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EUROPEAN QUALIFYING EXAMINATION 2000

PAPER A
ELECTRICITY / MECHANICS

THIS PAPER COMPRISES:

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CLIENTS' LETTER

Our company is a natural gas supply company that exploits gas fields both on land and offshore, and stores recovered natural gas prior to supplying it to end users. We also supply the gas to the end users via a distribution network.

As the quantity of gas on the mainland is decreasing, we become more and more dependent on the offshore supplies. This generates a number of problems as most offshore production sites are not directly connected to our gas preparation and distribution installations. Typically, the gas is transported to the mainland by means of specialised tankers, which obliges us to have large capacity storage facilities on land.

One of our research people, Mr. I. N. Ventor has been investigating the use of cavities within salt formations for this purpose. We enclose a copy of his internal report. As Mr. Ventor mentions in this report, it is known to use salt formations for the storage of natural gas. It is also generally known that natural gas deposits are often found inside salt formations. Document DI, which was published some years ago, also describes an example of the use of such cavities for the storage of energy.

In our opinion Mr. Ventor sets out some valuable proposals in his report. Please would you prepare a patent application relating to Mr. Ventor's proposals.

The National Gas Company

Internal Report Nr. 20000405

Date: 5 April 2000

Author: I. N. Ventor

Title: Energy Storage Systems

I have been investigating energy storage systems, and in particular the storage of natural gas in underground cavities in salt formations. It is already known to use such cavities for storing natural gas. Cavities can be made in salt formations by dissolving the salt using water and then removing the resulting brine. As the salt formations are impermeable to natural gas and offer a good resistance to internal pressure it is possible to store natural gas under pressure in these cavities.

In a known system, gas is pumped under pressure into the underground cavities. A pump can be used to compress the gas when filling the cavity. Some of the energy used in this process can be recovered by a turbine when the gas is subsequently released from the cavity. Electricity generated by a generator coupled to the turbine can be supplied to the electricity network.

It is normally necessary to use large cavities to permit storage of considerable quantities of natural gas. However, with very large cavities, no significant pressure builds up within the cavity when a relatively small quantity of gas is contained therein. In such a case, recovery of the natural gas becomes costly as it must be sucked out of the cavity.

I propose to improve the storage and recovery of natural gas and energy as described in the following.

Figures 1 and 2 illustrate examples of systems for storing and recovering energy in the form of pressurised natural gas.

Figure 3 illustrates a further example of a system for storing energy.

A first reservoir 1 is formed by an upper cavity in an underground salt formation 2 situated b earth layer 3. A second reservoir 5 is formed by a lower cavity located in the salt formation 2 bel first reservoir 1. A connecting bore 6 extends between the lower part of the first reservoir 1 and the lower part of the second reservoir 5.

Above ground, a pipe system 50 includes a supply line 54 from a natural gas supply 55, an inlet valve 51, an intermediate line 52, an outlet valve 53 and an outlet line 56 to a gas distribution network 11 that leads to end users. The intermediate line 52 is connected to an upper part of the second reservoir 5 via a line 18 formed as a borehole having a lining 20. The upper cavity is open to air 15 via a further line 17 formed as a borehole having a lining 19.

As can be seen in Figure 1, a fluid 23, which is more dense than and substantially immiscible (i.e. it will not mix) with the gas 21 to be stored, is provided in the lower portions of the first and second reservoirs 1 and 5 and the connecting bore 6. The difference between the levels 24 and of 25 of the more dense fluid 23 in the first and second reservoirs 1 and 5 is representative of the potential energy stored in the system that results from the difference in pressure between the gas 21 in the lines 52 and 18 and atmospheric pressure of the air 15 in the line 17.

The operation of the system of Figure 1 is as follows: In a static state as shown in Figure 1 the valves 51 and 53 are closed. If a supply of gas 55 is available at the inlet to the line 54 (e.g. because a gas tanker arrived), the inlet valve 51 is opened. The gas, which will have been pressurised for transport, flows through the lines 54, 52 and 18 into the second reservoir 5. The gas that is forced under pressure into the upper part of the second reservoir 5 causes at least some of the more dense fluid 23 to be displaced out of the second reservoir 5 and through the connecting bore 6 into the first reservoir 1. This causes the level 24 of the more dense fluid 23 to rise, increasing the potential energy stored in the system. After the gas tanker has been discharged the inlet valve 51 is closed.

