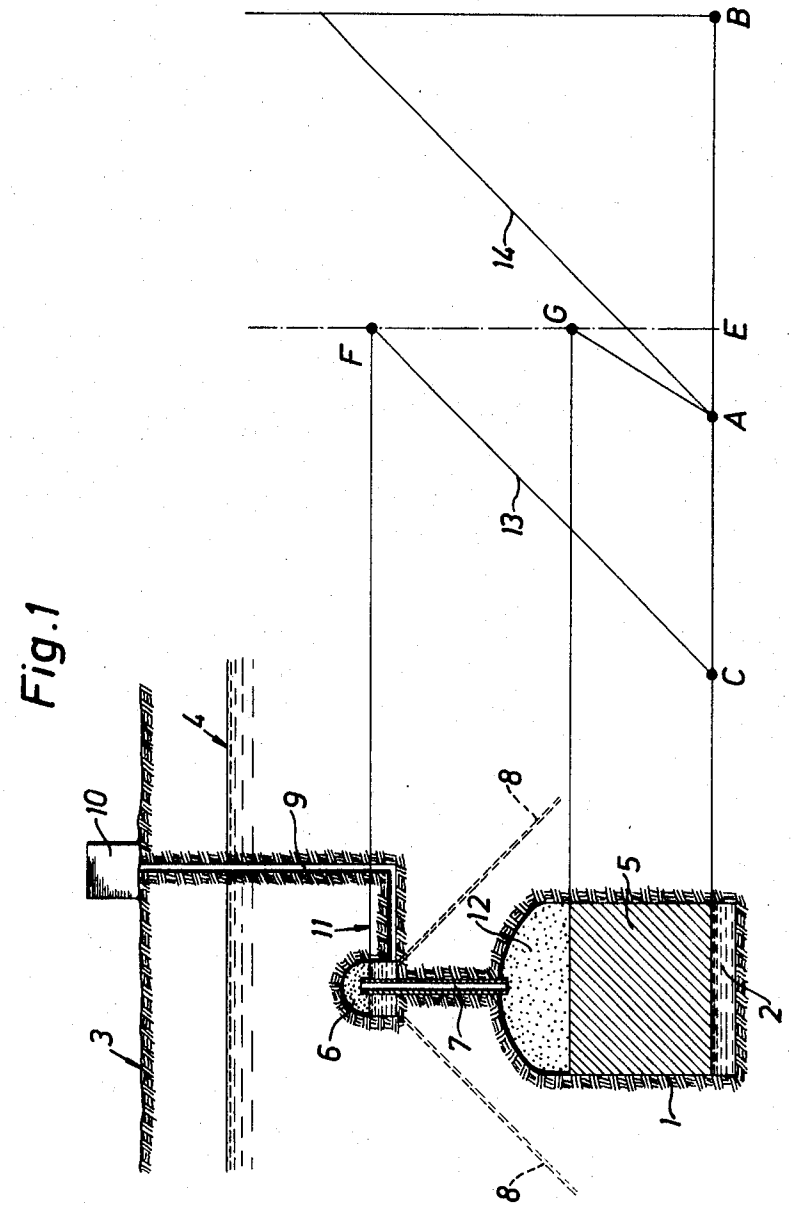


Fig. 2

