

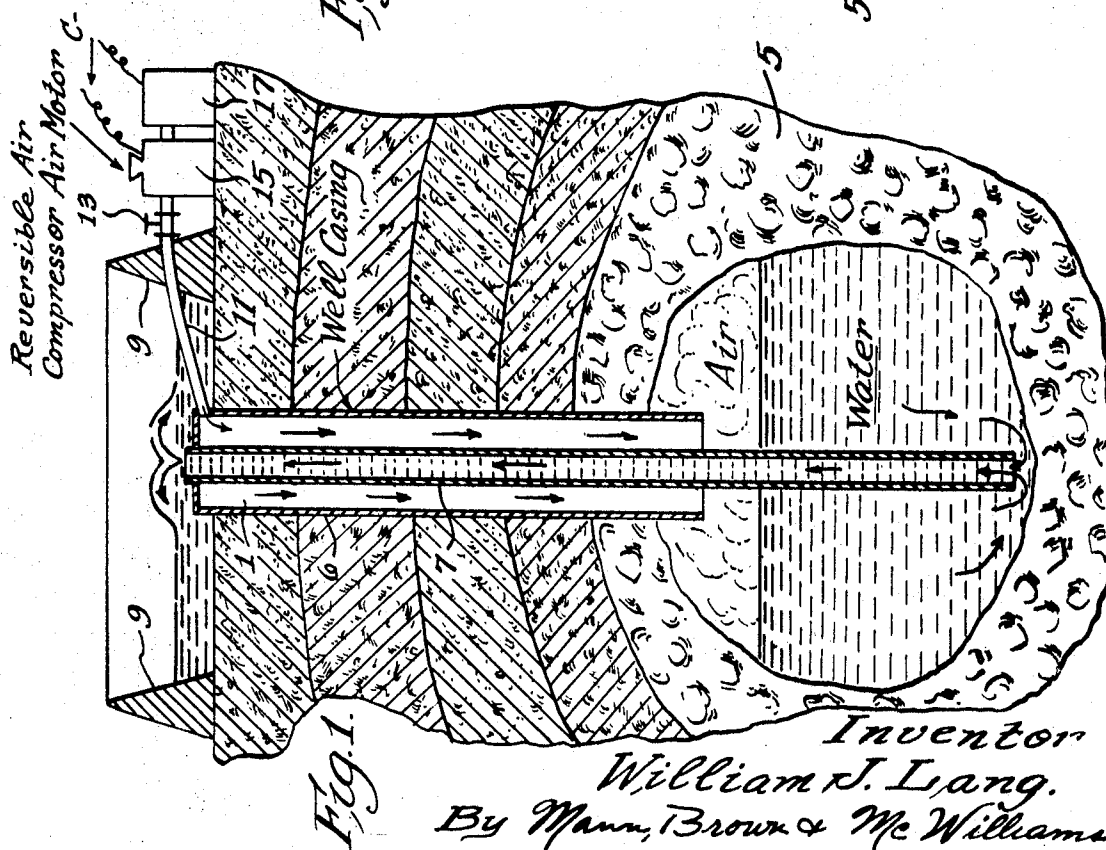
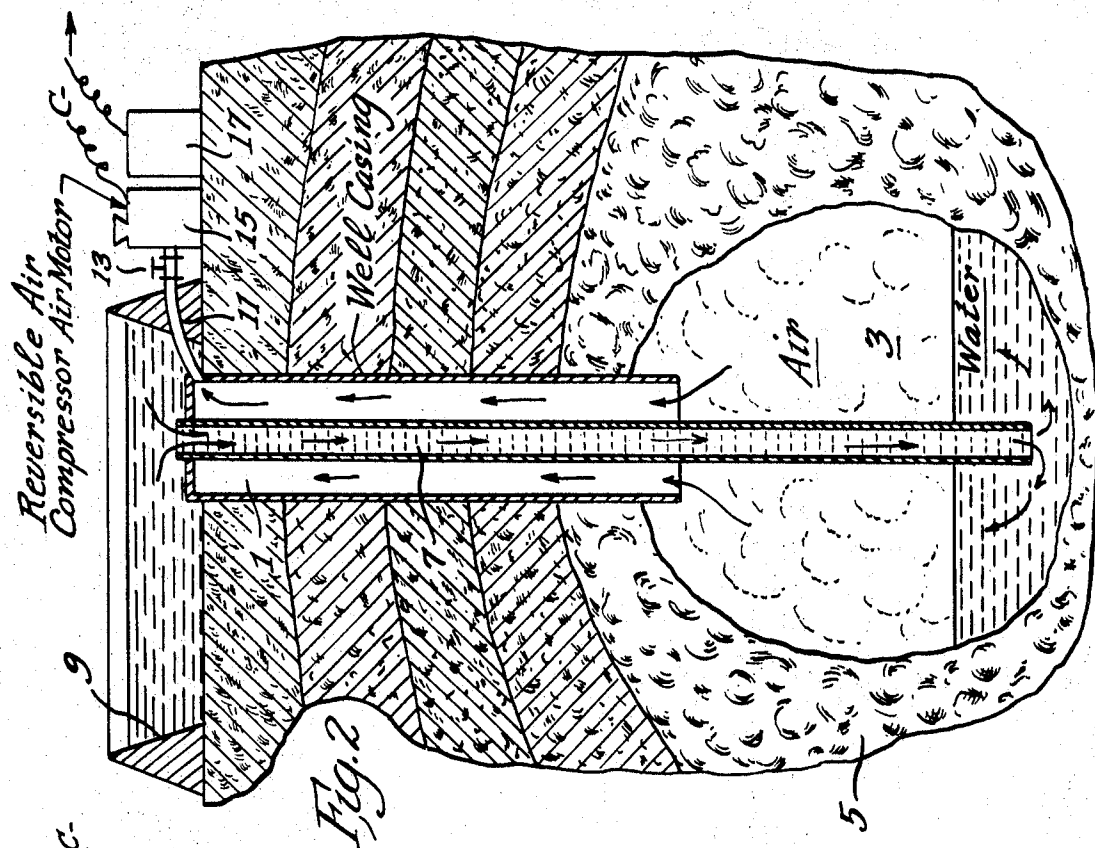
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METHOD AND APPARATUS FOR GENERATING POWER

