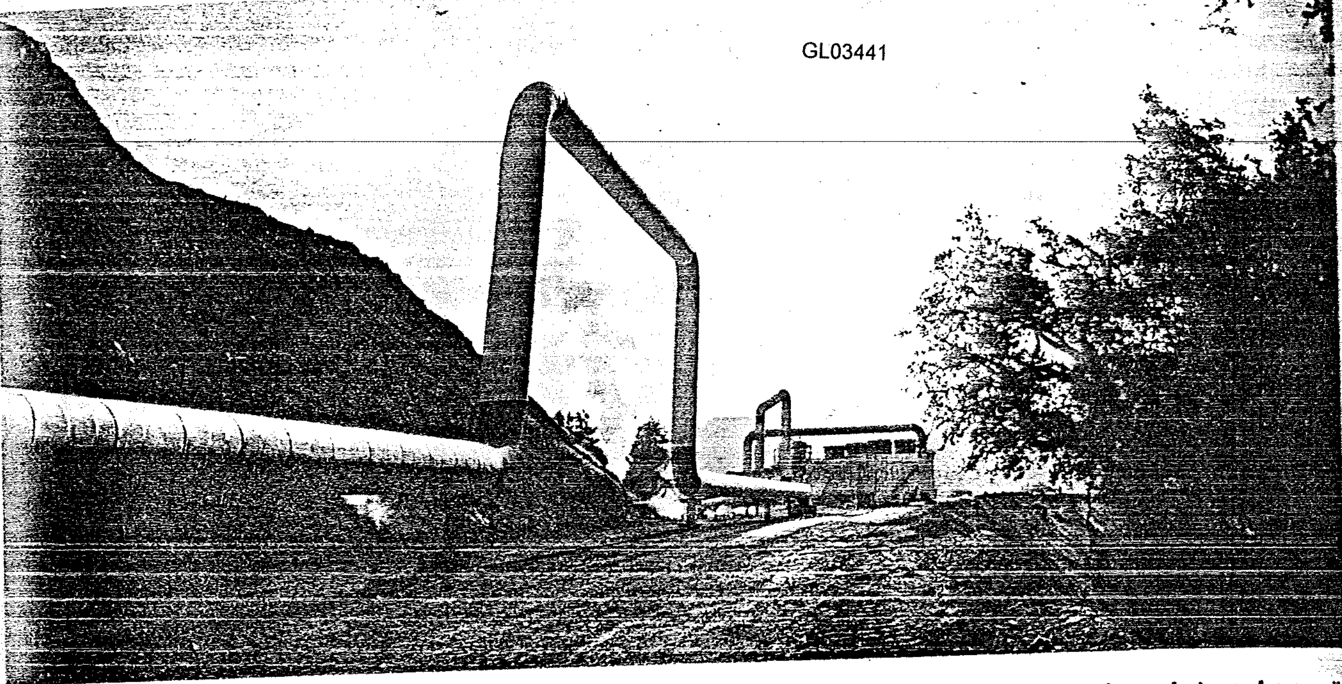


These expansion loops carry geothermal steam from wells drilled to a depth of more than 1.5 mi. to Pacific Gas and Electric's plant at The Geysers, Sonoma County, California.

Salt Domes As A Source of Geothermal Energy

by Charles H. Jacoby
Dilip K. Paul
International Salt Co.

The economic importance of salt domes has been recognized throughout the world, primarily because of oil and gas accumulations on their flanks, and to a lesser degree, for the value of their salt and potash. Recently they have become of value as hosts for cavities used to store hydrocarbons. In the near future we believe that their main value will be a source of geothermal energy.

