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The Present Status of Utilization of Geothermal Energy and Resources Research by the Aid of Japanese Government in Yangbajing Geothermal Field, Tibet, China

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ABSTRACT

Geothermal power generation of Yangbajing field has already operated over 25 years. Presently, although power capacity is 25.18MW, power output is about 15MW and reduction of power output has been obvious. Now geothermal fluid is extracted only from a shallow reservoir, while in the recent years it has been revealed that a deep, high temperature geothermal reservoir exists in the Yangbajing north field. So exploration and development of this deep reservoir is a important subject at Yangbajing. From 2001, a project started exploration and evaluation of the deep reservoir, conducted with Japanese Government aid. The project included not only geophysical and geochemical surveys but also drilling a deep exploration well and reservoir evaluation. Presently, drilling is being conducted. Hereafter, development of the deep reservoir and construction of a third geothermal power station is an important issue. In order to use the shallow reservoir properly, reservoir monitoring, improvement of reinjection system, measurement of scaling and corrosion, and conservation of the natural environment are also important subjects.

1. INTRODUCTION

The Yangbajing geothermal field has had initial exploration and development utilization since 1975. Nowadays the total capacity of Yangbajing geothermal power station is 25.18 MW. But the power station equipment has become obsolete through 26 years of running. The problem of corrosion and scaling in wells and pipes has not been solved. For effective utilization of the high-temperature geothermal resource, Japan International Cooperation Agency (JICA) of Japanese Government has given assistance for exploration of the deep reservoir in northern Yangbajing geothermal field.

This paper introduces the present status of Yangbajing field and the research project conducted with the aid of JICA.

2. GENERAL SITUATION OF YANGBAJING GEOTHERMAL FIELD

The geothermal reserves of Tibet are ranking the first in China. The geothermal resources of Tibet are distributed over a wide range, with high temperature and vast reserves. The Yangbajing geothermal field is known all over the world. The Yangbajing geothermal field has had initial exploration and development utilization since 1975. The Yangbajing geothermal field is located about 90 km northwest of Lhasa, the capital city of Tibet. The field is divided into southern and northern parts by the China-Nepal highway. The total area of the field is 14.62 km^2, of which the area of the southern part is 7.393 km^2, while the northern part is 7.227 km^2. The capacity of the total field can reach 34 MW and has been exploited continuously for 30 years to use the dynamic supply reserves and the static (accumulated) reserves (Table 1).

Table 1: Exploitation parameters of Yangbajing geothermal field

Exploitation mode	Exploitation parameter	Southern part S=7.393 km^2	Northern part S=7.227 km^2	Total field S=14.62 km^2
Single exploitation Q(dynamic)	Capacity of generation (MW)	12.5965	16.6211	29.2586
	Total flowrate of hot water (t/h)	1799.5	2380.3	4179.8
	Flowrate of single well (t/h)	100	90	95
	Wells	18	26.4	44
	Density of well (wells/km^2)	6.89	8.67	7.78
	convert into area of single well (km^2)	0.145	0.115	0.129
	Average distance of wells (m)	380	340	359
Mixed type exploitation Q(dynamic + static)	Capacity of generation (MW)	14.88746	19.22676	34.11422
	Total flowrate of hot water (t/h)	2126.78	2746.68	4873.46
	Flowrate of single well (t/h)	100	90	95
	Wells	21.26	30.5	51.3
	Density of well (wells/km^2)	8.14	10.02	9.07
	convert into area of single well (km^2)	0.123	0.1	0.11
	Average distance of wells (m)	350	316	332

According to the geological, geophysical and geochemical surveys, the logging data of well ZK4002 and ZK352, and the geothermal investigation of the northern part of the field by the Geothermal Geological Team of Tibet in 1993, there are deep high-temperature geothermal reservoir layers at different depths in the area about 3.5 km^2. It is estimated that the electric generation potential can be reach 90 MW. Well ZK4001 was drilled in 1995 for further investigation of the deep geothermal reservoir. It is determined that the well has a flowrate of 300 t/h of proven extractable reserves (of which 37 t/h is steam), and has electric generation potential of 12.58 MW. The parameters of the deep wells of northern Yangbajing geothermal field are shown in Table 2.