When it is desired to recover the stored natural gas, for supply to the gas distribution ne outlet valve 53 is opened. The more dense fluid 23 then flows under the effect of gravity bac first reservoir 1 to the second reservoir 5. This causes the gas 21 to flow from the upper part of th second reservoir 5 via the lines 18, 52 and 56 to the gas distribution network 11.

When sufficient natural gas has been taken from the second reservoir 5, the return flow of the natural gas is interrupted by closing the outlet valve 53. The system will then again be in a static state.

Figure 2 illustrates another example of a system for storing and recovering natural gas. The system shown in Figure 2 is generally similar to that shown in Figure 1. However, in this example, a pump/ turbine unit 8 is located at ground level 7 above the first reservoir 1. The pump/turbine unit 8 has a shaft 10 connecting it to an electric generator/motor unit 13.

The generator/motor unit 13 is connected to an electricity network (not shown) and functions as both
(a) an electric motor to drive the turbine when supplied with electricity from the network, and
(b) a generator of electricity when driven by the turbine.

The pump/turbine unit 8 functions as both
(a) a pump for compressing gas when driven by the electric motor of the unit 13, and
(b) a turbine which receives and is rotated by compressed gas, this rotation being transmitted to the generator of the unit 13 to supply electricity.

The low pressure end of the pump/turbine unit 8 can be connected either to the gas distribution network 11 by means of a line 26 provided with a valve 27, or to the supply line 54 via a line 58 provided with a valve 59. The high pressure end of the pump/turbine unit 8 can be connected to the intermediate line 52 and the line 18 via a line 28 provided with a valve 29.

In a static situation as shown in Figure 2 the valves 27, 29, 51 and 53 are closed. If there [illegible] of natural gas available in the gas supply line 54, e.g. because a new charge of natural gas is fe[illegible] system by a gas tanker, the system can be operated in two different modes.

In a first mode of operation the inlet valve 51 is opened and the further operation is as described with respect to Figure 1. The gas thus stored in the second reservoir 5 can be subsequently recovered in two ways. Firstly, the gas can simply be recovered by opening the outlet valve 53, as explained with respect to Figure 1. Secondly, the gas can be recovered by opening the valves 27 and 29, whereby the pressurised gas flows through lines 18, 52 and 28, pump/turbine unit 8 and lines 26 and 56 to the gas distribution network 11. In this latter case, the turbine of the unit 8 can be driven to recover part of the pressure energy in the gas. The recovered energy can be supplied into the electricity network via the generator of unit 13.

In a second mode of operation, inlet valve 51 is not opened. Instead, the valves 59 and 29 are opened. The excess gas present in line 54 is thus fed to the second reservoir 5 through line 58, pump/turbine unit 8 and lines 28, 52 and 18. In this second mode of operation the unit 8 operates as a pump and the gas 21 can be fed to the second reservoir 5 under an increased pressure, thereby increasing the capacity of the reservoir 5. The recovery of the gas from reservoir 5 can be effected in two ways as described above with respect to the first mode of operating the system of Figure 2.

A system similar to that shown in Figure 2 can be used in a more general way for storing and recovering energy. An example of such a system is described with respect to Figure 3.

The underground part of the system shown in Figure 3 is the same as that shown in Figu that the first reservoir 1 is not open to atmosphere. The pump/turbine unit 8 is provided abov as in Figure 2. A line 26 is connected to the line 17 and a line 28 is connected to the line 18. The fluids used in the system are a first fluid 23 having a higher density and a second fluid 22 having a lower density. It is possible to use a liquid as the more dense, or heavier, fluid and a gas as the less dense, or lighter, fluid, or two liquids with different densities.

This system can be used for the storage of energy, for example, during periods when demand for electricity is low. This energy can be subsequently recovered when demand for electricity is high.

For the storage of energy the valves 27 and 29 are opened and the pump/turbine unit 8 is operated as a pump using energy from the electrical supply network. In this case, lighter fluid 22 from the upper reservoir 1 is forced into the lower reservoir 5 by the pump/turbine unit 8 via lines 17, 26, 28 and 18. As a result, the level 25 of the more dense fluid 23 in the lower reservoir 5 drops and the level 24 of the more dense fluid 23 in the upper reservoir 1 rises. In this way the electrical energy supplied to the pump/turbine unit 8 is converted into potential energy within the system, as represented by the increased difference between the levels 24 and 25 of the more dense fluid 23.

