PRESENT STATUS AND PROSPECTS OF YANGBAJAIN GEOTHERMAL FIELD

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ABSTRACT

This paper presents the preliminary results of a geothermal project executed by the United Nations through its Department of Technical Cooperation for Development. The characteristics of the wells are examined, together with the distinctive features of the reservoir (permeability, temperature, pressure) and the fluid produced with special emphasis given to its composition and scaling tendency. The surface equipment and the existing power plants (1 MW + 2 x 3 MW) are described and their behavior during operation is discussed.

The operating aspects are outlined, along with the future prospects for the exploitation of the resource.

INTRODUCTION

General Background

Although the application of geothermal energy for power production got off to a late start in China, it has developed very rapidly. Since 1970, various kinds of experimental geothermal power plants have been installed, in Fengshun (Guangdong Province), Huailai (Hebei Province), Huitang (Hunan Province), Wentang (Jiangxi Province), Xiongyue (Liaoning Province), Xiangzhou (Guangxi Autonomous Region), and Zhaoyuan (Shandong Province). The total installed capacity of the foregoing plants is about 8.5 MW.

Tibet has extensive geothermal resources owing to its special geological configuration. According to data provided by the comprehensive scientific exploitation team sent to Tibet by the Chinese Academy of Sciences, there are 612 hot water sources in all, of which 354 have been investigated in situ.

In order to meet the urgent electricity demand of the Tibet region, the government has decided to give priority to the exploitation of geothermal energy at Yangbajain. The first 1 MW experimental unit was put into operation in October 1977, and another two 3 MW pilot units were erected soon thereafter. Due to improvements made on the units and the thermal cycle, electric power generation is continuously increasing. In the first 3 months of 1984, the power plant generated 1.2 x 10^7 kWh, ranking it first among the plants of the Lhasa network.

Considerable technical and financial efforts have been allocated to the study and development of the Yangbajain field.

Worth stressing is the comprehensive joint activity carried out by Chinese and Italian experts during 1983 and 1984 in the framework of project CPR 81 011 signed by the government of China and the United Nations and concerning "Exploration, development and utilization of geothermal resources in China."*

Location and Geothermal Framework

The Yangbajain field is located at an elevation of 4300 m, some 90 km northwest of Lhasa, in a narrow intramontane plain extending northeast to southwest.

The valley bottom is crossed by the Zan Po River, whose flow rate varies greatly between winter (~1 m^3/sec) and summer (~ 400 m^3/sec). Temperatures range between 0 to 10° C. The ambient temperature of the Yangbajain plain has a pluriannual average of 2.5° C, with historical

The views and opinions expressed in this paper are those of the authors and do not necessarily reflect those of the United Nations.

*This project is being implemented under contracts between the United Nations and the Italian companies ENEL and AQUATER (ENI).

extremes of +24° C and -30° C.

The structural setting of the Yangbajain area is characterized by a narrow, elongated, recent graben trending northeast-southwest, which separates the Tang Range from the Nyaingen-Tanglha Range. This graben is linked with a regional displacement that was active during various periods in the past.

The upper portion of the graben is filled by Quaternary lacustrine and fluviolacustrine sediments of variable thicknesses (up to several hundred meters) whose coarse levels represent the reservoir now being exploited. The temperature of this reservoir is 150 to 170° C.

Many thermal manifestations, both active and fossil, are present in some parts of the Yangbajain valley and at the margins of the graben.

Geothermal exploration in this area began in late 1974. The geological, geochemical and geophysical surveys conducted in 1974 - 75 made it possible to identify a promising area of 14 to 15 km^2 (Figure 1), where drilling activities were undertaken.