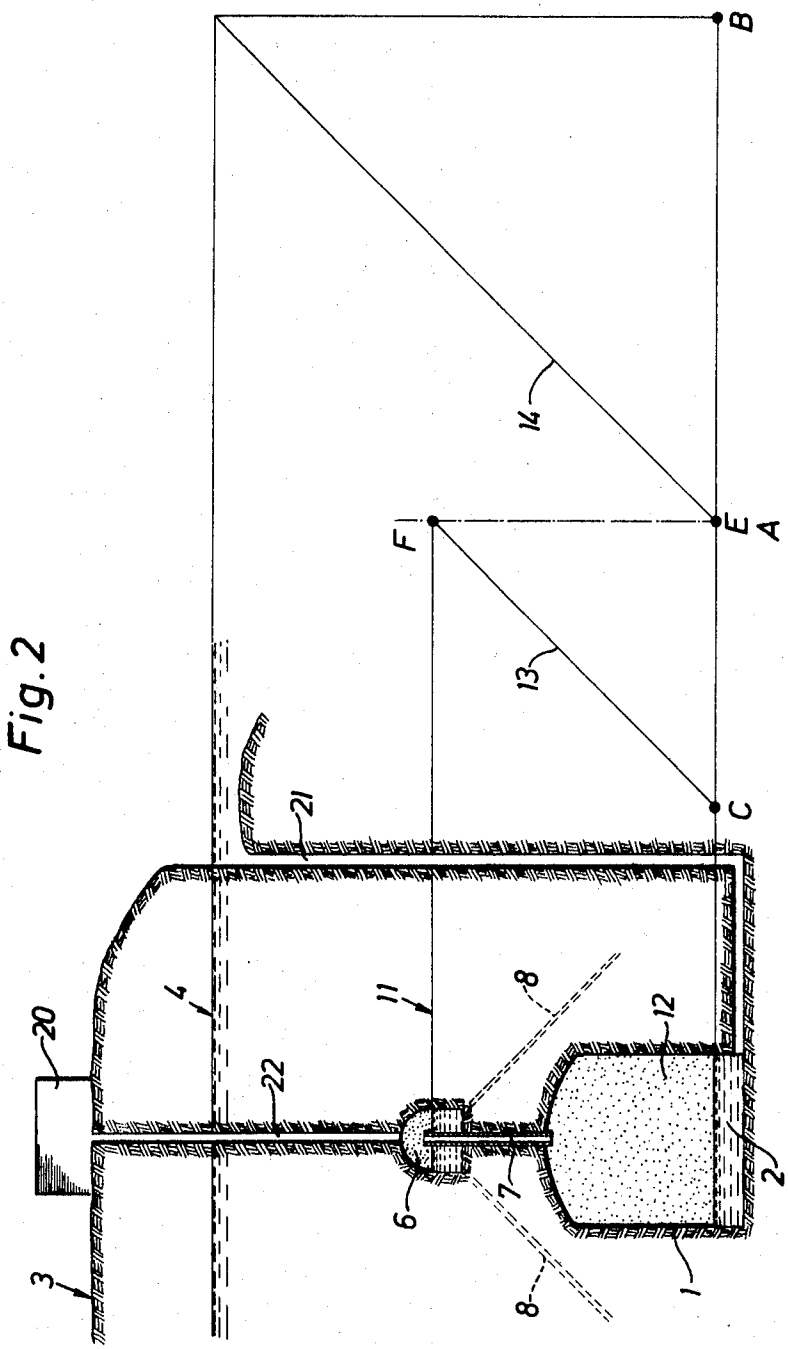


Fig. 3

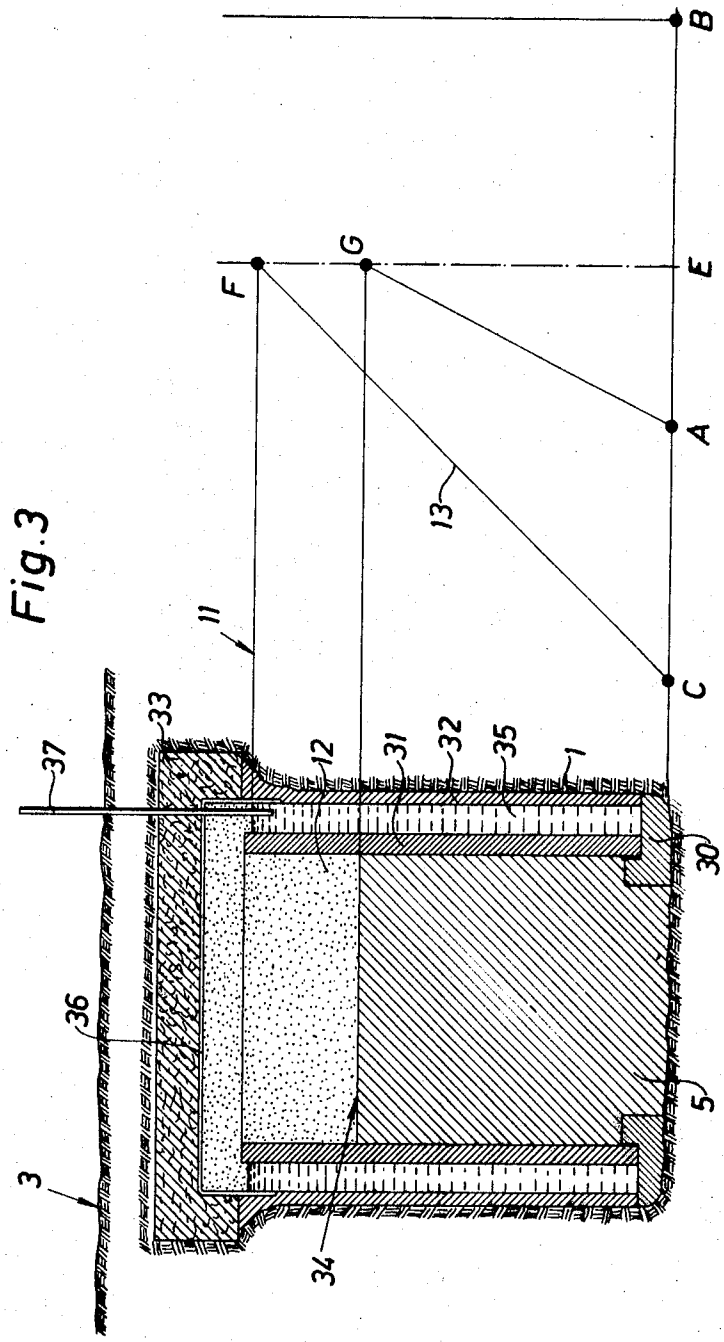