In order to recover the stored energy, the valves 27 and 29 are opened and the pump/turbine unit 8 is operated as a turbine and, under the effect of gravity, lighter fluid 22 present in the lower reservoir 5 is allowed to flow through lines 18 and 28, pump/turbine unit 8 and lines 26 and 17 to the upper reservoir 1. As a result, the level 24 of the more dense fluid 23 in the upper reservoir 1 drops and the level 25 of the more dense fluid 23 in the lower reservoir 5 rises. In this way potential energy stored within the system can be recovered, which energy is represented by the decrease in the difference between the levels 24 and 25 of the more dense fluid 23. The recovered potential energy is converted into electric energy by the pump/turbine unit 8 and associated generator of the unit 13 and is fed into the electricity network.

CLIENT'S DRAWINGS

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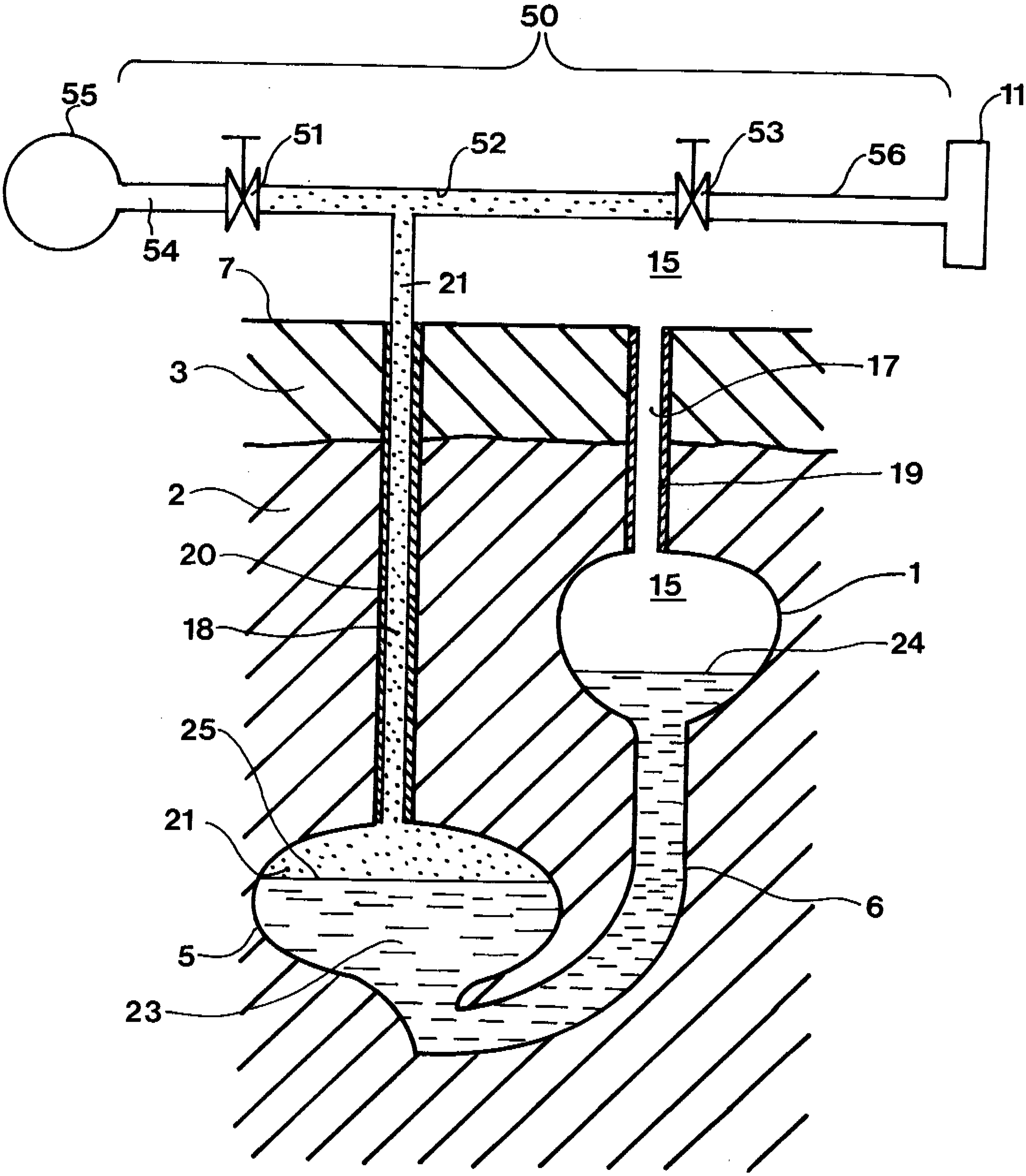