Unit 1 geothermal demonstration power station with 1 MW capacity was built in September 1977. The station has expanded the building several times. Nowadays the total capacity of Yangbajing geothermal power station is 25.18 MW. The electric power generation is about 100 million kWh per year, which provides 20% of the electric energy to the Lhasa electric network in summertime and 35% in wintertime. Yangbajing is the main power generation station of the Lhasa electric network. The total investment is 270 million Yuan RMB, of which the investment of geological and drilling work is 30 million Yuan RMB. The Yangbajing geothermal power station plays an important role in the Central Tibetan electric network (including Lhasa district, Shannan district, Xigaste district and Naqu district). The cumulative electric power output generated is 1.8 billion kWh until 2003. This provides significant contribution to industry and agriculture, and enriches people's living standard in the Tibet autonomous region.

Table 2: Parameters of deep wells of northern Yangbajing field

Well No.	Drilling time	Depth (m)	Lip pressure (MPa)	Highest temperature in well (º)	Flow rate (t/h)	Generation potential (MW)
ZK352	1987	974		202		
ZK4002	1993	2006.8		329		
ZK4001	1996	1459.09	1.5	251	302.4	12.58
CJZK3001	Designed depth 2500 m. Drilled to 2248 m at present. The temperature is 260 ºC at 1500 m.					

3. PRESENT STATUS OF YANGBAJING GEOTHERMAL FIELD AND POWER STATION

Until now, only the shallow reservoir has been utilized for electric generation. During the exploitation over more than 20 years, effects of exploitation have appeared such as land subsidence, dry up and disappearance of hot springs, boiling springs and geysers, pressure drawdown in the production wells, etc. The shallow reservoir shows visible signs of decline. The output of production wells can not reach the designed capacities. Many phenomena show that the production from the shallow reservoir is much greater than the recharge. The present status is described below:

3.1.1 The resources of the geothermal field

According to the management experiences in geothermal fields of other countries, the monitoring work of land subsidence, gravity surveys and well lip parameters were undertaken in Yangbajing geothermal field from 1983 to 1992. As there has not been long-term, continuous monitoring in Yangbajing, so far there is no reservoir model of the field. It is hard to describe the present status of geothermal field quantitatively.

The maximum value of land subsidence has been measured to be 276.6 mm from 1983 to 1991 (monitoring report of Yangbajing geothermal field, 1983 – 1991). The production wells, both in northern and southern area, can not discharge by themselves. The average static water levels in the production wells have drawn down by 45 m (measured at Yangbajing geothermal power station). Most active geothermal areas have disappeared (a former thermal water lake with 35 m depth has dried up).

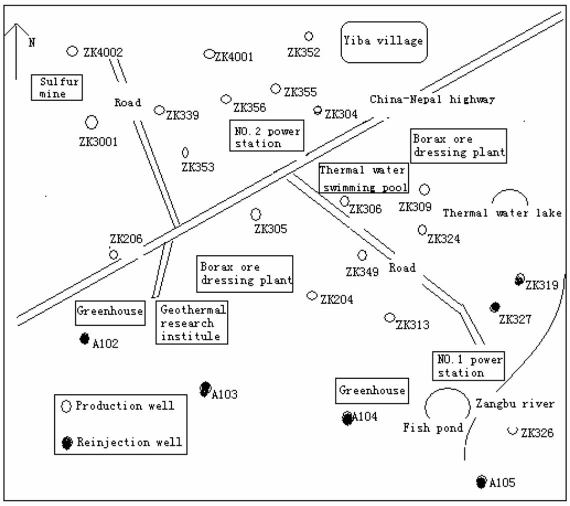

Figure 1: Location of power stations, wells of Yangbajing Geothermal field

There are about 60 production wells in both northern and southern areas, and now only 14 wells are used for power generation. This shows that the exploitation area of geothermal field has been reducing. The maximum temperature drawdown in production wells is 21ºC in both northern and southern area during the 26 years exploitation and utilization (Table 3).

Table 3: Wellhead parameter comparison between wells

	Well No.	1984		2003	
		Temperature(ºC)	Pressure(MPa)	Temperature(ºC)	Pressure
Southern field	ZK324	147	0.4316	126	0.162
	ZK309	146	0.4616	126.4	0.18
	ZK310	125	0.2916	110	0.13
	ZK319	130	0.3316	55	-
	ZK313	131	0.3316	67	-
	Well No.	1990		2003	
		Temperature(ºC)	Pressure(MPa)	Temperature(ºC)	Pressure
Northern field	ZK329	132	0.19	121	0.134
	ZK304	140	0.39	126	0.155
	ZK354	141	0.43	120	0.156
	ZK359	138	0.383	131	0.17
	ZK357	129	0.313	126	0.164
	ZK346	135	0.35	53	-
	ZK353	128	0.295	52	-

It is clear that drawdown is quite serious in Yangbajing geothermal field.