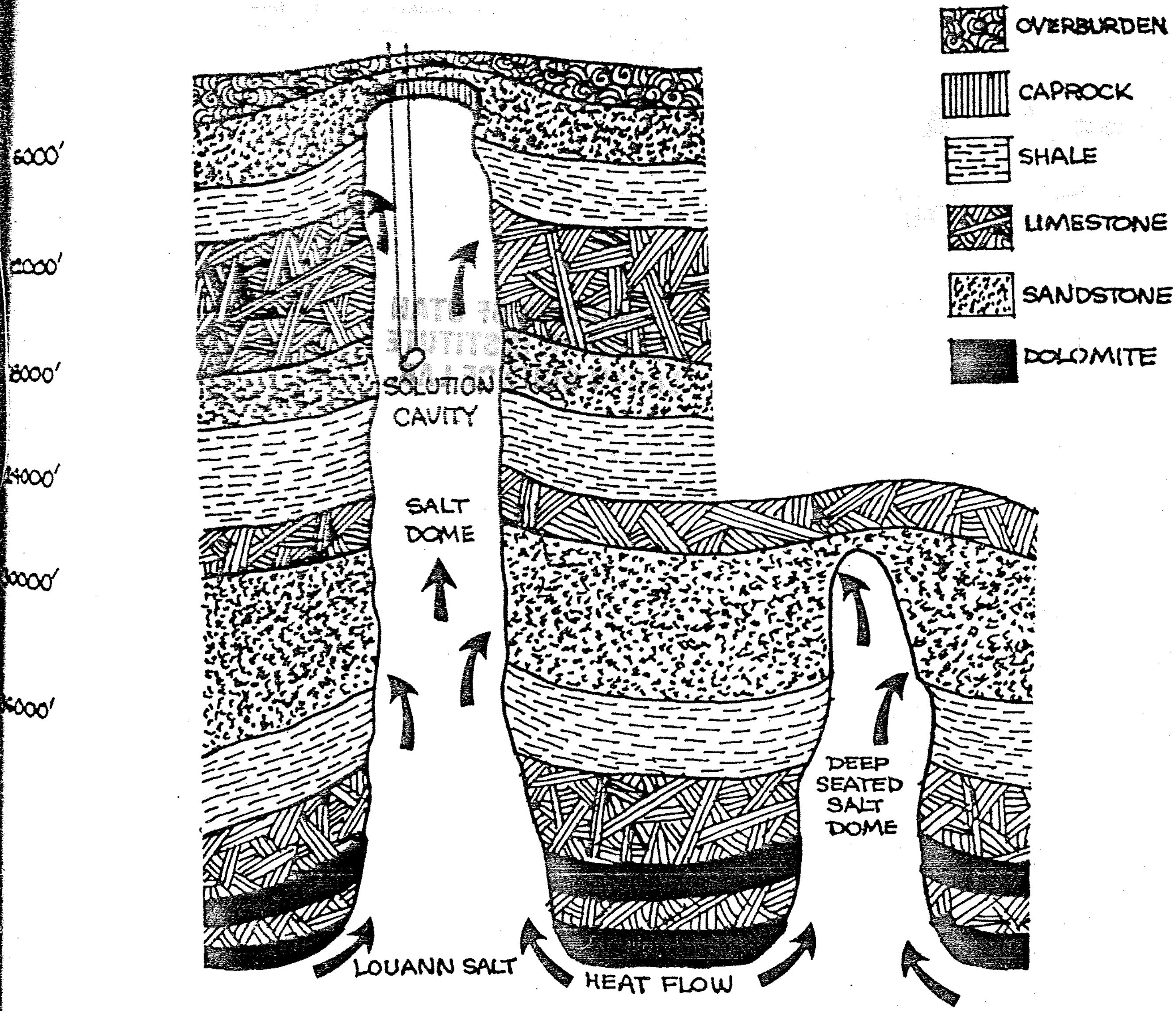
Although tremendous effort has been expended on the understanding of the geology and physical characteristics of the strata intruded by salt domes, relatively little energy has been exerted in the comprehension of the salt dome itself. Salt domes have long been recognized as a geological heat anomaly. With respect to other sedimentary rocks, salt is a good conductor of heat. Expressing values in 10^{-3} cgs units, sedimentary rocks vary from 1.0 to 8.0; metamorphic rocks from 5.2 to 8.4 and igneous rocks from 3.1 to 9.8. Rock salt in its pure form has a thermal conductivity of 17. Thus a salt dome can be expected to act as a conduit bringing heat vertically from deep within the earth's crust.

This was in part substantiated in 1958 when a horizontal core hole was drilled from within the Avery Island Mine at the 500 ft level. The horizontal hole was started where the ambient temperature of the salt was 74°F. and drilled toward the center of the dome. At the end of the 2000 ft hole the temperature was 90°F, indicating a horizontal temperature gradient of 7°F./1000 feet. Because this core hole penetrated a shear zone containing connate water that appeared as a "cold spot" on the temperature gradient, the foregoing data can only be regarded as indicative.

