GEOTHERMAL HEAT MINING BY CONTROLLED NATURAL CONVECTION WATER FLOW IN HOT DRY ROCK FOR ELECTRIC POWER GENERATION

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Key Words: heat mining, hot dry rock, natural convection flow, Shulman Star Heat Mining Concept, directional drilling, deep crustal heat.

ABSTRACT

Of all energy sources found on earth in various forms, by far the largest is thal stored in "hot dry rock" strata of the earth's crust, within reach of modern drilling techniques. This accessible resource base is 300 times larger than all sources of fossil energy resource fuels consisting of oil, gas, and coal.

This paper presents a novel method by which the thermal energy in hot dry rock might be transferred to a multiple set of water-filled pipe loops radially disposed about a large central riser connected to the radial loops at top and bottom. The down-flowing water in the radial loops, which reach far out from the central riser, gathers heat from the rock strata as it descends, reaching maximum temperature at the bottom where the central riser gathers all of the down-flow from the radial loops. The riser then delivers this water to the surface by natural convection circulation caused by the hydraulic head difference between the colder down-flow water and the hotter up-flowing water, thus requiring no auxiliary pumping power. At the surface the thermal energy of the water is transferred to a steam power cycle, either directly by flashed steam or through a heat exchanger. The water thus cooled then enters the down-flowing loops by a ring-manifold at the top for another heat gathering circuit. To account for draw-down in the rock temperature the return down-flow to the radial loops may be cycled, especially at low night time demand, to allow for heat recovery in this rock.

1. INTRODUCTION

The natural heat produced by our planet Earth represents an enormous renewable energy resource which we call geothermal energy. This heat is produced by radioactive decay processes taking place in the mantle or deeper at high temperatures, which radiates through the earth's crust to outer space. It is only the protective insulation of the crust from this heat that allows all life forms on the surface to exist.

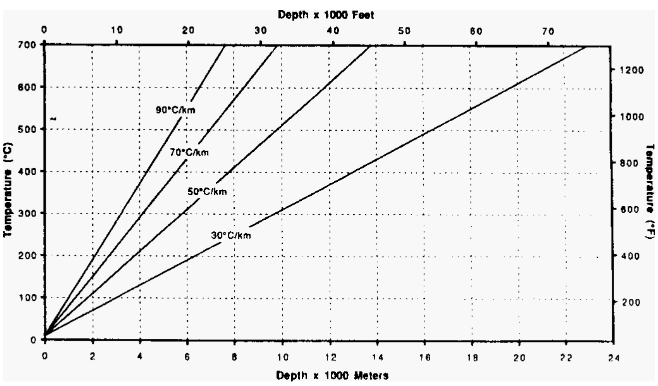
This paper will focus on a method to convert the geothermal energy that exists everywhere in the crust into sustainable electric power generation. Sustainable energy means not subject to variations in cost and reliability from uncontrollable forces such as weather and foreign imports.

A great advantage of this means of power generation will be the complete absence of environmental atmospheric and disposal impact in contrast with that resulting from fossil fuel and nuclear fuels. Such a plant, once installed, would operate almost as automatically and with as little manpower as a modern hydroelectric power plant. Unlike any other source of electricity today, it could be located anywhere in the world independent of weather, terrain, fuel transportation, and major transmission networks, and would produce power at a constant cost without escalation due to future supply and demand for fossil fuels.

An apparent major hazard to modem civilization is looming from the "greenhouse" gases emitted by fossil fuels for power generation and transportation. Since approximately 65% of all U.S. electric power, for example, is generated from fossil fuels (500,000 MWe) this creates the huge annual carbon build-up in the upper atmosphere of 2.6 billion gross tons. A progressive replacement of these fuels by heat mining as a source of sustainable energy will be a great technical achievement for mankind.

We classify the increase of temperature with depth in the crust as the geothernia! gradient. An average for all surface locations is recognized to be approximately 30°C per kilometer of depth. Higher gradients appear to be the result of vulcanism or magmatic intrusion. Figure No. 1 illustrates several geothermal gradients from 30°C/km to 90°C/km, showing the various temperatures increasing with depth. We will use for our heat mining model a geothermal gradient of 90°C/km, because of the high rock temperature available at the relatively shallow depth of 7 km which can be reached with present day drilling techniques.

