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THE GENERATION OF ELECTRICITY FROM GEOTHERMAL RESOURCES IN ENGLAND

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Introduction: Two types of geothermal reservoirs exist in the United Kingdom, permeable formations in sedimentary basins, the largest being perhaps 4km deep, and hot dry rocks. Temperatures exceeding 200°C are unlikely to be found within 7km of the surface in the dry reservoirs and the maximum temperature expected at the bottom of the sedimentary basins is 125°C. (Burley 1980)

Both resources are of rather low quality, in that both have about normal temperature gradients, one is rather cool and the other depends on unproven technology. However, the price of fuel in the UK is so high that both merit investigation at least, as sources of electric power.

Hot Dry Rocks: The techniques required to render dry rock permeable have been the subject of an experiment at the Camborne School of Mines and financed by the UK Department of Energy and the European Commission. The original concept of a hot dry rock reservoir as proposed by the Los Alamos National Lab (fig. 1) (Smith 1975) has been discarded as it is now realized that the natural fault system within the rock determines the growth of the fracture system. At Los Alamos the aim of producing one fracture of sufficient area to be able to provide hot water over the 20 year's life of the power station has been replaced (fig. 2) by a number of smaller fractures in parallel (Los Alamos Scientific Laboratory 1980).

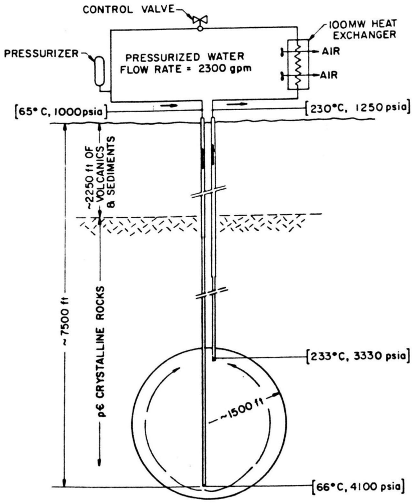

Figure 1: Original Hot Dry Rock concept.

The Camborne approach questions whether the joint structure would permit the fabrication of such a system and suggests a different geometry. It is believed that the reservoir is highly fractured and an idealized plan view is shown in figure 3. Hydrofracturing just serves to open some of the natural flow

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paths. Batchelor (1980) believes that the connection from the borehole to the joint system offers the greatest impedance to water flow and has demonstrated that the use of explosive charges may substantially increase the number of connections.

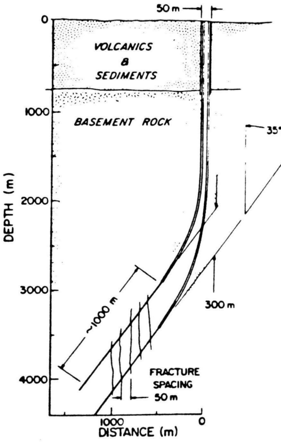

Figure 2: Reservoir planned for Fenton Hill Phase II System.

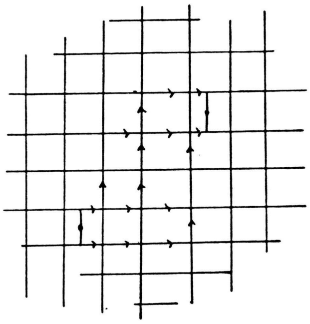

Figure 3: Idealized plan view of natural joints in granite.

Great care must be taken when using explosives to fracture rock since if the explosion is incorrectly designed, plastic deformation will occur in the rock around the well bore making it impermeable (fig. 4). Batchelor's unfocused charges serve to produce a highly fractured zone around the well bore (fig. 5) and the fractures were subsequently grown by hydrofracturing. This explosive pretreatment reduced the impedance substantially but needs to be confirmed on a commercial scale. The boreholes at Camborne were just 40m distant and at a depth of just 300m. A new reservoir is now being constructed at 2000m where the earth's stresses will be more representative of those at "commercial depths" of 5km.

The impedance of the loop at Camborne had an impedance of 0.7 GPas/m^3 when flowing < .01/m^3/s with negligible water loss and the production borehole being held at atmospheric pressure.

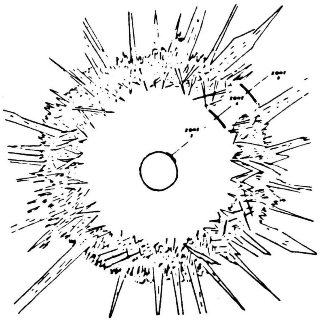

Figure 4: Result of explosive treatment of borehole with too high a charge. Note impermeable zone caused by plastic deformation.