The source rock of our southern salt domes is the Louann formation. Depending on the location of the dome, the Louann has been estimated to have been buried at a depth of 40,000 to perhaps as deep as 60,000 ft. Balk has estimated that salt domes at a depth of 25,000 feet experience a temperature of 570°F. Gussow[37] states that salt becomes completely plastic in all axial directions at 662°F. Hiroy[35] reports, at a depth of 14,552 ft the temperature of a salt dome was recorded to be 460°F.

...dome the hotter the dome. The reason ...ed for this has been given as a loss of heat in ...lder domes to the surrounding rocks. It should ... be taken into consideration that the older ...es in the Gulf Coast region have their "mother" ... at a depth considerably below that of the ...ger domes. Another factor which should be ... consideration is the heat generated as the ...te moved along its dodecahedral glide plane, ...h in the case of the younger domes, would ... had less time to dissipate. It has also been ...ested that the salt in the base of the dome is of ...wer temperature than the surrounding rocks. ... agree with this theory since the thermal con...ivity of the salt would allow for the heat's ...sfer up the stock of the dome.

...ical salt dome as shown below could act as a conduit, ...ging heat vertically from deep within the earth's ... Source of the salt is the Louann formation, buried ...0-60,000 ft.



...the extraction of geothermal energy.

We know thermal conductivity K=

$$\frac{\text{Heat flow}}{\text{Temperature gradient}}$$

$$\frac{\text{calories (or Btu's)}}{\text{time} \times \text{distance} \times \text{temperature change}}$$

The thermal conductivity of rock salt varies from

8×10^{-3} cal/cm²-sec.-c°-cm

to 17×10^{-3} cal/cm²-sec.-c°-cm

(1.93 Btu/hr/ft²/°F/ft to 4.16 Btu/hr/ft²/°F/ft)

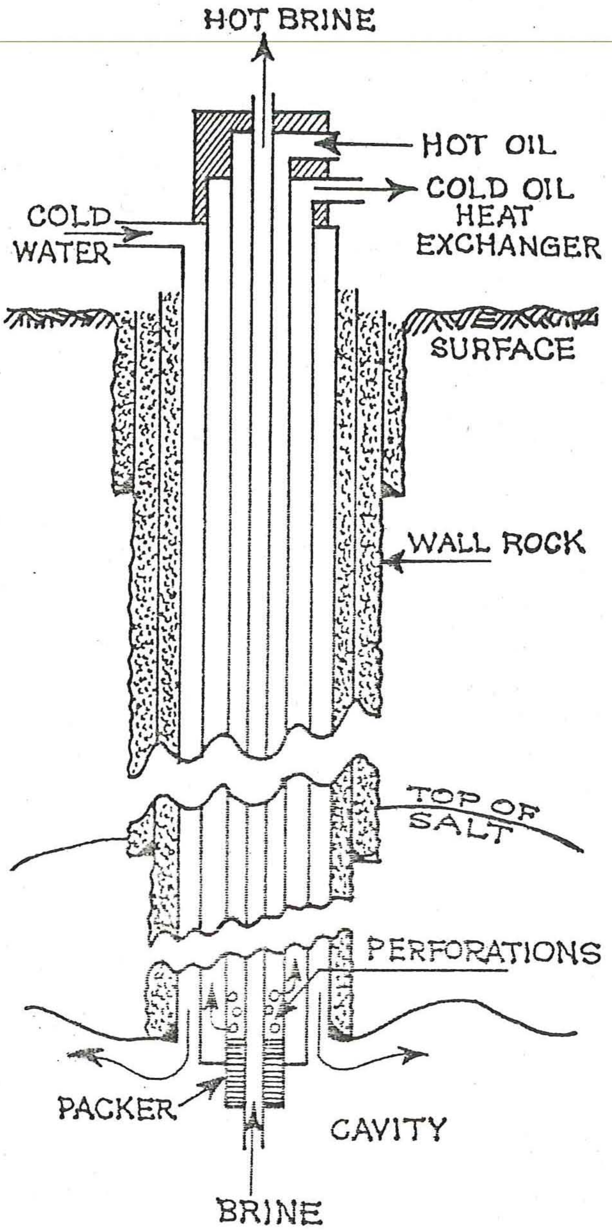


Diagram of a single-well system shows the piping configuration required to produce hot brine. Hot oil is used to prevent crystallization during the ascent.