Figure 1
GEOTHERMAL GRADIENT CHART



2. WELLHEAD DESIGN

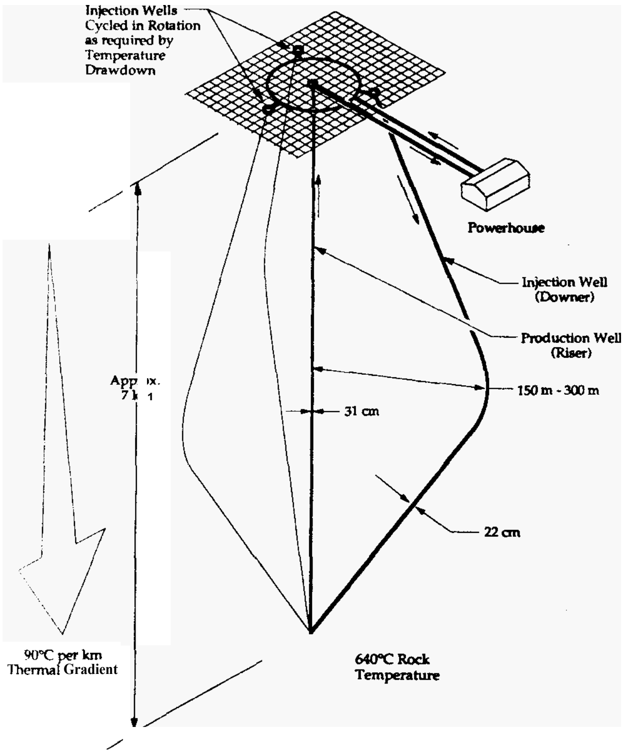
The group of wells shown in Figure 2, described as the Shulman Star Heat Mining Concept, consists of several injection wells (downers) and one production well (riser). The unique feature of this concept is the large area for heat transfer available from the widely dispersed rock area which is gathered to one production well in the center for delivery to the power plant.

The production well is drilled directly downward to the 7 km depth and a 31 cm I.D. casing is cemented in place from the surface to within 20 m from the bottom. This space will be used as a target into which the injection wells will be drilled. Three injection wells, located in a circle near the production well at the surface, are directionally drilled to a 4 km depth at a distance away from the production well and then continued directionally to intercept the 20 m space at the bottom of the production well. The injection wells have an 22 cm I.D. casing cemented in place to a depth allowing continuous flow of water into the riser.

Gravity carries the higher density cool water (114°C)exhausting from the power plant to the lower depth of the injection wells where it is heated by the hot rock to a lower density. This lighter water is then propelled to the surface by the pressure differential imposed on the riser by the heavier down-coming water. Thus, with this convection flow, heat from the lower rock is brought to the surface for conversion to electric power.

As the heat in the rock area is drawn down, each injection well may be shut down for a period of time, or cycled, to recover heat by conduction from adjacent hot rock. During this period the remaining injection wells continue producing the convection flow in the riser. The ability of these wells to recharge with heat over time will determine the number of injection wells required in an area at a specific geothermal gradient for sustained power generation.

Figure 2
SHULMAN **STAR HEAT** MINING CONCEPT



3. HEAT MINING PLANT DESCRIPTION

We have selected a 90°C/km geothermal gradient for initial design analysis of a commercial Heat Mining Power Plant to produce 11 MWe. This type of high gradient area should make sustainable operation more likely with existing drilling hardware. However, in this regard, the development of directional drilling tools must be improved to work with the higher temperatures expected.

The process flow diagram of the 11 MWe Heat Mining Power Plant is shown in Figure **3,** and the following relates to that diagram.

Starting with Point 1 at the wellhead of the production well, we find a steam and water mixture at 61.2 kg/cm²a, 271"C. The two phase flow then passes through a throttle valve at Point **2** which controls the pressure to 5.63kg/cm²a and the temperature to 156°C in the separator at Point 3. The separated steam enters the turbine at Point 4 at 5.27 kg/cm²a, dry saturated, with a mass flow of 90,700 kg/hr to generate 11 MWe with an exhaust of 63.5 mm HgA into the condenser at Point 5. This condensate, at 41°C is pumped from the hot well at Point ***6*** to Point 7 where it is joined by water from the separator at a mass flow of 159,300 kg/hr, 156°C.

To begin the heat mining, the combined condensate and separated water with a mass flow of 250,000 kg/hr, 5.63kg/cm²a and a temperature of 114°C, now enters two of the injection wells at Point 8. The water flow then continues through the hot **rock** with a total heat transfer surface of 9,631.4 sq.m. to Point 9 at **7** km depth. This water at 501 kg/cm²a, 332°C now rises by convection to Point 10 where steam begins to flash at a well depth of 1,494 m at 112.5kg/cm²a, 318°C. The steam formation creates an additional lift to deliver the two phase flow to Point 1 to then repeat the cycle. In this manner the heat is mined from the hot rock at depth and deliv- ered to the surface by convection and steam lift without auxiliary pumping assistance for conversion to electric power.