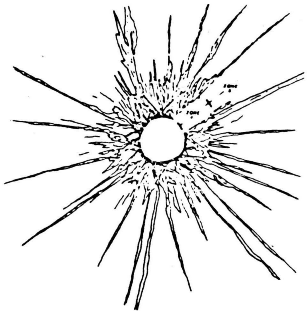

Figure 5: Satisfactory explosive treatment of borehole.

It is possible to reduce this impedance by applying a back pressure to the production borehole thus pressurizing the reservoir and inflating the fractures. However this also reduces the total pressure drop across the reservoir and does not always result in an increased flow rate. For reservoirs operating at zero back pressures it is possible to develop a simple economic model to calculate generating costs. The results of such an analysis yields the curves shown in figure 6. The 1980 generating costs in the UK were 2.2p/kWhe so an impedance of 0.1/GPas/m^3 will be required for economic operation (White 1981).

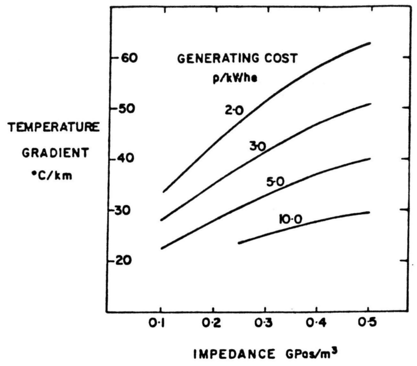

Figure 6: Optimum generating costs (1980) for Hot Dry Rocks. CEGB selling price was 2.2p/kWe for same period.

Sedimentary Basins

Feeedwater Heating: The extraction of heat from moderate temperature permeable strata in sedimentary basins is a proven technology with the French pioneering the use of production reinjection doublets. With a maximum temperature of just 120°C, the low conversion efficiency of the Rankine cycle would, at first sight, preclude the direct generation of electricity from these sources. However it is possible to generate greater quantities of electricity from a given low temperature source by incorporating the geothermal fluid into a conventional steam power cycle (Kestin et al. 1978). All the steam-driven power stations in the CEGB, and most other utilities, have feedwater heaters which use steam bled from the turbines to preheat the boiler feed water (fig. 7). These are employed since it is a consequence of the second law of thermodynamics that the heat of combustion of the fuel will be converted into work with a greater conversion efficiency, the higher the boiler inlet temperature. The geothermal heat may be supplied to the steam cycle by replacing some of the feedwater heaters and allowing the bled steam to remain in the turbine, thus generating more electricity (fig. 8).

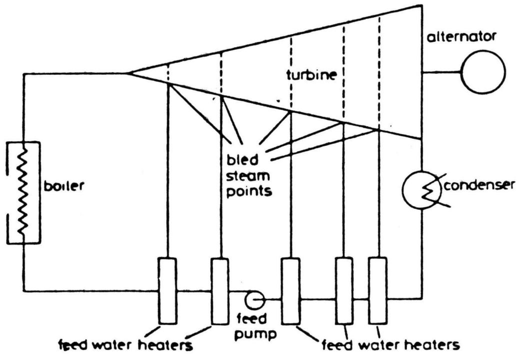

Figure 7: Conventional boiler cycle.

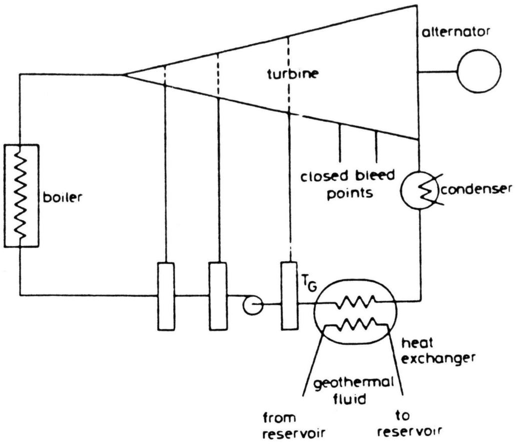

Figure 8: Boiler cycle modified to accept geothermal heat.

An analysis of the thermodynamics of such a hybrid plant indicates that the efficiency with which the heat contained in this steam is converted into work is determined by its enthalpy at the bleed point and at the condenser. Varying the geothermal temperature T_G just alters the quantity of steam so saved and not the conversion efficiency (White 1980). Conversion efficiencies of as high as 11% for geothermal well head temperatures of 100°C may be expected whilst the efficiency of a Rankine turbine generating from the same source will probably be less than 6.5% (Milora & Tester 1976).