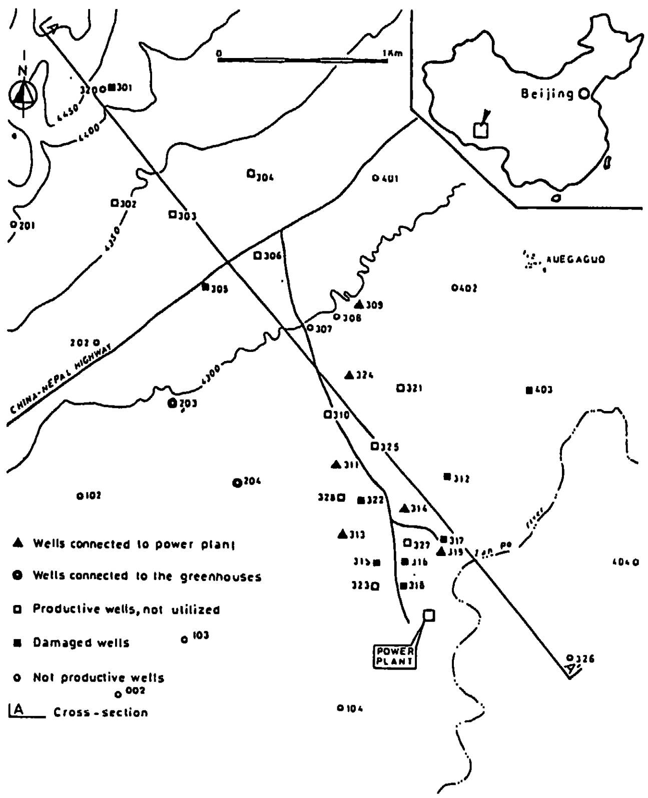

Figure 1. Location map of Yangbajain geothermal field

CHARACTERISTICS OF THE FIELD

Wells Drilled

So far 42 wells have been drilled (Figure 1), with depths ranging between 43 and 603 m. One well (ZK-308) was deepened for exploratory purposes to 1726 m, within the granitic body underlying the Quaternary sediments.

Excluding the exploratory wells, which are smaller in diameter, the wells have generally been drilled with diameters ranging from 15½" to 8½". The productive layers are completed with a slotted liner of 9⅝" or 7".

No particular difficulties are encountered in drilling, aside from control of mud losses or fluid overflows. The success ratio has proved to be high.

Reservoir Characteristics

On the whole, the terrains crossed are attributable to the Quaternary sediments filling the graben (gravels, sands, silts and clays), at times cemented in lenses or layers by hydrothermal circulation, and at times with the presence of layers of lacustrine facies. In the southeastern part of the field, pyroclastic products are found below the Quaternary sediments, made up of rhyolitic-dacitic ash flows cropping out at the southern edge of the graben. A continuous granitic bedrock is present at shallow depth, characterized by cataclastic features probably linked to tectonic orogenic stresses and by widespread hydrothermal alterations. The latter form veins and patches of calcite, quartz, epidote and chlorite.

Figure 2 shows a cross section of the field, with a schematic flow pattern.

Hot waters rise through deep-reaching faults of the granitic bedrock, then spread into the porous Quaternary sediments. Impermeable layers of sedimentary (lacustrine clay, silt) or hydrothermal origin (sinter) act as the cover to this system.

The temperature distribution inside the shallow reservoir is quite homogeneous, ranging between 150 and 160° C, with a sharp decrease of temperature at the border; higher values (172° C) are recorded only in the northwestern sector (see Figure 3). This hot water field is located in correspondence to an uplifted block of bedrock within the graben clearly evidenced by both drilling and geophysical surveys.

A noteworthy feature of the temperature distribution in several wells is the evidence of an inversion, with a temperature maximum at 100 to 150 m depth.

The deep exploratory well ZK-308 proved that the temperature decrease extends deep into a tight granitic bedrock. Below 1000 m the temperature again rises and the thermal gradient is about 40° C/km (Figure 4).

The pressure distribution is quite smooth, with a very low horizontal gradient from northwest to southeast.

In the southern part of the field, the wells are artesian, with a shut-in pressure of about 2 bars abs. On the other side, in the topographically higher wells in the north, the water level is below the ground.

Transient tests performed in the summer of 1984 showed that the permeability is very high (up to 10 Darcy) in the inner part of the productive zone, whereas towards the borders of the field, values one or two orders of magnitude lower are found.

The back-pressure curves of the wells presently connected to the power plant are shown in Figure 5. Two distinct groups displaying different characteristics in both wellhead pressure and flow rate can be recognized. The average enthalpy of the produced fluid is 650 kJ/kg, corresponding to the value of saturated water at reservoir temperature. This indicates that the wells are fed with water, without evaporation in the formation.

