PROCEEDINGS

of the

THIRD ANNUAL CONVENTION

Jakarta, June 3—4
1974

INDONESIAN PETROLEUM ASSOCIATION

GEOTHERMAL ENERGY DEVELOPMENTS IN THE UNITED STATES

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INTRODUCTION

Mr. Chairman, members of IPA, distinguished guests, I appreciate the invitation to present a paper on geothermal energy to this distinguished audience. I regret being unable to attend this meeting in person because of unexpected developments, but I am pleased that my experienced colleague and associate is able to read this paper on my behalf.

GEOLOGY

Geothermal Energy is in the broadest sense, the "natural heat of the earth", but as a practical matter this is not available to us for capture. Normally we think of geothermal energy in terms of the "fluids" that are in contact with hot rocks and that can be captured and from which the energy can be extracted.

It is well-known that the temperature within the earth is considerably higher than at the surface and this difference causes heat to flow towards the surface. This heat flow occurs everywhere but we are not normally aware of this.

The normal geothermal gradient is about 3 degrees F. per 100 feet, or at a depth of 15,000 feet the temperature equals about 300° F. This temperature is too low and too deep to capture. However, in certain areas, molten rock or magma, formed at great depths in the crust, succeeds in working itself very close to the surface causing a sharp steepening of the geothermal gradient which may be ten times the normal gradient or more.

The areas of above normal heat flow and steepening of the geothermal gradient occur in zones or belts that extend around the world. These zones are usually zones of crustal weakness and are characterized by such phenomena as frequent earthquakes, volcanic activity, steep, geologically young mountains, etc.

Such bands or belts extend from the tip of South America through North America, Alaska, and around the Western Pacific, such as Kamchatka, Japan, and the Philippines to Indonesia, along Southern Asia into Southern Europe. In there bands much of the world's seismic activity is consentrated. Please note that these zones of seismic events also delineate the areas of active volcanic activity, characterize mountain chains, and are associated with areas of geothermal development. Chile, Mexico, Geysers, Kamchatka, Japan, Philippines, New Zealand, Italy, Iceland. Incidentally, according to the newest theory of "plate tectonics" these seismic bands mark the borders of the stable, but moving, continental plates, with adjacent "subduction zones". In these mobile areas of weakness, magma succeeds in working itself closer to the surface. If, somehow, groundwater is adjacent to these magmatic bodies or is mixed with hot gases and steam emanating from the crystallizing molten rock, it will be heated and begins to rise to the surface causing such phenomena as hot springs, geysers, and fumaroles.

Hot water in a continuous column is subjected to the pressure of its own weight, raising the boiling point of water progressively with depth. For instance, at 1,000 feet, water boils at a temperature of about 420 degrees. If a well is drilled deep into a fissure which is bringing thermal fluids to the surface, the hot water can be relieved of its overlying pressure and will flash into steam. The higher the temperature, the higher the ratio of steam to water when it comes to the surface. If the original heat content of the rocks is high, or the

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formation fluid pressures are below normal, the fluid may occur in superheated form and be all in the steam phase, and from the well it can be directly piped into the generating plant. In the case of flashed "hot water" a steam separator is required. The excess water is then disposed of. It is thought that the hot water geothermal fields will be by far the most abundant.

HISTORICAL DEVELOPMENTS

The first utilization of natural steam to generate power took place at Larderello, Italy, in 1904, in a hot springs and fumarole area that was repeatedly described through history, among others by Dante, in the 13th century. Larderello is 40 miles west of Florence. By World War II, it was producing 100,000 kw, but the plants were completely destroyed by the retreating German armies. After the war they were rebuilt and expanded, and current production is about 385,000 kw. New discoveries have been made south of Larderello.

New Zealand initiated a geothermal power project after World War II at Wairakei, New Zealand, prompted by its severe power needs. By 1954 eighteen wells produced enough steam for 20,000 kw power. By 1958 the production was 65,000 kw. Current power capacity is about 190,000 kw.

In the United States the major geothermal development is at The Geysers, located about 90 miles north of San Francisco. The developments began in 1960 with a 12,500 kw generating plant. There is now an installed generating capacity of about 412,000 kw, the largest geothermal development in the world. In the Jemez Mountains of New Mexico, north of Albuquerque,Union Oil recently announced a geothermal discovery, for which we hold great promise. Another area that has been much in the news is the Imperial Valley of California, where very hot, but very saline geothermal fluids have been encountered.

