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PLOWSHARE STIMULATION OF GEOTHERMAL SYSTEMS

D. H. Stewart - J. Burnham

Geothermal energy may be ^{present} available in many forms: dry steam, as in the Geysers area of California; very hot water ($>350^{\circ}\text{C}$) as in the brines of the Salton Sea area of California, moderately hot water $<180^{\circ}\text{C}$ or in dry hot rock (rock $>350^{\circ}\text{C}$ at less than 10,000 ft.). In the U.S. only the dry steam field at the Geysers has been developed and it is planned to produce a minimum of 1000 MWe by 1980. The power costs are attractive around 5.0 mills/Kwhr including the price paid for steam which is 2.9 mills/Kwhr.

The hot water system can be developed as in New Zealand where 172 MWe are produced by flashing 10% of the hot water to steam and using the steam in low pressure turbines. The hot water is wasted and with this system as well as many others which ^{are} water limited, it would appear ~~much~~ greater energy *conservation* and production could be achieved by reinjection of the hot water back into the formation.

The moderately hot water systems are in great abundance, and if useful electrical energy could be extracted with a binary cycle using freon, ammonia or isobutane, ^{they} it could prove a large ^{source of electrical power,} resource. A test of the Magma ^{well} binary cycle is planned by San Diego G&E in the Southern California region.

MASTER

The dry hot rock may prove to be the sleeping giant of geothermal energy. The energy content of a single area in Montana could equal the whole north slope oil field - and perhaps it would prove no more difficult to ^{put into production,} ~~extract~~. Preliminary heat flow investigations in shallow drill holes (1500' deep) and ^{by} a gravity survey suggest the presence of ^{large} ~~such a~~ heat source near Marysville, Montana. These investigations suggest the presence of a granitic pluton 20-80,000 years old, less than 2 km deep, with a volume of 100 km^3 , and at temperatures in excess of 500°C .

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Temperature gradients of 300°C to 350°C/Km were measured. The country rocks are highly impermeable Precambrian sediments and Mesozoic and Cenozoic intrusives. There are no surface manifestations of high temperatures within a radius of 30 km from the site. It has been suggested, however, that this anomaly also is a hydrothermal one and that the reservoir simply does not leak to the surface. Thus further exploration and drilling are necessary to even establish that dry-hot systems are present. *The energy in this rock could support 30,000 MWe for 30 yrs. REX*

A recent estimate by Dr. Robert Rix, University of California, Riverside, and somewhat modified by others shows estimates of the size of the resource in the Western and Gulf Coast areas of the U.S.

	<u>Probable</u>	<u>Ultimate</u>
Dry Steam	29.8 Q	60 Q
Hot Water	129 Q	257 Q
Hot Rock - above 6 KM's	149 Q	300 Q
- between 6 KM & 10 KM		600 Q

In any event the potential size of the resource is significant.

The capital requirements of geothermal systems are low compared to other power systems. PG&E's total investment in a two unit 110 MWe plant added in 1972 ~~paid~~ ^{was} only \$120/KWe. This may be compared to from \$250 to \$350/KWe of capacity for 1000 MWe ~~plants~~ ^{plants} operating on fossil fuel or nuclear energy. The fuel costs are paid to the Resource Company which develops the field and in the above case, 2.9 mills/Kwhr is being paid. Steam wells are extraordinarily produced with a single well producing 10 to 30 MWe. Efficiencies are low ~20% steam per Kwhr, but as the cooling water comes from cooling the condensed steam in a cooling tower, there are ~~no~~ off site water requirements, ~~are nil.~~

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The problems of producing power from hot water or hot rock may ^{cause the power to be} ~~prove more~~ expensive but the utility capital requirements will remain relatively low.

The uses of Plowshare in the stimulation of ~~the~~ geothermal systems could be of great value in stimulation of natural geothermal systems and the development of dry hot rock systems. The main difference in the use of nuclear explosives for these applications is the size of the device required. For natural systems 5KT - 40 KT would be expected to produce economic results while in the dry geothermal systems - depending on the temperature and depth of the formation - the sizes of 100 KT to 1000 KT would be required.

^{\$} There are potential benefits which could be expected from nuclear stimulation of natural geothermal systems:

1. In cases where inadequate steam or steam and water flow is obtained from a geothermal bore due to limited permeability of the producing area, the cavity produced from a 5 KT detonation could result in increases in production by as much as a factor of 20. When flow is limited by cracks the order of 0.1 mm or less, the flow is proportional to the $\log_n \left(\frac{d}{D} \right)$ where d = the diameter of the borehole and D is the diameter in the reservoir beyond which fall in pressure under borehole drawdown is negligible. D can be the order of 70 meters for some formations. Under these conditions doubling the d has little effect and the d must be greatly enlarged if improved production is to be obtained. The effective d would be about 21 meters if a 5 KT device were detonated. A production increase from 20,000 #/hr to 400,000 #/hr would be worth \$460,000/yr.