The value of thermal conductivity varies with temperature. This value is two to five times that of most sedimentary rocks associated with salt domes. Heat flow is accomplished by conduction, radiation and convection mechanism along certain temperature gradients. The heat flow in salt domes should depend upon a complex combination of the heat flow by the agencies of all mechanisms.

The average heat flow in the Gulf Coast area is 1.2×10^{-6} cal/cm²-sec. whereas the geothermal flow rate in salt domes has been found to be between 6.2×10^{-6} cal/cm²-sec. to 10.1×10^{-6} cal/cm²-sec. The heat flow, which is a product of temperature gradient and thermal conductivity, is five to eight times larger than in the average area.

The geothermal gradient also varies by a wide margin. Temperatures of 330°F. at 10,000 ft, 455°F. at 15,000 ft, 580°F. at 20,000 ft are typical in salt domes. The typical geothermal gradient will vary from 2.2° to 2.6°F./100 ft. The geothermal gradient will also vary according to the location of the probe in the dome itself.

There are a number of ways the geothermal heat of the salt domes can be utilized. Some of the typical concepts are outlined below.

Geothermal Saturator

In this concept a salt dome is drilled to a predetermined depth of between 12,000 and 15,000 ft, depending on the characteristics of the dome and the location on that dome. A single-well system or a two-well system is created. In a single-well system the water is injected into the outer annulus and pumped into the cavity with the resultant brine being forced up the central tubing. Numerous piping configurations can be used. Hot oil is used to keep this central tubing warm to prevent crystallization during the hot brine's 2½ mi flow to the surface. It is probable that two additional strings of pipe would be required; one for an oil or pneumatic pad while the other might be a "sand string" depending on the quantities of anhydrite sand that were produced.

A more preferred system embodies the construction of two wells drilled to the desired depth. One would be deflected from its vertical trajectory over the course of its last few thousand feet. The lower portion would be underreamed after installation of the main casing.

After a bore hole survey had located the precise position, a second well, which subsequently would become the production well, would be drilled to intersect the underreamed portion of the first well. It would be cased in such a manner as to insulate and/or protect the brine tubing from heat losses which might cause the premature crystallization of salt in the production tubing.

The nether ends of the wells, if not connected by intersection, can be connected by using one of several other devices that are available. With the connection of the two wells, water is circulated down the injection well and produced through the adjoining well. In the case of the geothermal saturator, the main purpose is to produce a brine sufficiently hot so that it flashes to produce salt and steam. Thus, any domal temperature sufficiently in excess of the 220°F. boiling point of brine will be satisfactory to meet the needs of the process.

Before the selection of a temperature depth for the location of the cavity's construction within the dome, certain basic parameters must be established such as the total volume of salt the facility is expected to produce, the temperature required for the brine at the wellhead, and the average rate at