3.1.2 Reinjection and environmental protection

Yangbajing geothermal field has beenexploited for more than 20 years, and its exploitation effects have occurred quite clearly. That is, the geothermal resources is in depletion, and the environmental pollution is quite serious. The waste thermal water of the geothermal power station includes abundant deleterious elements. The discharge quantities of sulphide, fluoride and arsenic exceed the national standard. Reinjection is the best method for solving the drying up of geothermal resources and protecting the environment. The reinjection system is taken by reinjecting the waste water into the boundaries of the geothermal field. The reinjection wells are distributed along the boundary zone of the southern field. The reinjection zone and the reservoir production zone of the southern field are almost at the same depth. The temperature of the injection water is about 55ºC. The reinjection system has been built through three construction periods from 1990 to 1998. Eight reinjection wells have been drilled. Six wells are in use, but the effect is not good. The maximum injection volume is 18,500 tons per day, which is 37% of the waste water of the geothermal power station. This has improved of the environmental pollution to a small degree. But there are some technical problems about the location, structure, and equipment of the reinjection wells. Monitoring of the reinjection has not been undertaken so far. Thus, the impact on the reservoir due to the reinjection is not clear.

3.2 Present status of the geothermal power station

The cumulative energy output of Yangbajing geothermal power station is 18×10^8 kWh so far. At the initial time of exploitation, the plant could generate 9 kWh of electricity energy by using 1000 kg of geothermal fluid. But now it can only generate 4 kWh by using 1000 kg of fluid. To assume that 1000 kg of geothermal fluid can generate 6.5 kWh electricity energy, 2.77×10^8 tons of geothermal fluid have been consumed. The equipment of the power station have become obsolete through 26 years of running. The problems of corrosion and scaling in wells and pipes have not been solved. The temperature and pressure in production wells decline rapidly. Electric generation efficiency has declined from 6% at initial time to 4% (Tables 4, 5).

3.2.1 Thermodynamic system

Along with the continuous exploitation, the various parameters of geothermal field have changed. Although the thermal fluid pipelines have been rebuilt several times during the past 20 years, they do not fit the transportation of the geothermal fluid. There are four pipelines to transport the thermal water and steam by high and low pressure separately, but the transportation pressure does not adapt. The problems of water hammer, two-phase flow of water and steam, and the damage of the thermal-protection material result in a maximum temperature drawdown of 5º C/km. This causes the electric power generation to decrease by 0.105 MW in a 3 MW unit for the same flow rate.

3.2.2 Corrosion and scaling

Corrosion and scaling are the main technical problems of a geothermal power station. The geothermal fluid includes abundant of H_2S, SO_2, chloride, $CaCO_3$, and SiO_2. Equipment is corroded and scaled so that it cannot adapt to the requirements of the running parameters. Especially the thermal engineering control system has been largely out of action. Now the control system is operated by hand so that it is hard to guarantee equipment such as the steam turbine is running safely, constantly, and economically.

Table 4: Capacity and electricity output of Yangbajing geothermal power station

	No. of the power unit	Time of start running	Rated capacity (MW)	Maximum output ever (MW)	Present output (MW)	Rated capacity (MW)	Maximum output ever (MW)	Present output (MW)
No. 1 power station (southern field)	Unit 1	Sep. 1977	1	1	0	10 (Unit 1 stopped running since 1986)	10	4.8
	Unit 2	Nov. 1982	3	3	2			
	Unit 3	Dec. 1981	3	3	1.8			
	Unit 4	Jul. 1985	3	3	1			
No. 2 power station (northern field)	Unit 1	Oct. 1986	3.18	3	1.7	15.18 (Unit 1 is made in Japan, FUJI company)	15	10.5
	Unit 2	Jan. 1989	3	3	2.6			
	Unit 3	Jan. 1989	3	3	2.6			
	Unit 4	Jan. 1991	3	3	1.8			
	Unit 5	Jan. 1991	3	3	1.8			