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METHOD AND APPARATUS FOR GENERATING POWER

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2 Claims

ABSTRACT OF THE DISCLOSURE

Energy is stored during low load requirements of a power generating plant by using the excess power available to compress gas such as air and injecting it under high pressure into a subterranean salt or other gas impermeable cavity or reservoir. The cavity is in communication with a water reservoir at the surface of the ground so that the hydrostatic head of the reservoir is imposed on the gas in the cavity. When load requirements are high, gas is withdrawn from the subterranean cavity under the hydrostatic head of the water pressure and used to operate an air motor or other auxiliary prime mover which in turn drives generating equipment. The gas reservoir is maintained under substantially constant pressure.

BRIEF SUMMARY OF THE INVENTION

Pumped hydro-storage as a means to store energy for power generation during peak demands has become a well established practice. In accordance with this practice, the hydro-storage reservoir is constructed at a sufficient elevation above the power plant to provide the necessary head of water to drive turbines which motivate the electrical generators.

Another method for storing energy is to compress air by using excess electrical capacity during periods of low load requirement and inject it into a subterranean salt bed or dome and then use the air under superatmospheric pressure to drive generating equipment during high load demands. One of the drawbacks with the latter method is that as the air is withdrawn from the reservoir the pressure rapidly decreases so that a large amount of the stored air is unusable, thereby necessitating larger storage capacity than is necessary where all the gas is available; or the air must be stored under much higher pressure than would otherwise be required.

It is an object of this invention to provide energy storage in which the drawbacks of present hydro-storage and air storage are obviated, thereby considerably reducing the capital cost of providing the storage facility and effecting other economies.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is an elevational view illustrating the invention during the period when gas is being stored in the subterranean reservoir;

FIG. 2 is another elevational view of the invention illustrating the invention during the period when gas is being withdrawn from the subterranean reservoir to operate auxiliary air motors for operating electrical generating equipment.

DETAILED DESCRIPTION

In the drawing the numeral 1 indicates a well bore extending from the surface of the ground to a cavity 3 formed in a subterranean impermeable rock or salt formation 5. Cavity 3 may be formed either by mechanical mining operation or by solution extraction of the salt from the salt bed. The bore is cased with corrosion resistant casing 6 made of steel or other suitable material and cemented in place. A pipe 7 extends from the surface through well bore 1 to the bottom of the cavity 3. Aqueous

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reservoir 9 is constructed at the surface of the earth so that the upper end of pipe 7 opens into or is connected to the lower portion of the reservoir. The capacity of the water reservoir is preferably about the same as the gas reservoir although it may be larger or smaller. The volume of the gas cavern will depend on the requirements for auxiliary power.