Fig. 1

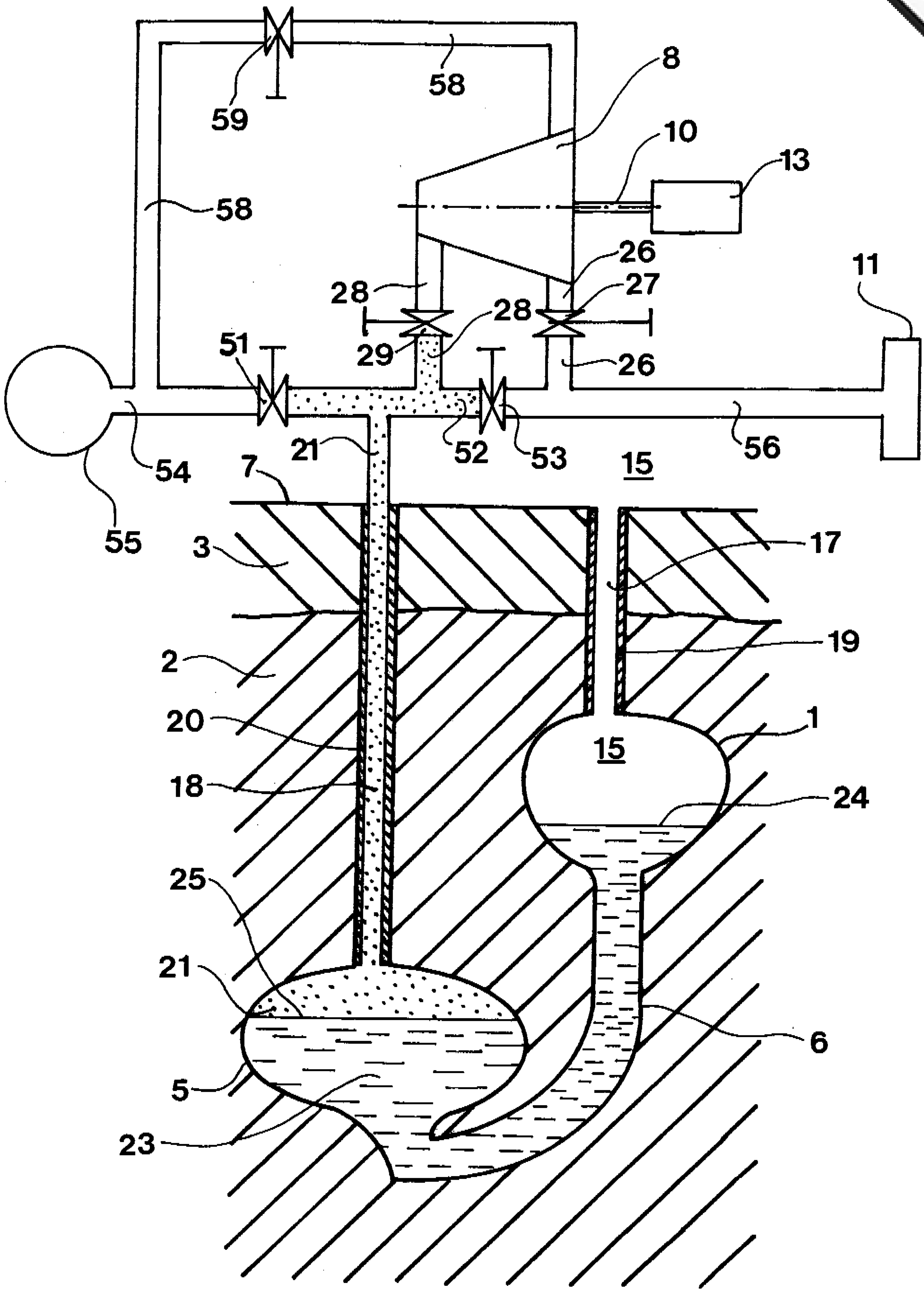
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Fig. 2