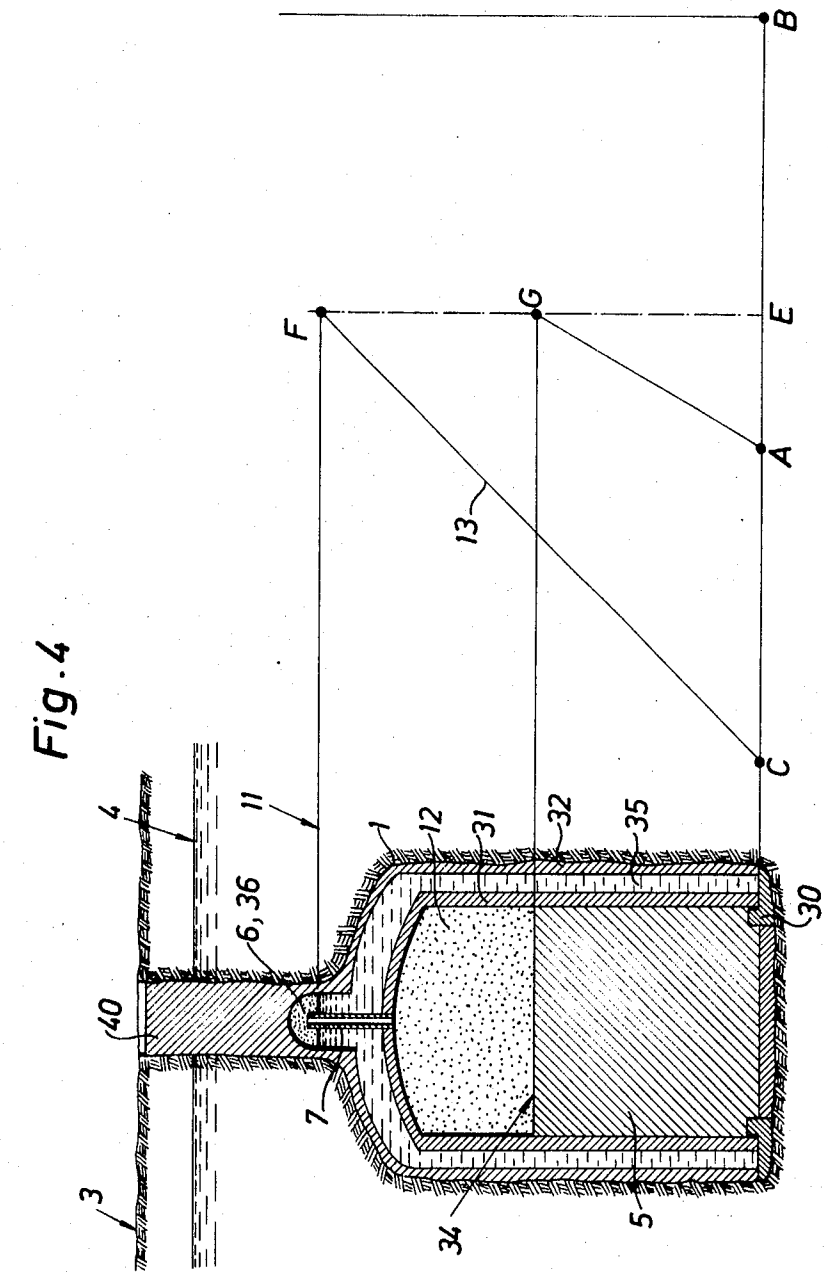