Table 5: Main technical standard of 3 MW steam turbine set made in China

Steam turbine D3-1.7/0.5	Rated power	3MW	Steam flasher	First step operating pressure	0.18 MPa
	Maximum power	3.56MW		Second step operating pressure	0.06 MPa
	Rated rotation speed	3000r/min	Condenser	Operating pressure	8×10^{-3} MPa
	First time steam pressure	0.167MPa	air removal jet	Operating pressure	0.4 MPa
				Operating quantity of water	750 T/h
	Second time steam pressure	0.049MPa		Bleed air flow	185 kg/h
	First time steam consumption	22.7T/h	Generator QFD-3-2	Rated power	3MW
	Second time steam consumption	22.8T/h		Rated voltage	3.15KV
	Pressure of steam discharge	8.8×10^{-3} MPa		Rated rotation speed	3000r/min

3.2.3 Comprehensive utilization

The temperature of the waste water of the power station is 80 – 100ºC. Comprehensive utilization of the waste water for crop production, livestock breeding, tourism, processing of livestock product, and other industries, can not only economize the resource and reduce the pollution, but also gain the ideal economic, environmental, and social benefits. Nowadays there are greenhouses with gross area of 50,000 m^2, a fish farm with gross area of 20,000 m^2, two processing plants for borax ore dressing to use waste water directly. There is a thermal water swimming pool to use the waste water for tourism.

4. DEVELOPMENT AND UTILIZATION PROSPECT OF GEOTHERMAL ENERGY IN TIBET

The great western development movement is taking place in China; the Qinghai-Tibet railway will be built and open to traffic. Rapid development of the economy in Tibet needs a large amount of electric energy. Energy is quite absent in Tibet. Thermal power generation, for which the transportation cost of fuel is more expensive, has problems of poor economic efficiency and environmental pollution. Due to the influence of the climate and landform, it has more difficult to develop hydropower. Most hydroelectric power plants of the Central Tibetan electric network (include Lhasa district, Shannan district, Xigaste district and Naqu district) are run-of-river type plants. Their adjustment ability is poor, and the structure of the power sources is inconsistent. Lack of electricity is very serious in the winter low flow season. It is estimated that there will be a gap of 50 MW electric capacity in the Central Tibetan network until 2006.

Geothermal energy is a kind of renewable energy that has less pollution to the environment, simplicity of utilization techniques, safety, and credibility. Nowadays, the valuable geothermal fields for development and utilization in Tibet are the deep northern geothermal reserve in Yangbajing, as well as Yangyi, Langjiu, and Naqu geothermal fields. To make the energy structure consistent and to relieve the lack of energy in Tibet, it is essential to develop and utilize the abundant geothermal resources. In order to realize sustainable development of utilization of the geothermal resources and to protect the ecological environment in the development process, the works hereinafter must be done.

4.1 To enhance the scientific research work on geothermal resources, comprehensive evaluation of the development and utilization of shallow reserve in Yangbajing geothermal field

In order to realize sustainable development of utilization of the geothermal energy, it is necessary to find out the cause of the decline in the geothermal reserve. To reach this aim, comprehensive monitoring of the whole geothermal system is necessary. (1) To set up the geological model of geothermal reserve, to estimate the shape of the deep geothermal reserve, the ransportation mode of geothermal energy, the storage status of the medium carrying the thermal energy, and the cycle and exchange mode of the thermal flow. (2) To set up the reservoir engineering model. Such a model can be used to determine the dynamic changes the parameters of heat flow, to forecast the varying tendency of heat flow in the exploitation process, to establish the optimum exploitation scheme with reinjection, and to prolong the lifespan of shallow reservoir of Yangbajing geothermal field. (3) To research and test techniques of anticorrosion, antiscaling, and descaling, and to optimize the thermodynamic system.

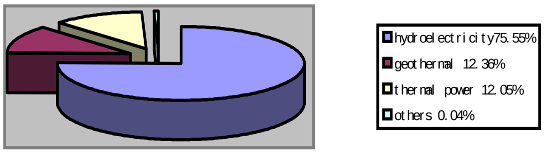

Figure 2: Proportion chart of power source in Central Tibetan network

4.1.1 Contents of comprehensive evaluation

(1) Reservoir engineering testing of geothermal field.

This includes testing of well parameters (temperature, pressure, flowrate) in 14 production wells and 15 surrounding observation wells. Flowrates and other tests of production wells will be taken using PRUETT logging tools and lip-pressure method. The production well discharge tests will be taken also. These tests can obtain the wastage of shallow reserve by comparing the data with the initial values.

(2) Reassessment and to carry out reinjection project.