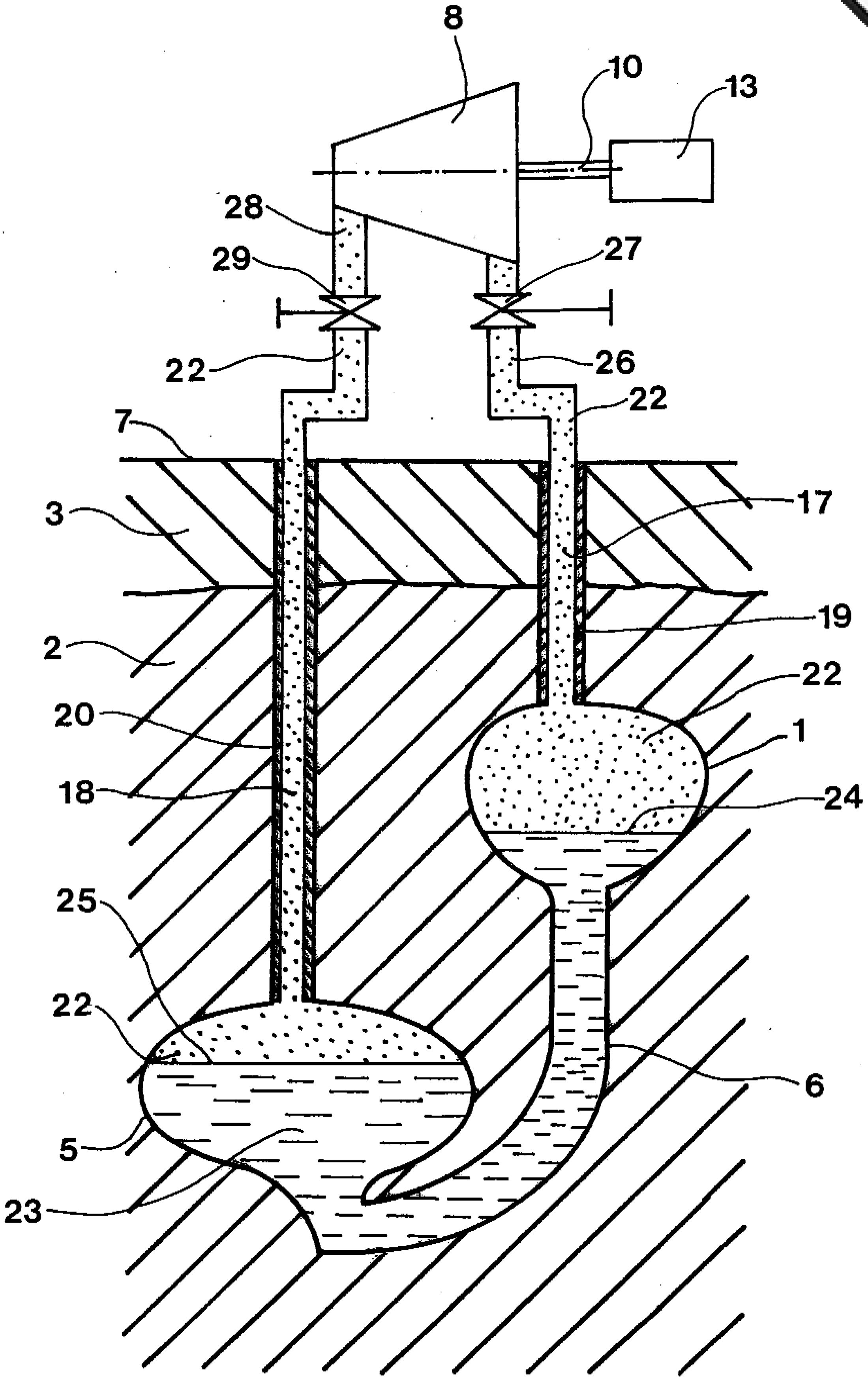

Fig. 3

DOCUMENT DI (State of the Art)

This invention relates to pumped energy storage systems.