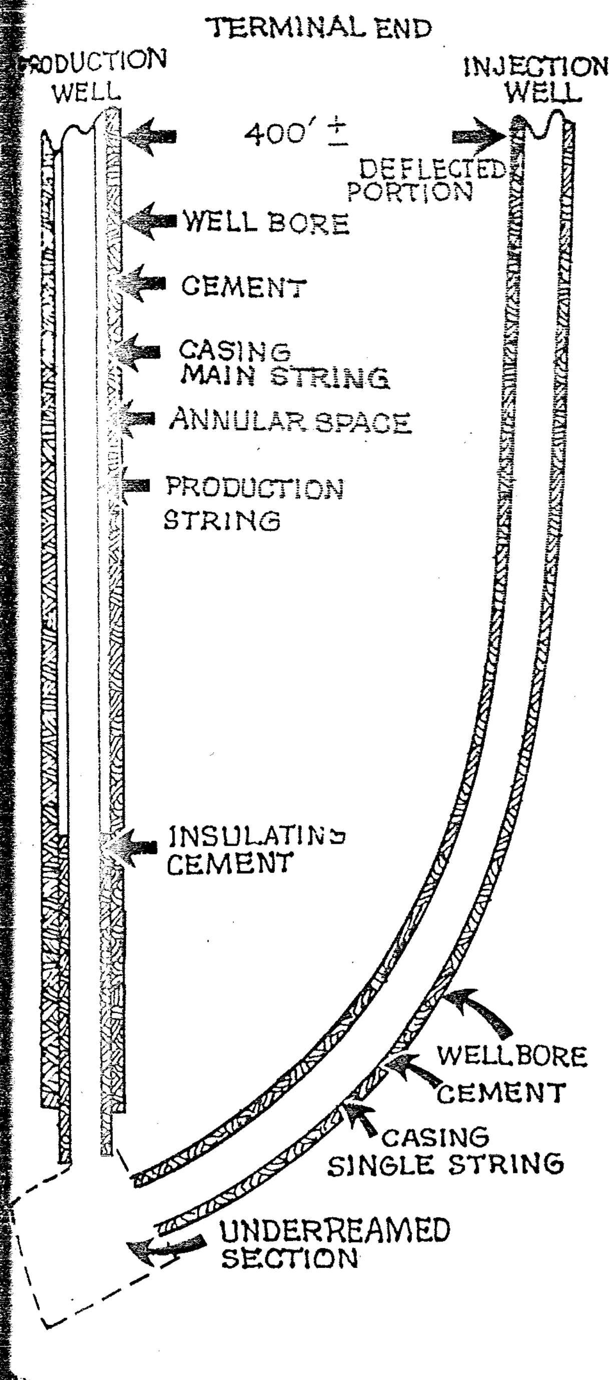
...ch the well is expected to produce. During the early youth of the cavity, an undersaturated ... will be produced. As the cavity grows, the re-...n time in the cavity grows with an increase in salinity and the temperature of the brine pro-...d. As the cavity matures the support of the ...g in the deviated hole or injection well will be ...ved, causing the casing to seek a plumb posi-... Eventually it will be necessary to carry an oil ...umatic pad around the injection well to limit vertical growth of the cavity.

As the deep-seated cavity is under high pressure ... temperature, plastic closure of the salt cavity expected. Extensive studies in rock mechanics have verified that a desired shape and size of the cavity can be maintained and controlled closures can be achieved. The plastic movement will prevent any sudden roof fall or other forms of unexpected rock failures.

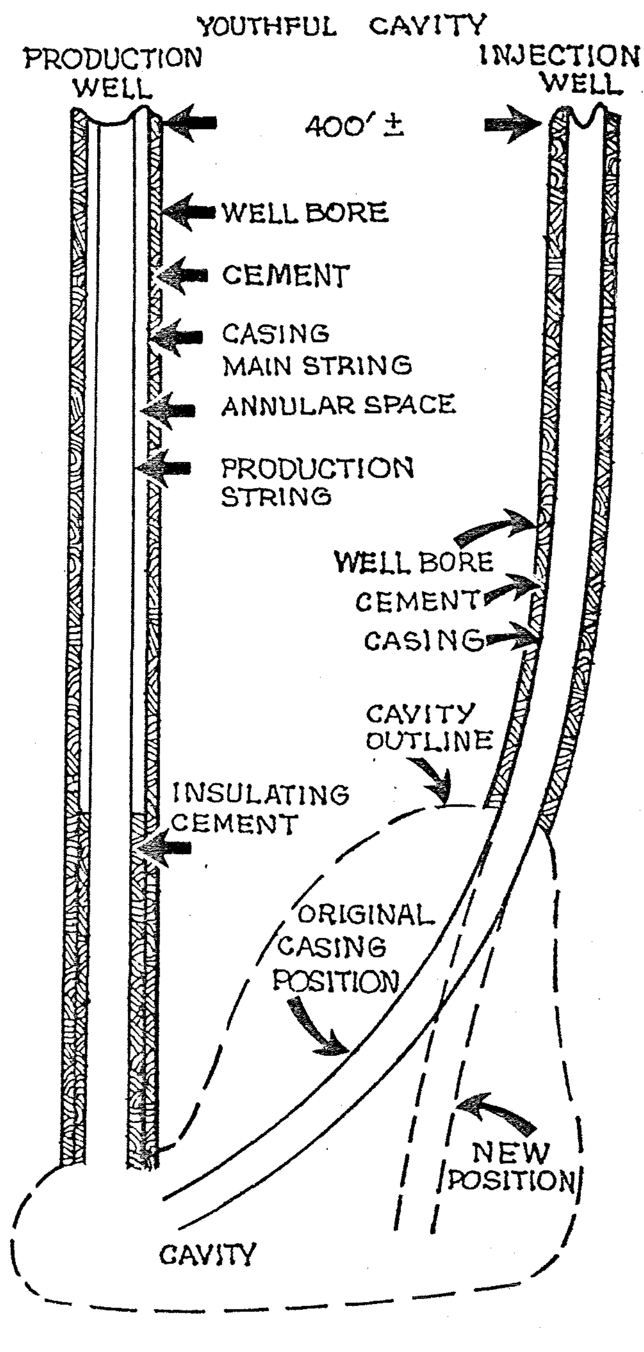
The high rate of geothermal heat flow will continually replenish the extracted heat and thereby assure the continuous operation of the process. In every case the rate of heat flow, plastic closures, and the rate of extraction of hot brine have to be properly balanced to ensure optimum recovery.