2. In cases where plugging of the formation occurs due to mineral deposition, the production of a 1.5×10^6 cu.ft. void volume could contain these minerals such that a well might produce for 20 yrs. instead of 18 mos. ~~An example is Well 85 at Larderallo~~ ^{(1) One well} which dropped from a production rate of 660,000 #/hr to 176,000 #/hr in 18 mos. Assuming only the 20% ^{of the} entrained water which flashes in the borehole deposits its silica near the borehole entrance, about 1,300 cu.ft./yr would be deposited. If this plugging of the formation accounts for the loss in flow, a cavity produced by a 5KT device could have maintained the production rate at 660,000 #/hr over 20 years. The additional steam would have produced \$5,800,000 of additional revenue at 3 mills/Kwhr and discounted at 6%. It is estimated that a 5 KT nuclear detonation, when in commercial use, could cost less than \$500,000.

3. A void volume could dry up a system producing both steam and water mixtures by providing space for flashing the hot water to steam underground rather than in the borehole itself. This would have three important effects. First, the energy normally lost in the separated hot water would remain in the system; second, the high mineral content of the water would not become a surface disposal problem; third, the water would not be lost from the system. In many systems, such as Wairakei, the total productivity of the system is limited by a lack of water recharge. The total quantities of water withdrawn are large as the water produces only 15 to 20% steam on flashing. One might assume 3 times the total production could be obtained from a hot water system such as Wairakei if all water were flashed to steam underground (170 MW_e to 510 MW_e).

4. The increased well bore diameter effect could also prove an effective way to recharge water to the system and to dispose of waste water from the generating plant. A special recharge hole would be drilled near the edge of the producing geologic area and a 5 KT device detonated. With adequate access to the producing formations, the normal head of cold water should prove sufficient to provide the "pumping." Water disposal by reinjection has been started at the Geysers and no deleterious effect has yet been noted at adjacent wells.

Perhaps the most important contribution of flowstone could make non-productive fields useful resources. This is analogous to the potential application of flowstone to natural gas fields that cannot be economically produced by conventional means.

In regard to the hot dry rock systems, it was found⁽¹⁾ that large devices were required to produce power economically and that they, ^{would} ~~presented~~ ^{in many cases} ~~largely~~ unacceptable seismic problems. However, if Dr. Blackwell's experimental evidence proves correct, that a thermal gradient of about 300°C per kilometer exists in a geothermal area near Marysville, Montana,⁽²⁾ this is more than double the 125°C per kilometer used in the ^{above referenced analysis and under these conditions} ~~original~~ calculations. Blackwell's data indicate that a temperature of 700°C could be expected at 3 kilometers in this area as contrasted to the 350°C used in the calculations. ^{By} ~~By~~ cooling this rock from 700°C to 200°C, the average thermal efficiency will increase from 22% to 30.5%. The combination of the increase in thermal conversion efficiency and increase in available sensible heat in the rock decreases the size of devices required by a factor greater than 2-1/2 to the 150 KT to 300 KT range.⁽³⁾ Another factor which is important in the economics of this concept is the diameter of emplacement holes. If the explosives could be emplaced in smaller-diameter holes, rather than the 24-inch-diameter holes assumed in these ~~the~~ calculations, substantial savings on each hole could be realized. ^{Depletion allowance} ~~Another factor that is not considered here is a~~ recent court decision, actually the second one of this type, ^{on the matter of depletion allowances for geothermal energy.} ~~The~~ ^{However, recently, an} appellate court confirmed an earlier decision that these resources are depletable. This decision ~~actually~~ will reduce the cost of this type of energy by about 0.3 mill/kWhr. The work of Kutter and Fairhurst, ~~discussed earlier,~~ indicates that the increase in radial cracking with subsequent nuclear explosions may significantly increase the enhancement factor beyond the range of 1-3 used in these ^{referenced study} ~~these~~ calculations. Likewise, there has been no credit taken for any thermal fracturing. Although the effect of this fracturing is unknown at this time, it could be significant in increasing the fractured volume.

(1) A feasibility study of a Phoenix ^{Geothermal Power Plant} April 1971
PNE-1550 TID 4550

(2) Blackwell, David. Exploration and Development in Dry-Hot ^{Rock} Systems, ARPA Conference, Lake Arrowhead, California, May 30-June 2, 1972.

(3) Use of Nuclear Arrays to Fracture Hot Rock BNWL 4237
Barnham & Stewart

Although other methods such as hydrofracturing or high explosives should be tried to stimulate geothermal systems or fracture hot rock, it is the opinion of the authors that nuclear explosives will prove to be the most effective. Large amounts of energy are required and the available space in a well bore is limited. The temperatures also create problems of explosive stability and it would appear that a nuclear device with cooling is most adaptable to this environment.

There is a great deal of accessible energy in the earth, and in the coming decades of serious energy shortages it behooves us to tackle the problems in the development of geothermal power. There is evidence that this year, for the first time, the government will be taking a serious look at the development of geothermal power and the contributions it could make in helping to meet the energy shortages.

STIMULATION VS DRY GEOTHERMAL

	<u>STIMULATION</u>	<u>"DRY"</u>
DEVICE SIZE	1-5 KT	200-1000 RT
GROUND WATER	RADIOACTIVITY PROBLEM	NONE
STEAM PRESSURE	50-100 PSI STEADY	800-1000 PSI DECLINING
TEMPERATURE	250 ⁰ F TO 350 ⁰ F STEADY	600 ⁰ F TO 350 ⁰ F DECLINING
SITES	KNOWN	VERY LITTLE INFORMATION

POWER COST VS YIELD

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