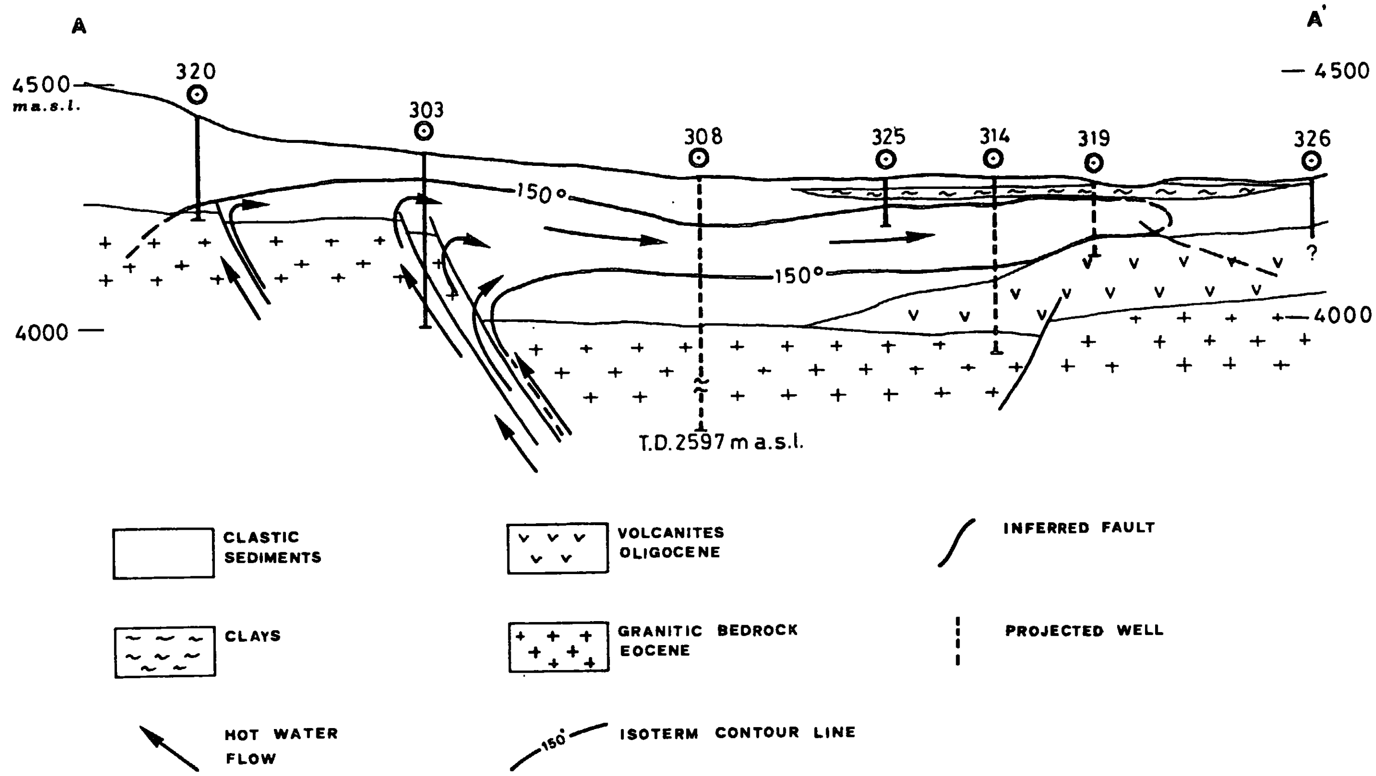

Figure 2. Cross section through Yangbajain geothermal field. See Figure 1 for line of section.