DRILLING TECHNOLOGY AND PROBLEMS

The geologic occurrence of geothermal resources is in areas of high heat flow, associated with igneous intrusive, extrusive, metamorphic rocks, much faulting and fracturing and mountainous setting. These are the conditions referred to, by geologists as "hard rock" conditions, mining type country. These are areas to sink shafts and tunnel, but not for drilling deep holes. Oil drilling tools were really developed for "soft rock" country. Yet in geothermal areas we start drilling where the self-respecting petroleum geologist ceases; it is referred to as "basement" in oil country.

For these reasons, the drilling of geothermal wells can be plagued with problems; hard, tough rocks, crooked holes, formation fluid pressures deviating from normal hydrostatic, causing blow-outs or lost circulation conditions. The elevated temperatures will affect the drilling fluids and drilling tools, causing metal fatigue and frequent failures and fishing jobs. Also, in well completion and cementing, heat is a serious problem. Finally, the naturally occurring gases such as H_2S and CO_2 can lead to exceedingly corrosive conditions, particularly at elevated temperatures affecting drill string and other equipment. As a consequence, costs of geothermal wells are frequently higher than oil wells of equivalent depth.

However, we are proud of our accomplishments, and progress has been made in the drilling of geothermal wells. In The Geysers of California, we are drilling regularly to about 9000 feet; in other areas to 7000 and 8000 feet. Yet much more progress needs to be made in all areas, improved metallurgy, better tools, better drill bits, new drilling fluids, new cement technology and whole new drilling procedures. We are experimenting with many new concepts and we hope it will begin to pay off soon.

UTILIZATION OF THE ENERGY

The heat energy of the geothermal systems is normally in the range of 450 to 600°F, which is considered "low quality" heat by fossil fuel standards. For this reason, the most efficient utilization of the energy would be for the purpose of "process heat" in industrial applications. But the distance over which the energy can be transported is very limited, approximately one mile. Beyond this, there is too much heat or pressure loss. For this reason the utilization for process heat calls for a unique set of circumstances bringing the resource and the industrial application together in one single geographic setting. There are a few such unique developments, such as space heating in Iceland, and certain towns in the United States, paper industry in New Zealand, but they are exceptional. By far, the largest application of geothermal energy is to generate electric power. It is not the purpose here to describe the steam power cycle commonly used in the power industry. Let me suffice by saying that a pound of steam coming from a man-made boiler or from the earth's boiler is undistinguishable and the steam turbine does not know the difference. Accepting then that electric power can be generated, and transported over a transmission system, the development of a geothermal deposit will solely depend upon the available load centers requiring the energy. In the United States a dense power grid brings now every geothermal deposit within reach of such a load center and good deposits will see ready development. In other areas of the world, however, the transmission cost to take the energy to the market is an additional factor that needs to be considered in evaluating the feasibility of geothermal power in comparison with an alternative source of electric power such as coal, nuclear or oil, where the fuel can be transported to its point of utilization and the generating plants.

In the United States, geothermal power is now developed in increments of 50 to 100 Mw which appear to be optimum blocks of power for the number of wells required, the pipeline distance and size and cost of the turbine. At increments of 100 Mw geothermal power is economically competitive with energy produced by fossil fuel and nuclear plants of about 1000 Mw. size that enjoy the advantage of economy of scale.

Many developing countries cannot handle such large increments of 1000 Mw to their installed capacity and smaller blocks of fossil power are uneconomic. This makes geothermal power a very attractive form of power generation in the developing countries that have the geologic potential.

ESTIMATES OF POTENTIAL

The Geysers field has now an installed capacity of over 400 Mw. and its potential is rated at about 1000 Mw. Over a 30-year life this is equivalent to approximately 400 million barrels of oil, an important energy supply by any standard.

Estimates are that with known or nearly known technology, approximately 12,000 to 15,000 Mw. can be installed by 1985, provided there are no major institutional impediments to development such as overly restrictive environmental considerations.

Further estimates project the potential of 75,000 Mw. of geothermal power by the year 2000, but this may call for additional technology, such as advanced power cycles, utilization of "low temperature" geothermal deposits in the range of 250-300°, and development of the hot "dry" rock technology.

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