Fig. 4



STORING OF GAS UNDER PRESSURE

The present invention relates to apparatus and methods of storing a gas under pressure in a reservoir such as a ground reservoir, a rock cavity, a concrete or other type of container or vessel within a cavity, or the like.

There are previously known reservoirs for the storing of gases under pressure, for instance gases which are partly in a gaseous and partly in a liquefied state. Such reservoirs have as a rule been constructed at such a depth below the ground water level that the weight of the ground water column, i.e. the pressure of the ground water in the earth formation surrounding the reservoir, corresponds to or is greater than the gas pressure. In certain cases when the gas has a high pressure however, the reservoir would have to be constructed at such a deep level that the costs for the drilling and blasting, installing pipes etc. would be too high, and accordingly this previously known method of storing gases is not justified from an economical point of view.

Special problems have been met in the storing of air in connection with certain new types of power plants, i.e. compressed air power storage systems, comprising air reservoirs below the ground level. In such a power plant the machine equipment such as turbine, gnerator, compressors etc. is as a rule accommodated in a building above ground. The air in the reservoir rests on a bed of water, and the reservoir is connected via a shaft to an upper water storage, for instance the sea or a lake. Preferably such an air reservoir is constructed at a considerable depth, i.e. 150–500 metres, below the level of the water storage. A connection pipe for compressed air extends between the power plant and the air reservoir. When the reservoir is charged at night, the generator, functioning as a motor, powers the compressors, surplus energy from the distribution network then being utilized. The compressors fill the reservoir with compressed air, the reservoir thereby being emptied of water. The air should be given a pressure somewhat above the pressure corresponding to the weight of a water column between the upper sea level and the level of the water in the reservoir. When, on the contrary, the power plant produces electrical energy, compressed air from the reservoir is led to the combustion chambers, the compressors then being put out of action.

From an air reservoir of the kind described, air leakage will occur, provided that the air pressure exceeds the ground water pressure at the roof of the rock cavity. Such leakage will be directed upwards and sideways into a zone around the rock cavity.

Measurements and calculations have shown that there is a distinct difference, under otherwise unchanged conditions, as regards leakage of air from cavities in a dry and water-impregnated rock formation, respectively. The air leakage from a dry rock formation has, thus, been measured to be about 5 percent of the total reservoir volume per day, whereas the corresponding figure indicating leakage from a reservoir in a water-impregnated rock formation is substantially less.

The present invention has for its object to accomplish a method of storing a gas under pressure, for instance air or partly liquefied gas, possibly on a bed of a liquid, using simple means in order to avoid the abovementioned drawbacks, so that reliable storing and less risk of leakage is achieved.

SUMMARY OF THE INVENTION

In a method according to the present invention, the pressure of the gas in the reservoir is applied to a surface of a body of liquid outside the reservoir, and the pressure of the body of liquid is applied the outside wall of the reservoir to resist leakage of gas from the reservoir.

In one use of the invention the reservoir is constituted by an underground cavity, and the body of liquid is directed into the ground around the cavity.

In another use of the invention the reservoir is constituted by a container within an underground cavity, the container having walls which are separated from the sides of the cavity by a space, and the body of liquid is introduced into the said space.