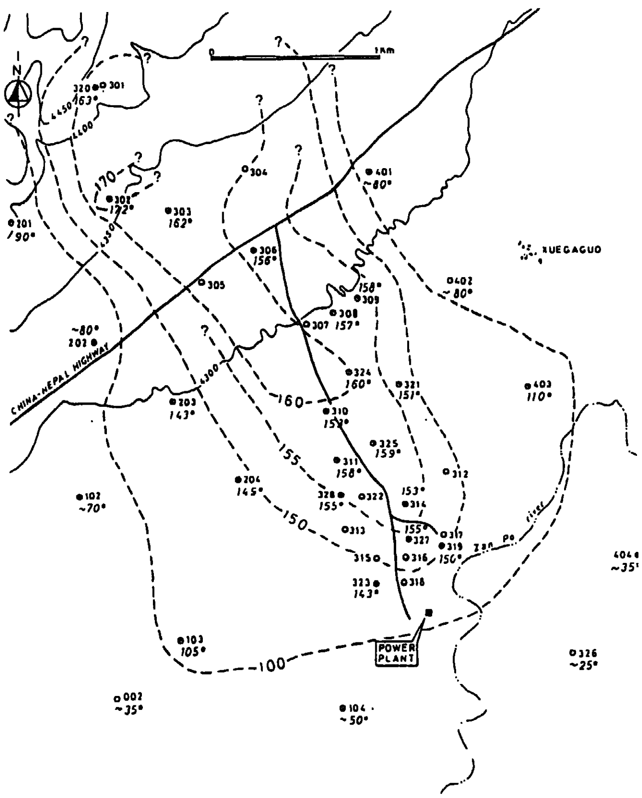

Figure 3. Map of the maximum recorded temperatures

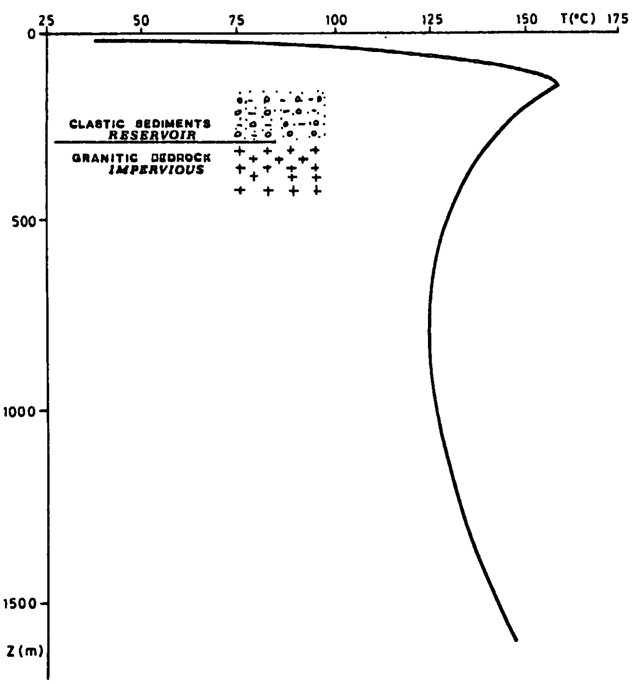

Figure 4. Temperature profile of well ZK-308

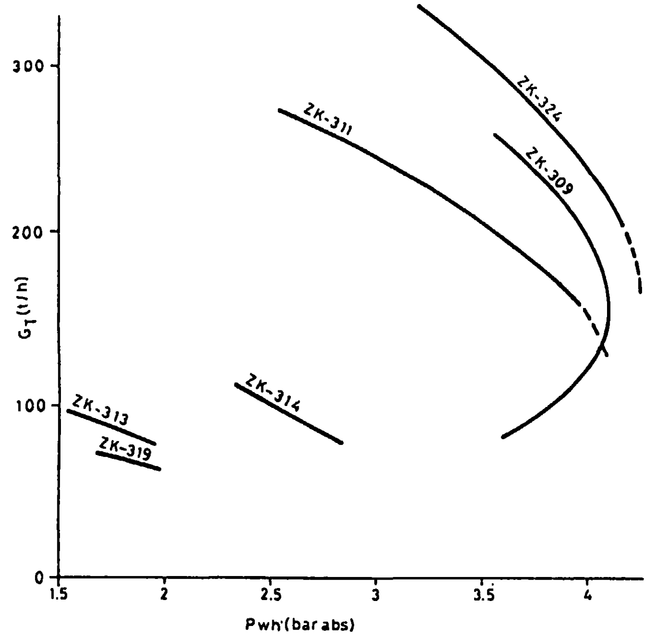

Figure 5. Back-pressure curves

Chemical Composition of the Fluid

The chemistry of the fluid produced by the wells drilled in the Yangbajain area is sodium chlorinated bicarbonate, with a TDS inside the reservoir of about 2100 mg/l. This value holds quite steady in the central part of the field, while in the outlying areas it tends to fall, evidently due to the phenomenon of mixing with meteoric waters.

In some "sterile" wells drilled in the zones to the north, fluids whose chemical and isotopic characteristics can only be explained by the ingress of condensed steam are present.