The advances in drilling technology, especially in the oil industry, have shown that problems associated with high pressure and temperature in deep

...-well system, showing the under-reamed section after installation of the main casing.



Water circulated down the injection well will produce a youthful cavity (shaded area).



drilling can be overcome. For the continuous success of the process, proper heat control must be maintained in the injection well, in the cavity, and in the production well. The success of the process will depend primarily upon successful heat insulation in the production well.

Peak Shaving of Power by Compressed Air Storage

This concept involves the evacuation of a deep-seated cavity to dryness. Compressed air would then be stored in the cavity during off-peak periods of electrical consumption. The compression would be augmented by the ambient temperature of the cavity with a resultant increase in the pressure of the stored air due to the increase in temperature. The exit well is capped until a peak power period when the heated high-pressure air is returned to drive a generator and produce extra power. This concept can have a number of variations with multiple cavities.

Geothermal Heat Exchanger

After a cavity has been excavated in a salt dome by either a single- or multi-well system, the brine can be displaced or replaced by a salt-insoluble heat exchanger fluid. This fluid in a relatively cool state would be injected into the cavity through an

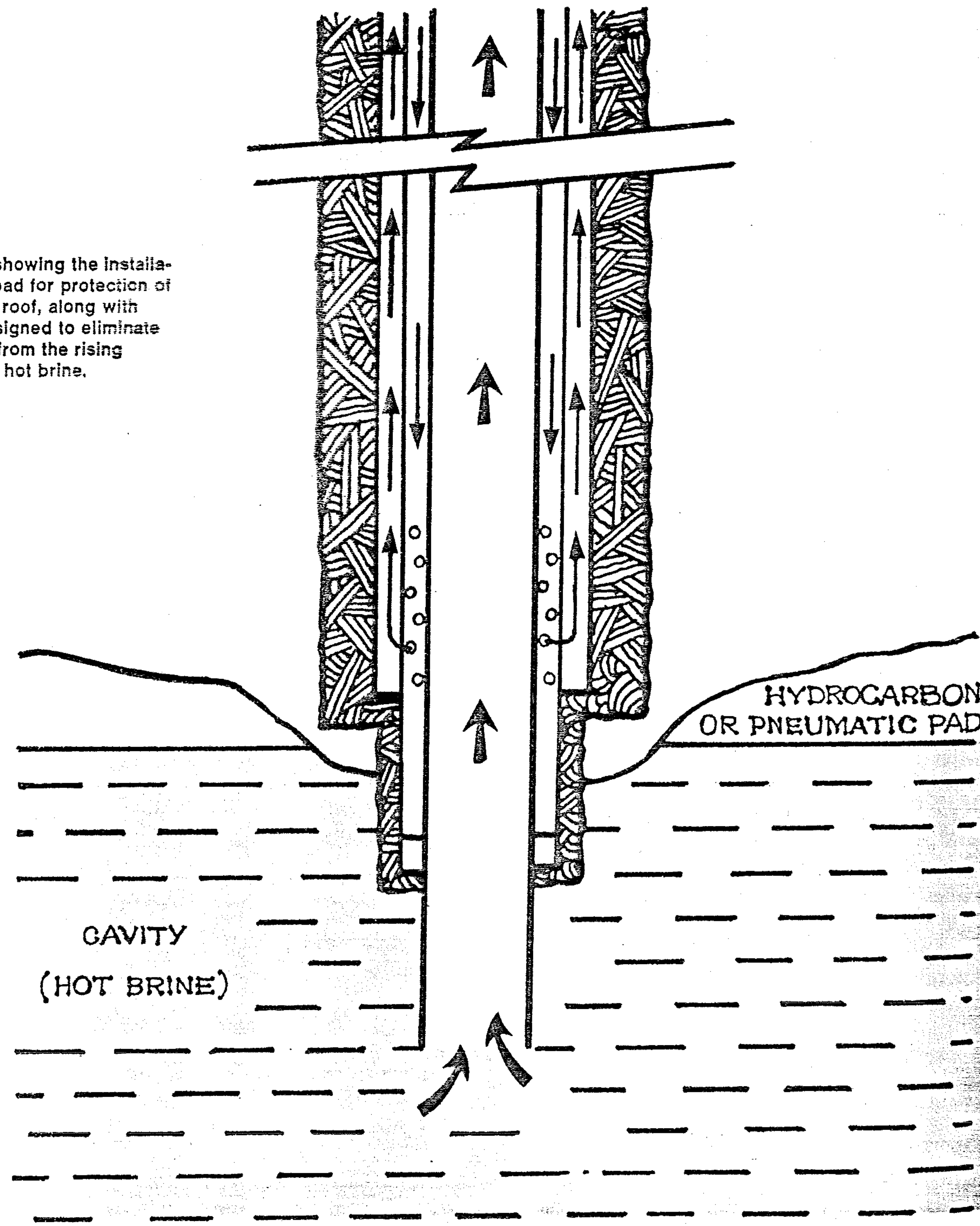


Diagram showing the installation of a pad for protection of the cavity roof, along with piping designed to eliminate heat loss from the rising column of hot brine.

injection well and extracted from an insulated recovery well. The hot fluid would be passed through a heat exchanger on the surface and then returned to the cavity. The recovery of this energy would entail no air, water or thermal pollution of any type. From time to time, as plastic flows tend to close the cavity, it will be necessary to dissolve additional quantities of salt. This would be required so that the retention time in the cavity will give the volume of fluid flowing through the system adequate time to heat.

Steam Generation

A calculated volume of water could be injected into a deep-seated hot cavity which had been emptied of fluids. The water would travel down a long injection pipe, through increasing geothermal temperature, and would be in a pre-heated condition as it entered the cavity. Based on heat flow into the cavity and the surface area of salt exposed in the cavity, the calculated volumes of water introduced would produce calculated volumes of steam which then pass through an insulated recovery well and enter a steam turbine to produce electrical energy. The shape and size of the cavity could be made to recover maximum quantity of steam per unit volume of the cavity.