According to research and tests of the reinjection effects of the original design scheme, the reinjection scheme will be modified, to increase reinjection gradually to 100%. Finally the aim is to keep the reinjection system in running order. That can solve the problems of environmental pollution and groundwater recharge during the exploitation of the geothermal resource.

(3) Monitoring of environmental pollution by waste water from the power station, to evaluate environmental capacity and to define the feasible discharge amount of waste water.

(4) To optimize thermodynamic system and to evaluate technical reformation scheme of electrical generation equipment.

(5) Research and testing of anticorrosion, chemical antiscaling, and descaling methods.

To refer to the advanced technology of descaling from both home and abroad, research into the feasibility of antiscaling by chemical and electromagnetic methods will undertaken, finally to choose economic chemical methods of antiscaling.

(6) To create and complete the monitoring system of the geothermal field.

(7) To evaluate the economical efficiency of the comprehensive utilization system of waste water.

By comprehensive analysis of testing and monitoring, and by comparing with the data and information obtained from the initial time of development of the field, finally a conceptual model of the shallow reservoir will be completed. At the same time, the project will create the database of development and utilization of the shallow reservoir and whole monitoring system of the geothermal field. It is suggested to monitor geothermal reservoir drift, land subsidence, well head parameters, production parameters, reinjection parameters, environmental parameters, and seismic data, to create the reservoir model of geothermal field. The model will combine the information of reservoir engineering, power generation engineering, reinjection engineering with discharge testing data of wells ZK4001 and CJZK3001, to evaluate the deep geothermal reservoir of the northern field, which can then be used to develop and utilize the geothermal resources more reasonably.

4.1.2 To undertake investigation on deep geothermal resources in northern Yangbajing field

There is a huge potential of development and utilization of the deep geothermal resources in Yangbajing field. It has important significance to develop the deep geothermal resource, to build a new geothermal power station and enlarge the capacity of Yangbajing field. The investigation must enhance the work of comprehensive research on the deep geothermal resource, to work out schemes of exploration, development, and utilization. Finally the study must realize a new step of capacity and electric generation technology of Yangbajing power station.

4.2 Development of Yangyi geothermal field

Yangyi geothermal field is located 55 km southwest of Yangbajing field. The area of the field is 10.769 km^2. Wellhead temperatures are about 200°C. The B degree exploitation quantity, which was authorized by Chinese mineral reserve committee, can be a design consideration to build power station. The mineable quantity of geothermal fluid is 16,500 tons/day, which is equivalent to 38,300 kcal/s of thermal energy. The geothermal field has the capacity to support a power station with 30MW capacity. A feasibility study report was finished in 1995, in which the design of 2×6MW units were specified in the first period of building the power station. According to the experience in Yangbajing, to make first-phase preparations of Yangyi geothermal power station, it is necessary to create a geological model, a reservoir engineering model and an ecological environmental protection system.

4.3 To establish the No. 3 geothermal power station in Yangbajing

Through the discharge test of well ZK4001, and drilling and discharge of well CJZK3001 with the aid of JICA, a comprehensive analysis can be taken of the status of the deep high-temperature reservoir of Yangbajing geothermal field. According to the evaluation results of the deep high-temperature reservoir, it is possible to draw up the development and utilization plan, to establish the No. 3 geothermal power station, which can relief the lack of electricity in the central Tibet area.

5. GEOTHERMAL RESOURCES - JAPANESE GOVERNMENT ASSISTED RESEARCH

5.1 Outline

Until recently, China conducted field exploration and development of geothermal resources at Yangbajing geothermal field with their available technology, with resources extracted only from shallow depth up to 300m. Chinese exploration during the 1990's, with additional research conducted with UN assistance, revealed that a high temperature deep geothermal reservoir exists in the Yangbajing north field at a depth of 1000m to 2000m.

The Power Company of Tibet planned to develop this deep reservoir and construct a new geothermal power station, but they have neither the technology nor funding required to explore and develop such a deep high temperature reservoir. Therefore, the Chinese government was asked to request assistance from Japan, perhaps through the Japanese Official Assistance Program. The Japanese government accepted the request and started an aid project conducted by Japan International Cooperation Agency (JICA).

This aid project is a cooperative project between China and Japan, with both sides bearing some expense, with the primary goal of exploration and evaluation of resources, including the transfer of certain required technology to China. JICA entrusted the operation of this project to Japan Metals & Chemicals Co., Ltd (JMC).