4. ECONOMIC FACTORS

In order for heat mining to become accepted in the commercial world of power generation, it must produce electricity at a cost competitive with fossil fuels. Given U.S. $.05/kwh as the present cost of fossil fuel fired power with new generation facilities, in 20 years with a 3% inflation factor this cost will rise to **U.S.** $.09/kwh. Heat mining must compete with these costs to be effective, although it carries the advantage of freedom from environmental externalities which are now being quantified for fossil fuels. If the described 11 MWe plant and wellfield can be installed for U.S. $SO million with an operating life of 30 years, the power costs can be ccmpetitive.

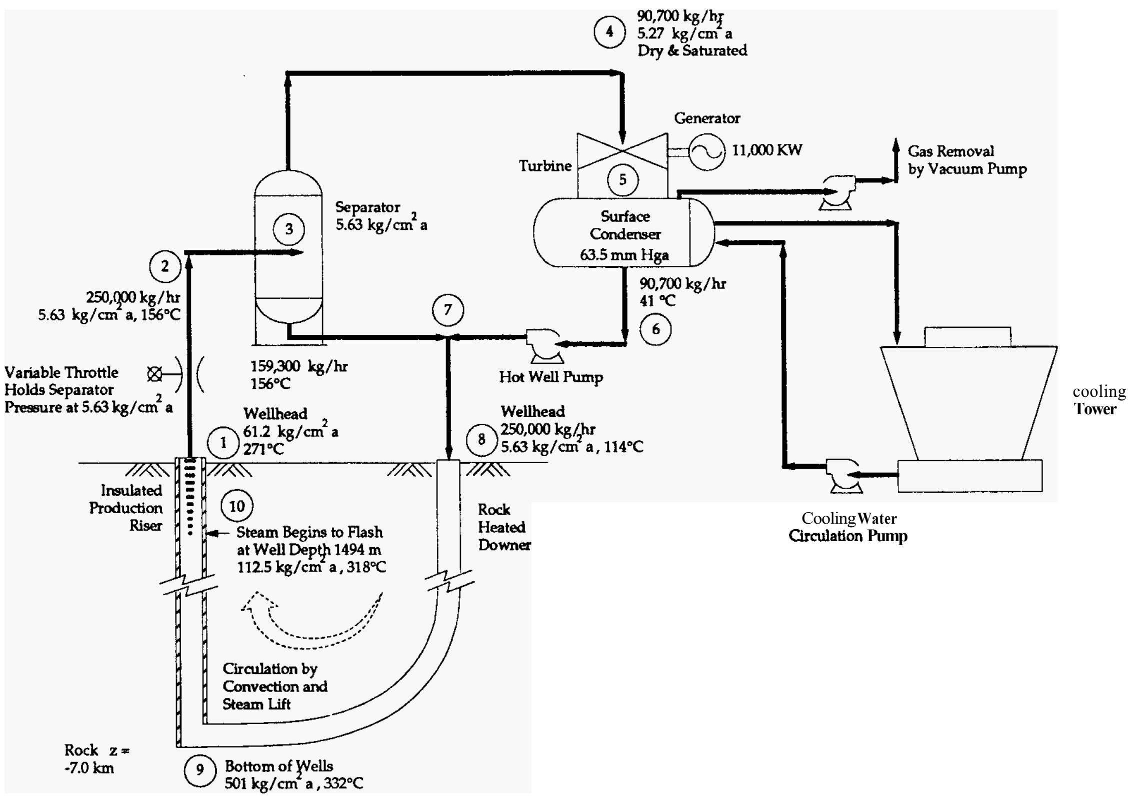
5. CONCLUSION

In the future Hot Dry Rock can serve as a nation's largest source of electric power, available in all regions of the world. Given the enormous size and indigenous nature of deep crustal heat, a serious development effort must be made for its conversion by heat mining to power generation by government funding on a par with nuclear fusion development.

At the present time several hundred thousand tons of low sulphur coal are being transported every day from western regions of the USA to eastern USA power plants, approximately 2500 km, in order to comply with environmental regulations for SO, discharge to the atmosphere. There **is** no doubt that the 9 km to16 km envisioned in geothermal heat mining would involve a great deal less effort and cost to attain this environmental objective. The advent of deeper drilling to reach heat productive zones in the lower crust will also produce greater heat exchange surface, ***so*** that these deeper wells will be even more suitable for heat mining.

Presented in this paper is one possible solution which should be verified by a test program of convection cells drilled and piped into hot dry rock. Development of deep drilling techniques into high temperature rock must also receive near term government funding. With major funding for this development there is no question that we can put in place a natural geothermal heat mining system that will be one of the great achievements of the twentieth century.

Figure **3.**
PROCESS FLOW DIAGRAM 11.0MWe **HEAT** MINING PLANT



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