So called pumped energy storage systems are designed to take surplus power from electrical power generating systems during low power demand or off-peak periods, store the power, and then recover it for use during peak power demand periods.

Known pumped storage systems are normally located above ground and include an upper reservoir and a lower reservoir. Conduits connect the upper reservoir to a power station and connect the power station to the lower reservoir. The power station includes an electrical power generating unit and a pumping unit. During heavy load periods, when additional electrical power is needed, water from the upper reservoir is directed to the power station to drive the power generating unit, with the discharge water being directed to the lower reservoir. During light load periods, when surplus electrical power is available, water from the lower reservoir is pumped back to the upper reservoir, to await a heavy load period when additional power will again be needed. This system is especially useful in mountainous regions where height differences are readily available and the construction of water reservoirs does not present too many difficulties.

In lowland regions, however, such height differences are not available or the height difference is insufficient to allow an efficient power recovery. It is therefore an object of the invention to provide a new and inexpensive pumped energy storage system which is not dependent upon the availability of surface height differences, but which can be applied in most lowland regions.

Other advantages and characteristics of the invention will become clear from the following description, reference being made to the annexed drawing.

Referring to the drawing, there is shown a first reservoir 4 and a second reservoir 8. As s Figure both the first and second reservoirs 4 and 8 are formed by respective cavities in a salt formation 12 under the surface of the ground. Such cavities may be obtained by supplying water desired locations in the salt formation, dissolving the salt to make salt brine, and then pumping the brine to the surface thus leaving the cavities. Thick salt deposits suitable for this purpose are quite prevalent in a number of regions with no mountains. It has been found that salt formations are quite impermeable to liquids and are essentially pressure stable.

The reservoirs 4 and 8 communicate with the atmosphere 22 via lines 20 and 24, respectively. As shown in the drawing, reservoir 4 is at a higher level than reservoir 8. Indeed reservoir 4 could also be a surface reservoir rather than an underground cavity as in the example of the drawing. The reservoir 4 contains a suitable liquid 16. Such liquid may be any liquid in which salt is insoluble, such as saturated salt brine or an oil-like liquid.

A chamber 28 is formed in the salt formation 12, at a location generally between the reservoirs 4 and 8 and near the level of the reservoir 8. A shaft 48 extends from the chamber 28 to ground level to provide access to the chamber 28. A reversible pump/turbine unit 32 contained in the chamber 28 is coupled by mechanical coupling 36 to a generator/motor unit 40. A conduit 44 extends from near the bottom of reservoir 4, through shaft 48 to the pump/turbine unit 32. A valve 52 controls the flow of liquid through the conduit 44. Another conduit 56 extends from the pump/turbine unit 32 to the lower part of reservoir 8. A valve 60 controls the flow of liquid between the pump/turbine unit 32 and the reservoir 8. The pump/turbine unit 32 can be a conventional power recovery pump-turbine. The generator/motor unit 40 can be conventional equipment capable of functioning as a generator to produce electricity when driven by an external power source, or as a motor when electricity is supplied to the unit. The generator/motor unit 40 is connected by an electric line 64 to an electricity network (not shown).

In operation, saturated brine 16 is supplied to reservoir 4 in sufficient quantity to allow p operation of the system. When electrical power is needed, valves 52 and 60 are opened so th brine 16 flows through conduit 44 to the pump/turbine unit 32 to drive the unit. The discharge br flows through conduit 56 into reservoir 8. The pump/turbine unit 32 in turn drives the generator/ motor unit 40 which produces electrical power that is supplied by electric line 64 to the electricity network (not shown). Brine 16 is directed to the pump/turbine unit 32 until either the demand for electrical power abates or all the liquid in the reservoir 4 has been supplied to the pump/turbine unit 32. As brine is discharged into reservoir 8, the air in the cavity space is forced out through line 24 to atmosphere.

When no electrical power is needed, and preferably during a low power demand period, the brine 16 in reservoir 8 is pumped back to reservoir 4. This is done by supplying electrical power via electric line 64 to the generator/motor unit 40 to drive the motor and thereby drive the pump/turbine unit 32. The unit 32 then pumps brine 16 from the reservoir 8 through conduits 56 and 44 back up to reservoir 4 where the brine will remain until power from the system is again needed.

DRAWING OF DOCUMENT DI (State of the Art)

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