Further features and advantages of the invention will be apparent from the description given below of some preferred embodiments thereof. The description refers to the accompanying schematic drawings in which:

FIG. 1 shows a reservoir in a rocky earth formation for the storing of partly liquefied gas under pressure;

FIG. 2 shows a compressed air storage power plant;

FIG. 3 shows a reservoir for the storing of cold gas; and

FIG. 4 shows a reservoir for the storing of a gas at a low temperature and a high pressure.

At the right of each Figure there is a diagram indicating the pressures at different levels in the reservoir and the surrounding earth formation.

Pipes for the filling and the removal of the stored product may be conventional and are omitted in the drawings. Corresponding parts have been given the same numerals.

Referring to FIG. 1, 1 denotes a rock cavity which constitutes a reservoir. The rock cavity is situated at a substantial depth below the ground level 3. The level of ground water present in the region is denoted 4. This level 4 has, however, no substantial importance for the utilization of the present invention. In the cavity, a petroleum product 5 such as a liquefied gas (LPG) is stored, above a bed of water 2.

At a distance above the cavity roof, a second cavity in the form of a pressure tunnel 6 has been excavated. The roof and the walls of this tunnel are made gas-tight, for instance by means of a layer of sheet metal, plastics, concrete or the like. The tunnel 6 is connected to the rock reservoir by a pipe 7. The pipe 7 projects above the bottom of the tunnel 6. A number of bore holes 8 extend obliquely downwards and outwards from the bottom of the tunnel, into the ground around the reservoir cavity 1. The pressure tunnel 6 is connected, via a line 9, to a pump 10 or to a supply of water under overpressure (not shown). The level of the water in the tunnel has been denoted 11. Above the level of the liquefied gas in the reservoir 1, in the connection pipe 7, and above the water level 11 in the tunnel 6, free gas 12 is present, the vapour pressure of which is determined by the physical characteristics of the actual gas at the prevailing temperature.

The vapour pressure of the gas stored in the reservoir 1 will thus act upon the liquid in the tunnel 6. The pressure of water at any point in the bore holes 8 will be the sum of the gas pressure acting on the surface 11 and the static head of the water corresponding to the vertical distance between the surface 11 and the point in question. Thus the water in the bore holes will all be at pres-

sures greater than the pressure of the gas, and the rock around the upper part of the reservoir will become saturated with water at pressures greater than that of the gas, and a state of equilibrium will be established. Consequently leakage of gas from the reservoir is counteracted. Leakage of liquid from the pressure tunnel **6** through the bore holes **8** is compensated by supplying water from time to time, for instance by means of the pump **10** or from a water supply at a higher level.

In the diagram at the right in FIG. **1**, vertical measurements show the vertical position of points being considered, while horizontal measurements show pressure, with zero at B, and increasing towards the left. The two sloping lines **13** and **14**, respectively, indicate the pressure of the water which is also under gas pressure, and the pressure of water in communication with the bed **2**. The distance A-B indicates the pressure at the bottom of the liquefied gas in the reservoir, whereas the distance E-B indicates the vapour pressure. The polygon C-A-G-F illustrates the pressure differential between the bore holes **8** and the reservoir **1**, at different levels. The distance B-E represents the pressure required from the pump or the high level water supply for introducing additional water into the pressure tunnel. As mentioned the necessary pipes for filling and removing the stored product in the rock reservoir are conventional and therefore not shown.

A second cavity positioned above the reservoir, especially a tunnel as just described, results in the advantage that it accomplishes a suitable distribution of strains in the surroundings of the reservoir, whereby the risk of tensile stress in the roof of the reservoir will be substantially reduced.

As removal of liquid leakage to the water bed of the reservoir or supplying new liquid to the second cavity will give rise to costs, possible water-containing cracks in the roof and the walls of the reservoir should be tightened or sealed. Such possible cracks can be located in a simple manner, by, before using the reservoir for its purpose, partly filling the second cavity with water, whereupon from the inside of the reservoir it can be ascertained where and to what extent leakage is present.