The upper end of bore 1 is closed and connected by pipe line 11 controlled by valve 13 to a motor 15 operable on compressed air. I prefer to use a reversible air compressor-air motor so that the same facility can be used to inject compressed air into the subterranean cavity or storage reservoir. One such device, the rotary screw, which will serve as an air compressor and an air motor to drive the generator is described by Whitehouse, Counsel and Martinez in "Peaking Power With Air," Power Engineering, January 1968, pages 50 to 52. Other suitable air motors for driving electrical generators are described at pages 275 to 305 of "Compresses, Air Plant," 5th Edition, by Robert Peal, published 1930 by John Riley and Sons, New York.

The air compressor 15 is used to drive generator 17 which generates the electricity required for peak load conditions.

During those periods when the main power plant is operating under partial load, the excess electrical capacity is used to drive the air compressor or reversible air compressor-air motor 15 to compress air and inject it through line 11 and bore 1 into the subterranean reservoir 3 against the hydrostatic head of water in pipe 7, thereby forcing the water in the cavity or reservoir up through the pipe 7 into reservoir 9 as shown in FIG. 1.

During periods of peak load when the capacity of the main prime mover of the power plant has been reached, air is withdrawn from the reservoir 3 through bore 1, pipe 11 and valve 13 to drive the air motor or reversible air compressor-air motor 15 which in turn operates generator 17 to generate the additional electrical power required.

It will be apparent that by closing valve 13 the reservoir system can be made to assume a static condition in which air is neither withdrawn from nor injected into the reservoir; or the pressure of air or other gas withdrawn from the well can be reduced to any desired level.

The height of the water column in pipe 7 will determine the pressure under which air or other gas is stored in the underground reservoir 3. Although gas at pressures of about 40 to 1500 pounds per square inch are usable, I prefer to store the gas at a pressure of approximately 100 to 1200 pounds per square inch. I prefer to use as high pressure storage as possible for the reason that the higher the pressure at which the air or the gas is stored, the smaller is the cavity and surface reservoir size required for a given generating capacity. Furthermore, by using high pressure storage the air can be pumped into the storage in a shorter period of time and this can be important where the low load periods are short as compared with the peak load periods. It will be apparent that the gas can be withdrawn from storage to operate the air motor or other prime mover either at the storage pressure or at a reduced pressure by partially opening valve 13.

The upper limit of pressure which is practicable for storing air or other gas is determined by the solution of the gas in the water or other aqueous liquid. The amount of gas which will dissolve is dependent on the nature of the gas fluid phase, temperature and pressure. While solution of gas in saturated sodium chloride brine is not nearly as serious as in water because of lower solubility, where the pressure is too high, large amounts of gas dissolve in the water or brine and are carried to the surface and released at atmospheric pressure, thereby resulting

in a large energy loss. It is important, therefore, to keep the storage pressure below that at which significant amounts of air or other gas dissolve in the brine or aqueous liquid. When using air and brine I have found that pressures between approximately 250 and 750 pounds per square inch are satisfactory. During injection of compressed gas into the reservoir 3, water or brine is forced from the reservoir up through pipe or tubing 7 into reservoir 9 and is displaced by the compressed gas which is maintained under the hydrostatic head of the water or brine in pipe 7. Obviously, a separate well bore may be used for gas injection and withdrawal from the underground cavity and for flow of water or brine between the underground cavity and surface reservoir. The system operates under very small pressure differentials and performs for all practical purposes as a variable volume-constant pressure storage reservoir. The system will accept gas at any pressure exceeding the hydrostatic pressure but will deliver gas at a constant pressure and rate until the total amount of gas is depleted from the reservoir. Because of the substantially constant pressure of the gas in the subterranean reservoir, the entire gas storage volume is usable for driving generating equipment and for that reason much smaller reservoir capacity is needed than in the case where straight gas storage is used. A further advantage of my system over straight gas storage is that when a salt cavity is employed as a reservoir, the periodic wetting of the cavity by the brine aids in sealing fractures and permeable zones in the rock salt wall, thereby preventing loss of compressed gas. Furthermore, because of the fact there is little or no pressure variation in the reservoir the likelihood of collapse of the roof structure is mitigated.