On the basis of samplings made at wellbottom, the average composition of the fluid can be summarized as follows: pH $\simeq$ 6.00; $Na^+ \simeq$ 450 mg/l; $K^+ \simeq$ 50 mg/l; $CA^{++} \simeq$ 15 mg/l; $Mg^{++} \simeq$ 0.25 mg/l; $Cl^- \simeq$ 500 mg/l; $HCO_3^- \simeq$ 420 mg/l; $SO_4^{--} \simeq$ 40 mg/l; $SiO_2 \simeq$ 220 mg/l; $H_3BO_3 \simeq$ 320 mg/l; $Fl^- \simeq$ 11 mg/l; $Li^+ \simeq$ 10 mg/l; $Rb^+ \simeq$ 1.1 mg/l; $Cs^+ \simeq$ 5.5 mg/l; $Br^- \simeq$ 1.6 mg/l.

The Ca^{++} in the reservoir conditions turns out to be in equilibrium with the formations the fluid circulates in. Thus, the abrupt rise in pH (approximately 2 units), resulting from degassing phenomena during the production process, leads to considerable supersaturation of the calcium ions with respect to their carbonates, and consequently to deposition of $CaCO_3$ in the well.

POWER PLANT

The power plant is presently composed of one 1-MW unit (Unit 1) and two equal units of 3 MW each (Units 2 and 3). Work on installing an additional 3-MW unit started at the beginning of 1984. All the units are of the condensing type and the cooling water is supplied directly from the Zan Po River.

The uncondensable gas extraction from the condenser is done by means of water ejectors.

Unit 1

This first experimental unit was put into operation on October 1, 1977. It is of the single flash type.

The unit was mainly used for comprehensive testing on the first wells drilled and to provide fundamental data for the design of further geothermal units, in addition to training the operators and satisfying the electricity demand of the construction site. This turbogenerator was manufactured in China in 1958.

Units 2 and 3

These units were put into operation in December of 1981 and at the end of 1982.

They are of the double flash type in order to increase the thermal efficiency; with the same steam conditions it is in fact possible to generate 20 percent more electricity than with the single flash type.

The main design specifications of the 3-MW units are given below:

Turbine Data	Type	Single-cylinder, two-stage entry, impulse condensing turbine (D) 3 - 1.7/0.5)
	Rated capacity	3000 kW
	Speed	3000 rpm
	Inlet condition: 1st/2nd stage pressure and temperature	1.7/0.5 bar abs 388/354° K
	Exhaust pressure	0.09 bar abs
	Steam flow 1st/2nd stage	22.7/22.3 x 10^3 kg/hr
Condenser Data	Type	Tray-type mixing condenser with barometric discharge
	Pressure	0.08 bar abs
	Cooling water temperature (design value)	16° C
	Cooling water flow (design value)	1575 x 10^3 kg/hr
	Locating elevation	6.5 m
Gas Extractor Data	Type	Water jet ejector (CS-185)
	Number	3
	Extraction pressure	0.078 bar abs
	Discharge pressure	0.65 bar abs
	Extraction flow	185 kg/hr

The gas content in the first stage steam is 1÷1.5 percent by weight.

The schematic flow diagram is given in Figure 6.

Due to the wellhead pressure and fluid enthalpy, the transportation of the geothermal fluid is carried out in separate phases. Separation takes place at the wellhead by means of a separator. This makes it possible to limit pressure drops during transportation.

As regards the extraction of uncondensable gas from the condenser, water ejectors have been installed because the pressure of the first stage steam (1.7 bars) is too low for economical steam consumption using steam ejectors.