5.2 Project scope and schedule

This project consists mainly of the following: geological survey, geochemical survey, electromagnetic survey, in addition to drilling of a deep exploration well (CJZK3001), discharge tests, and reservoir evaluation conducted by computer simulation. The JICA project began in 2001 and is expected to be completed in 2005.

5.3 Geological servey

Several geological surveys have been conducted in the past, so a complementary survey was conducted as part of this project. This survey confirms that there exist fault systems in both NE-SW and NW-SE directions in the Yangbajing field. The NE-SW fault system is harmonic with elongation of rock alteration zone and elongation of the high temperature zone in the shallow reservoir. In addition, the NE-SW fault system sometimes cuts the alteration zone. This data suggests that the NE-SW fault system is the dominant fault system controlling the reservoir.

5.4 Geochemical survey

Between September and October 2001, geothermal fluid samples were collected and analyzed from geothermal wells, river water and hot spring water. These data were examined, compared with existing data, and the resulting information was used to construct a geochemical model of Yangbajing field. This data will also be used as a starting point to monitor long term changes in geothermal fluid, as such monitoring has not been conducted up to now.

An outline of the geochemical model for this shallow reservoir is as follows:

- All available geochemical data collected to date except ZK4001 well (November 1996) are data collected from shallow reservoir fluid.

1) The geothermal fluid in the shallow reservoir is produced as a mixing of the geothermal water around ZK4001 well and the surface water since 2001.

2) The geothermal fluid flow in the shallow reservoir from the north region to south region, recognized until 1996, is very weak or nonexistent since 2001.

3) The shallow reservoir at north field seems to draw the long seated fluid from the surrounding region.

- Up to now there has been very little data available from deep reservoir geothermal fluid, so a comprehensive geochemical model of combined shallow and deep reservoir fluid is not yet possible. The JICA project includes plans for long-term discharge tests of CJZK3001 and ZK4001 wells (the only deep wells now available). After these tests are complete, a comprehensive geochemical model of the field will be constructed.

5.5 Electromagnetic survey

Between September and October 2001, an electromagnetic survey was carried out at Yangbajine north field. Conditions of the survey included: measurement of Ex and Ey in electric field and Hx and Hy in magnetic field using a 70m long electric dipole source, at 60 sites along 4 lines by wide-band MT (remote reference); measuring frequency and time are 100Hz and from 1000 second to 20 hours respectively; with data analyzed in both 1-D to 3-D.

The result of this electromagnetic survey did not clearly show details of the deep reservoir, but it indicates a deep-seated discontinuity of resistivity, which exists past the nearby ZK4001well and stretches in the NE-SW direction.

5.6 Drilling of exploration well

As one component of the JICA project, in order to explore the deep reservoir of Yangbajing north field, a 2500m exploratory well is planned. This well will be drilled with cooperation between China and Japan and will thus be known as "CJZK3001".

The target of drilling has been decided from data obtained until this time as a NE-SW fault zone which controls the deep reservoir. Because this fault zone inclines to the SE side, a directional drilling is planned for the SE side of the fault zone toward the NW direction in order to be sure to hit the fault zone. As Yangbajing has no experience with directional drilling, the technology for directional drilling is one key factor in technical transfer to China. JICA has contracted this drilling operation to be carried out by the Tibet Geothermal Geological Term.

Although the drilling operation started in autumn 2002, many factors delayed completion until autumn 2004, including inability to operate at midwinter, significant losses in drilling circulation fluid needed to measure at the shallow reservoir, and an intermission caused by the SARS epidemic in China.

CJZK3001 once hit a deep reservoir between 1000m to 1300m. But in order to continue exploring deeper areas, this reservoir was covered by casing pipe and drilling was continued. When the well reached 2254m, because data indicated there were no further deep reservoirs, drilling was stopped. From 877m well was sidetracked and a discharge test was conducted using the reservoir at 1000m to 1300m depths.

5.7 Reservoir evaluation

Up to now, a sufficient reservoir evaluation had not been conducted, so this was included in the JICA project plans. For the reservoir evaluation, monitoring of reservoir pressure and chemical change of some wells was started.

At this time, a discharge test of existing deep well ZK4001 is being prepared, and a discharge test at CJZK3001 is planned. In addition, a reservoir evaluation using a computer simulation of the reservoir has begun.

6. CONCLUSION

Although presently Yanbajing geothermal power station has some problems, there is a lot of hope for the future. We hope that any country government and any organization will give powerful aid to Yanbajing.

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