My invention has a considerable advantage over conventional pumped-storage in that large savings in capital costs are possible. In an article entitled, "How to Evaluate Pumped Storage for Peak in Generation," by John Pitt, published in the July 1964 issue of Power Engineering, pages 28 to 32 inclusive, it is disclosed that the cost of pumped storage is upward of \$80 per kilowatt. The cost of creating underground storage in a salt cavity is comparatively cheap as disclosed in Bureau of Mines Information Circular 77654, Section XXV, page 2, in an article entitled, "Underground Storage of Natural Gas in Coal-Mining Areas," by Wheeler and Eckard. By being able to construct a relatively small reservoir at ground level instead of having to construct a reservoir at an elevation considerably above the power plant a very significant saving in capital cost is effected. The combined saving due to smaller gas cavern size and location of the water reservoir results in a large capital cost reduction.

Although the invention has been described with particular reference to storage and use of air for driving air motors to generate additional electrical power, it should be understood that other gases such as carbon dioxide and natural gas, and liquefied gases such as LPG can be stored under pressure for use either in driving power generating equipment or for purposes such as heating, air-conditioning or chemical processing.

As an example of the invention, a cavity having a volume of 11,000,000 cubic feet was prepared in a rock salt formation by solution washing at a depth of 852 feet from the surface to the bottom of the cavity. A concrete reservoir is constructed immediately adjacent to the well bore at ground surface, the reservoir having approximately the same volumetric storage capacity as the sub-surface cavity. The air in the cavity is stored under a gage pressure of 442 pounds per square inch, equal to a hydrostatic column of saturated brine of 852 feet. Under these conditions, the gas storage capacity will be about 330 million cubic feet measured at standard temperature and pressure. Air is pumped into the cavity displacing brine to the surface reservoir at a pressure exceeding the hydrostatic pressure by a few pounds per square inch, or at greater pressures if high injection rate is

desired. The air is withdrawn from the cavity at a pressure of 442 pounds per square inch at a rate of 69,300 cubic feet per minute at the inlet of a reversible compressor-air motor which, in turn, drives a generator which is capable of generating about 67,000 kw. for a maximum of 79 hours or a total of 5,300,000 kw. hours. The storage is used to provide emergency power or peaking power for daily or weekly cycles.

I claim:

1. A system for generating electric power comprising:
 - (a) a substantially gas-impermeable subterranean salt cavity,
 - (b) a liquid reservoir at the surface of the earth, the vertical distance between said cavity and said reservoir being sufficient to create an hydraulic pressure head of about 250 to 750 lbs. per square inch, said reservoir having at least as much capacity as said cavity,
 - (c) a liquid conduit extending from said reservoir to a locus adjacent the bottom of said cavity,
 - (d) a solid column of brine extending through said conduit from said cavity to said reservoir,
 - (e) a casing surrounding said conduit and extending from the upper part of said cavity to above the surface of the earth,
 - (f) means operatively connecting the upper end of said casing to a reversible prime mover capable of compressing air to a pressure of at least 250 lbs. per square inch,
 - (g) said prime mover being operatively connected to an electric generator to drive the generator when the prime mover is charged with gas from said cavity, and
 - (h) means for driving said prime mover by means of excess electric power during periods of low power load in order to compress gas and inject it into said cavity.
2. The method of operating an electric power supply plant comprising:
 - (a) compressing air by means of power generated by an electric power supply plant during periods of low load,
 - (b) interjecting said compressed air into a substantially gas-impermeable cavity formed in a subterranean salt bed,
 - (c) maintaining a reservoir of brine at ground surface level of sufficient capacity to replace gas withdrawn from said cavity without substantial change in pressure in the cavity,
 - (d) maintaining a solid column of said brine between the liquid in said ground reservoir and liquid in said cavity,
 - (e) forming air from said cavity to the surface by means of the hydrostatic head of the brine in said ground surface reservoir,
 - (f) injecting said compressed air into said cavity at a pressure between about 250 and 750 pounds per square inch, said pressure being sufficient to raise the brine to the level of said surface reservoir, and
 - (g) utilizing the air forced from said cavity, to generate electricity during periods when said plant is operating at high load.

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GLEN R. SIMMONS, Primary Examiner

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166—305; 290—43, 54

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,538,340 Dated Nov. 3, 1970

Inventor(s) William J. Lang

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 19, change "constnat" to --constant--.

Column 4, line 53, change "forming" to --forcing--.

SIGNED AND
FILED
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(SEAL)

Attest:

Edward M. Fletcher, Jr.
Attesting Officer

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Commissioner of Patents