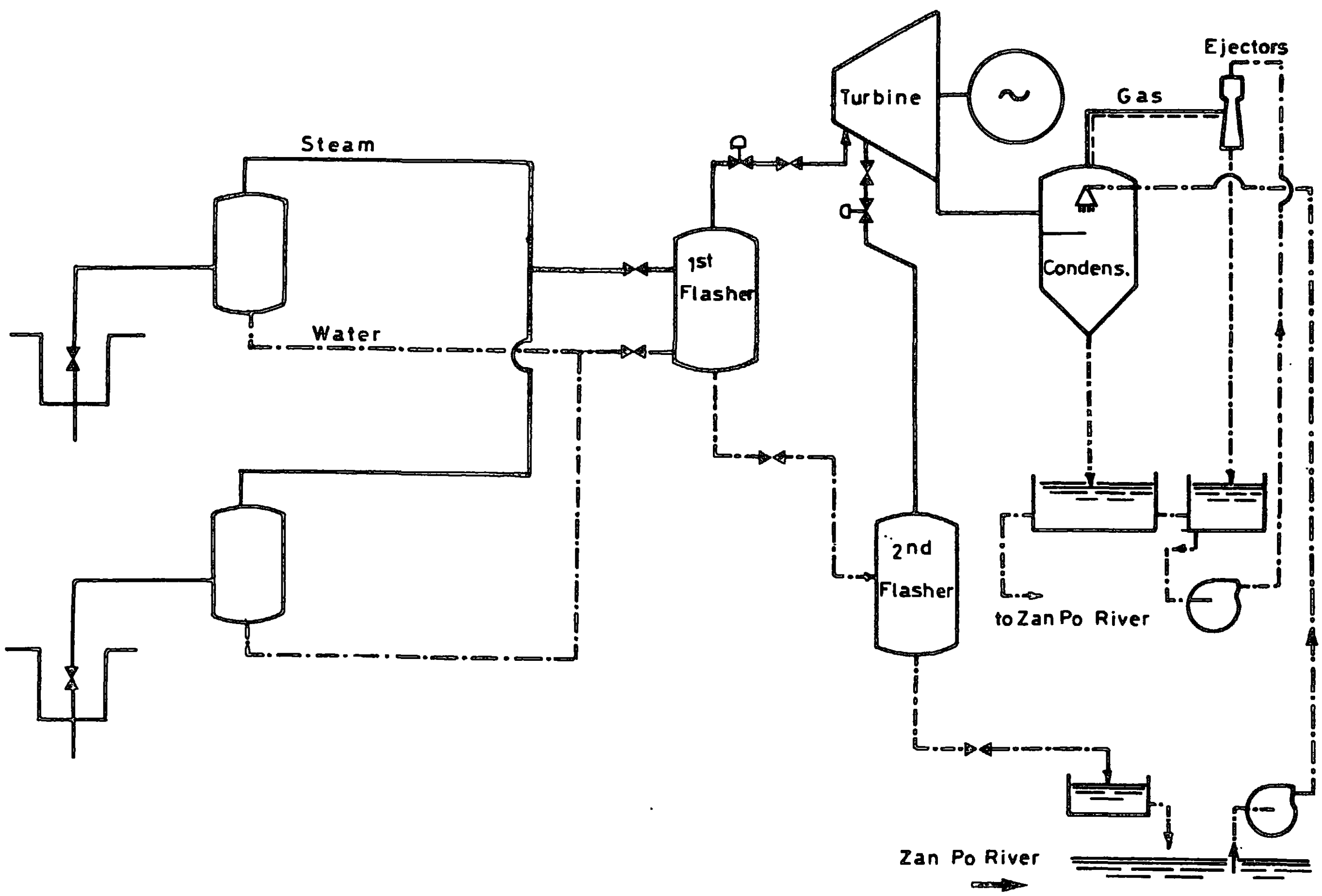

Figure 6. Schematic flow diagram of Unit 3

OPERATING ASPECTS

Scaling

The composition of the scale in the wells and the deposition mechanism have been determined. The major constituent in the deposits is $CaCO_3$; in some of the wells it amounts to as much as 90 percent. In a few wells, SiO_2 accounts for a significant proportion (wells ZK-309 and ZK-319).

Mechanical removal of the deposits in the casing is successfully carried out in all wells, with a cleaning frequency of 2 to 3 days. The operation is performed by means of an easy to handle apparatus featuring low-maintenance costs.

Each wellhead is provided with a hoister (10 to 20 kW) for lowering a heavy tubular tool into the well for the cleaning operation. While the work is being done the well does not feed the power plant but does discharge to the atmosphere in order to eject the removed scaling.

At the end of the job, which requires only two workers, the cleaning tool is positioned inside a stuffing box mounted on the wellhead.

Corrosion

Corrosion problems are present mainly in the condenser-ejector circuit of the power plant due to the low pH value in the circulating water with the presence of oxygen and chlorides.

The corrosion rates measured in the condenser and ejector pool waters are very high for carbon steel and cast iron, while the stainless steels show very good behavior.

Failure of the impellers of circulating pumps in fact occurs within about two months and the foreseeable life of other parts of the vacuum circuit is 3 to 4 years (at an average corrosion rate of 1 to 2 mm/year). It is therefore necessary to try alternative solutions to the use of carbon steel alloys.