In FIG. **2** there is illustrated an application of the invention to a compressed air power storage system, so that the rock cavity **1** serves as an air reservoir. A power plant building **20** is constructed above ground, and contains a gas turbine, generator, compressors etc. The rock cavity **1** is connected by a pipe **21** to a store of water, for instance the sea or a lake. Above the rock cavity **1** there is excavated, as in FIG. **1**, a pressure tunnel **6**, which is connected to the reservoir by a pipe **7**. From the bottom of the tunnel a number of bore holes **8** lead to the ground around the reservoir as described above. Between the reservoir and the power plant there is a pipe **22** for air under pressure. At night the generator in the plant is driven as a motor powering the compressors, surplus energy from the electric distribution network then being utilized. The compressors fill the reservoir with air, water in the reservoir then being displaced. In the daytime, when electrical energy is required, such energy is produced in the power plant, air being permitted to flow from the reservoir into the combustion chambers of the turbine. The water level in the reservoir will then rise, so that firstly the whole reservoir is filled, whereupon, if desired or necessary, water is also supplied to the pressure tunnel **6**. Such filling of the tunnel is permitted until the water level has risen to the upper end of the pipe **7**.

When the reservoir is again charged with air, the increased pressure of the compressed air will act upon the liquid in the pressure tunnel, and this liquid will be forced via the bore holes **8** into the surrounding ground, so as to create the necessary sealing of the area around the air reservoir. The liquid in the tunnel **6** is thus depleted. At the end of the next period of power production the tunnel is automatically refilled as described above. This is achieved without the use of special equipment for introducing water into the tunnel. The tunnel is preferably provided with means for remote indication of the water level.

FIG. **2** also includes a diagram showing the pressure differential at different levels (C-A-F), and the desired air pressure in the reservoir (A-B).

If all of the air stored in the reservoir is not utilized for powering the turbines, sufficient refilling of water in the pressure tunnel will not take place. In this case, water can be supplied to the tunnel by means of a high pressure pump or by introducing water from a high level water supply.

FIG. **3** shows a reservoir intended for the storing of a cold gas which is partly liquefied. In a rock or earth formation there is excavated a cylindrical cavity **1**, in which a concrete cylinder **31** is cast. This cylinder is movably supported on an annular foundation **30**. When the cylinder is cast, the cavity walls are provided with a concrete lining **32**, and a free space **35** is formed between the cylinder and the lining. This free space is filled with a liquid capable of transmitting pressure to the walls of the cylinder. The material used as this liquid is one which remains plastic or liquid at the temperature of the liquefied gas. Examples of such liquids are bitumen or other petroleum or mineral oil products. The reservoir is covered by a ceiling **33**, which is thermally insulated and provided on its underside with a lining of metal sheet **36**. This lining extends downwards at its edges to below the level of the liquid in the space **35** in order to obtain a gas-tight seal.

In the reservoir there is stored a liquefied gas **5** having its surface at **34**. Thereabove free gas **12** is present, the vapour pressure of which acts upon the surface **11** of the liquid in the space **35**, with the consequence that the pressure on the outside of the concrete cylinder will always be greater than the internal gas pressure. Liquid in the space **35** is refilled via a pipe **37**. The level of liquid under pressure may be controlled by means of a level indicator, and delivery of liquid may take place by means of a high pressure pump. At the right of FIG. **3** the pressure conditions are shown. The sloping line **13** represents the outer pressure for the liquid in the space **35**, E-B the vapour pressure of the free gas, A-B the internal gas pressure at the bottom of the vessel, and the polygon C-A-G-F the resultant pressure differential on the concrete cylinder.

If desired, the concrete cylinder may be provided with an inner ceiling. Then the gas pressure can be brought to act upon the liquid in the space **35**, for instance by means of openings or ports provided in the cylinder or the said ceiling. This is illustrated by FIG. **4**.

FIG. **4** shows a reservoir for the storing of a gas at low temperature and a high pressure. In a cavity **1** exacvated in a rock formation there is constructed a container **31** provided with a roof and permitted to per-

form expansion and contraction movements on a foundation **30**. The walls of the cavity and the roof are stiffened by means of concrete or other type of layers **32**. In the space between the said layers and the container walls and the roof there is a space **35** which is filled with a liquid such as bitumen having the purpose to transmit pressure to the container. A connection pipe **7** is passed through an opening in the roof of the vessel and ends in a chamber **6** which is sealed by means of a metal or other type of sheeting **36**. The gas **12** stored in the container communicates with the said chamber above the liquid level **11**. A plug **40**, for instance made of concrete, seals the space above the said chamber, the height and structure of the plug being chosen to suit the designed gas pressure. The pressure conditions are shown at the right of FIG. **4**. The pressure differential acting inwards against the container at different levels is represented by the polygon C-A-G-F and the maximum pressure directed outwards towards the cavity walls is represented by the distance C-B.