Marchwood Experiment: The UK Department of Energy required a site to drill an exploratory geothermal well to help assess the geothermal potential of the Hampshire Basin. The CEGB offered the free use of a site adjacent to an old 8 x 60 MWe oil fired power station which could later be provided with feedwater heating should the borehole encounter a suitable reservoir.

The extra steam flow thorough the last stages of a turbine provided with feedwater heating could cause reduction in a stage efficiencies and so a simulation experiment was performed using two turbines.

A crosslink was made between two adjacent sets which allowed the interchange of the inlets to the third feedwater heaters. The turbines were run for a period of one hour with the bleeds to feedwater heaters 1 and 2 of set A closed (fig. 9). In this way, set A experienced external feedwater heating and the fuel efficiency ζ, or heat rate, of the set was determined. The crossover was then removed, and the sets were run in the normal condition (fig. 10). The change in fuel efficiency of set A between the two runs enabled a calcula-

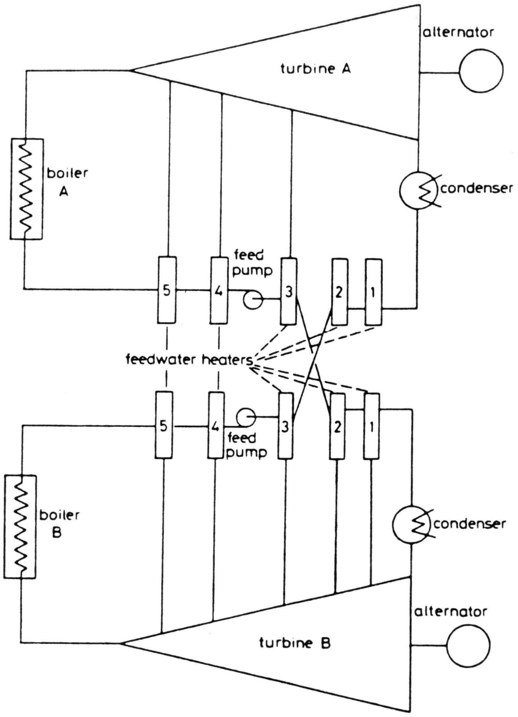

Figure 9: Crosslink experiment for simulated geothermal feedwater heating.

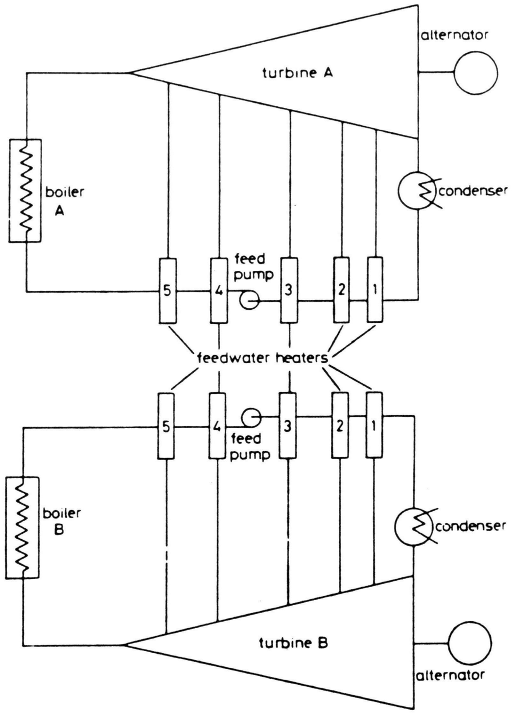

Figure 10: Normal operation.

tion to be made of the extra output caused by using geothermal heating to keep the inlet temperature of the third feedwater heater at 90°C. The result of the test was an increase in fuel efficiency of 2.8 ± 0.2 % equivalent to a conversion efficiency of 11%.

Further calculations showed that the last stages of the turbine suffered a decrease in efficiency of 0.5 ± 0.5%.

The 2.8% increase in output was accompanied by a 16% increase in pressure drop from bleed point 1 to the condenser and a 6% increase from bleed point 2 which could severely affect the blades' lives if the turbine were run for some time in this off design mode. Ideally a new power station, built over a suitable geothermal resource, would have feedwater heating included in the design stages with the turbines' final stages being suitably increased in size.

Unfortunately, the Department of Energy well encountered water at a shallower depth than expected, the water temperature being just 70°C, not the predicted 90°C. No decision has been made by the department if and how to use the well. Paper studies, however have shown that aquifer 3km deep at 100°C having a transmissivity of about 3.5×10^{-4} m^2/s could produce electricity competitively with fossil fuel, if used in a hybrid station (White 1979).

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