Environmental Aspects

The main environmental aspects regard the presence of subsidence, and water and air pollution. As far as subsidence control is concerned, a benchmark network has been set up and level control measurements are now in progress. To date no significant subsidence phenomena have been registered.

The water pollution in the Zan Po River varies from month to month during the year. It is particularly high in the winter months, when the flow rate of the river is considerably reduced and the power plant runs at full load. This pollution derives both from the power plant discharge and from the presence of numerous thermal manifestations along the river itself. Controls are carried out by means of repeated samplings of the river water upstream and downstream from the power plant.

Air pollution, due to the presence of H_2S, is limited to the area surrounding the power plant and the wellheads and does not represent a serious problem.

HOT WATER UTILIZATION

Comprehensive utilization experiments have been carried out on a large scale. Since 1976, bathrooms with hot water, heating systems and greenhouses have been installed on the construction site. These direct utilizations have yielded remarkable results in terms of energy savings and economic benefits. Taking the greenhouses as an example, vegetables can be grown all year round; the average production per square meter per year is about 15 kg. In other words, the production per mu (about 666 m^2) is up to 10,000 kg annually, which is extremely good for a region 4300 m above sea level.

CONCLUSIONS AND FUTURE PROSPECTS

— With the exploratory wells drilled during 1984, the areal extension of the reservoir under exploitation appears to be defined (Figure 3). In this shallow layer, the hot water supply is from northeast to southwest.

— The bedrock of the Yangbajain field is mainly granite with a thermal gradient of 40°C/km. Well ZK-308 is the deepest one in the field (1726 m depth); it is sterile and the temperature measured at 1600 m is only 145°C (Figure 4). It thus appears uneconomical to exploit the hot water in the granitic body except that in faults.

— Scaling and corrosion are still priority items for study in the near future. Scaling prevention tests will be carried out by injecting, with suitable equipment, a scaling inhibitor into a production well below the flash level. Moreover, the use of downhole pumps is envisaged to prevent the deposition of $CaCO_3$ inside the well and to increase wellhead pressure and production considerably. With this solution, however, the $CaCO_3$ deposition will occur in the flashers.

— By adopting downhole pumps, saturated steam at higher pressures can be obtained. In this way it is possible to utilize the steam ejectors to maintain the vacuum in the condenser, replacing the water ejectors presently installed.

The installation of downhole pumps will permit the transport of hot water, under pressure, from the reservoir to a preliminary flashing stage, operating at about 4 to 5 bars abs., located at the power plant. From this unit most noncondensing gas will be released together with the steam necessary to feed the steam ejectors. The water from the preliminary flashing stage will feed the first flasher and then the second flasher, as in the scheme of Figure 6.

The above solution will make it possible to eliminate most of the operating problems (corrosion, erosion, maintenance) now present in the condenser, water ejectors and water circuit.

— The hot water discharged from the power plant must be fully utilized. On the basis of 10 MW, considering the new unit under construction also, each day a total of about 20 x 10^3 t of hot water at a temperature of 80°C will be discharged.

The most effective ways to utilize this low-enthalpy source are: (a) to build more greenhouses for growing vegetables and also to supply heat for homes and bathrooms; (b) to generate additional electricity using a binary cycle system. For this second solution a technical and economic evaluation must be completed before building the plant.

— The choice of the capacity to be installed depends on both the potential of the resource and on the characteristics of Tibetan energy sources. While the geothermal power plants run at full load during the winter period, in the summer months, when the flow rates of the rivers are high due to the melting of the glaciers and it is thus possible to produce electricity with hydroelectric plants, they work at quite low load. Their annual load factor is therefore low as well.

— Due to the urgent electricity demand of the Lhasa region, especially in the winter time, the government has decided to install another 2 x 3 MW unit at Yangbajain by 1986 (construction began on one of the units in 1984). The total installed capacity will then amount to 13 MW.

— The scale of exploitation of the Yangbajain geothermal field is rather limited, considering the limited size of the reservoir currently being exploited, together with the low temperatures encountered in the granitic bedrock. So the exploitation of other geothermal fields, such as Yangyixiang and Laduogang, is becoming very urgent.

In conclusion, the exploitation of Yangbajain and of the other geothermal fields represents an important contribution to meeting the electricity and heating demand of the Lhasa region.