Geothermal Chemical Retort

Various endothermic reactions can be caused by the introduction of specific chemicals into a hot, dry cavity. By equipping the well with concentric strings of tubing, multiple reactants in calculated volumes can be introduced into the geothermal chemical retort. Although salt is inert to many chemicals, some care would be necessary in the selection of reactants and the resultant products. Catalytic agents could be installed in the cavity.

Geothermal cavities in salt would be impervious to most chemicals, with little or no chance of fluid losses in the cavity itself.

Geothermal Water Purification

This concept envisions the introduction of a brackish or polluted water into a hot deep-seated cavity which had previously been evacuated to dryness. A recovery well could carry steam which would produce power and recover potable water.

These concepts will demonstrate how this underutilized energy source may be used for economic purposes. Of course, as in all other new concepts, there would be some trial and error. Nonetheless, this vast geothermal energy resource in the salt domes will find various uses. For the formation of wells, cavity, and the utilization of energy, salt will be a much easier product to handle. Dome salt has purity that approaches 99 percent in many cases and the impurity is mainly calcium sulphate. In some instances the effluent will be a marketable commodity, thus completely avoiding all pollution problems. Other geothermal brine contains numerous basic and acid radicals which create pollution and operational problems in the handling of the effluent.

Because of the deep-seated origin of the salt domes, sometimes reaching 10 to 12 mi underground, the energy will continue to be replenished in almost inexhaustible quantities. The rate of supply and demand must be balanced.

Conclusions:

In view of America's future energy needs, it appears that we will eventually turn to the salt domes of Louisiana, Texas, Mississippi and Alabama for a sizeable portion of our needs. Here, unlike exhaustible reserves of oil and gas, is a vast reserve of almost inexhaustible energy. To properly and fully develop this "pipeline" of power will require creativity, innovation, capital, and time. Many known problems and even more numerous unknown problems will be encountered where answers will be needed.

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