Frozen ground water is likely to be present in the region of the reservoir, because the temperature of the ground will approximate to that in the reservoir. In particular water will freeze in any cracks that may be present in the rocky earth formation surrounding the reservoir. Consequently, despite the high pressures that will possibly occur in the reservoir, the liquid in the space **35** will not leak out of the space in an uncontrolled manner.

I claim:

1. A method of storing gas under pressure in a reservoir having a wall which is not reliably gas-tight, comprising: applying the pressure of the gas in the reservoir to a free surface of a body of liquid outside the reservoir, the free surface being at about the same or a higher level than the top portion of the reservoir wall, and applying the pressure of the body of liquid to said wall from outside said wall to resist leakage of gas from the reservoir.

2. A method according to claim **1**, applied to a reservoir constituted by an underground cavity.

3. A method according to claim **1**, applied to the reservoir constituted by an underground cavity, in which the body of liquid is directed into the ground around the cavity.

4. A method according to claim **1**, wherein a second cavity above the reservoir is provided, a connection is provided from the reservoir which opens into the second cavity above an intermediate level, and passages are provided leading from the second cavity from below the intermediate level into the ground around the reservoir, the method including supplying liquid to the second cavity up to the intermediate level.

5. A method of storing air under pressure in a reservoir acting as an underground storage chamber of a compressed air power storage system comprising the steps of applying the pressure of the air in the reservoir to a surface of a body of liquid in a second cavity above the reservoir by means of a connection from the reservoir opening into the second cavity above an intermediate level, and directing liquid from the second cavity from below the intermediate level into the ground around the reservoir, the method further including supplying liquid to the second cavity up to the intermediate level.

6. A method according to claim **5**, in which the reservoir is connected to a water supply, the method including forcing air into the reservoir, and later receiving air from the reservoir into a power plant, thus permitting water to enter and fill the reservoir and also to enter the second cavity and to serve as the body of liquid.

7. A method of storing gas under pressure in a reservoir constituted by a container within an underground cavity, the container having walls which are not reliably gas-tight and which are separated from the sides of the cavity by a space, comprising the steps of introducing a body of liquid into the said space and applying the pressure of the gas in the reservoir to the surface of the body of liquid such that the pressure of the body of liquid being thereby applied to the walls of the container to thereby resist leakage of gas from the reservoir.

8. A method according to claim **7**, in which the gas is at sub atmospheric temperature and is at least partly liquefied, and said body of liquid is a material which remains plastic or liquid at the temperature of the gas.

9. Apparatus for storing gas under pressure, comprising a reservoir having a wall which is not reliably gas-tight, means for applying the pressure of gas in the reservoir to a free surface of a body of liquid outside the reservoir, the free surface being at about the same or a higher level than the top portion of the reservoir wall, and means for applying the pressurized liquid to said wall from outside said wall to resist leakage of gas from the reservoir.

10. Apparatus according to claim **9**, in which the reservoir is constituted by an underground cavity, the apparatus including a second cavity above the reservoir, a connection from the reservoir which opens into the second cavity above an intermediate level, and passages leading from the second cavity from below the intermediate level into the ground around the reservoir, the walls and the roof of the second cavity being sealed by means of a concrete layer.

11. Apparatus according to claim **9** in which the reservoir is constituted by a container within an at least partly underground cavity, the container having walls which are separated from the sides of the cavity by a space, said space being filled with a liquid, the top of the container being constituted by the roof of the cavity, and said roof being lined by a gas-tight ceiling having edges which extend downwards into the liquid in the space.

12. Apparatus according to claim **11**, wherein said liquid is at least one of a petroleum product or mineral oil product.

13. Apparatus according to claim **11**, wherein said liquid is bitumen.

14. A method according to claim **1**, applied to a reservoir constituted by a container within an underground cavity.

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