GEOHERMAL POWER PLANTS OF THE SOVIET UNION
A TECHNICAL SURVEY OF EXISTING AND PLANNED INSTALLATIONS

by

Ronald DiPippo

Southeastern Massachusetts University
North Dartmouth, MA 02747

Brown University
Providence, RI 02912

January 1979

Performed under
Department of Energy
Division of Geothermal Energy
Contract EY-76-S-02-4051.A002

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

fy

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

This report describes some of the geothermal areas in the Soviet Union which may support electric generating stations. The plants at Pauzhetka (single-flash steam), at Paratunka (Freon binary), and at Bolshoye-Bannoye (multi-flash steam) are described in technical detail. The reference list contains some of the most recent sources of information on geothermal power plant developments in the Soviet Union.

ACKNOWLEDGEMENTS

This work was performed as part of the effort to draft the Sourcebook on the Production of Electricity from Geothermal Energy, a project of the Division of Geothermal Energy, Department of Energy, C. B. McFarland, Project Manager, J. Kestin, Principal Investigator.

TABLE OF CONTENTS

	<u>page</u>
1. Introduction	1
2. Pauzhetka	2
3. Paratunka	4
4. Bolshoye-Bannoye	7
5. Makhachkala	8
6. Yuzhno-Kurilsk	8
7. Conclusion	9
References	10
Tables	12
Figure Captions	14
Figures	

1. Introduction

Although the Soviet Union has a huge potential of moderate-temperature geothermal waters which may someday be exploited for space or process heating, the only known sites which are being used or contemplated for electric power production are located on the Kamchatka peninsula, well-removed from the main population centers. Whereas the potential for direct heating from geothermal resources is estimated at 48,000 MW (thermal) [Tikhonov and Dvorov, 1970], the geothermal electric power capacity may be only in the order of hundreds of megawatts.

An extensive survey of potential geothermal applications in the Soviet Union concentrated on non-electrical uses, but there were identified several areas in the Kurile Islands and on the Kamchatka peninsula where electric power plants could be installed [Makarenko, et al, 1970; Tikhonov and Dvorov, 1970]:

1. Pauzhetka
2. Uzono-Semyachik
3. Mutnovo-Zhirovo
4. Bolshoye-Bannoye
5. Goryachy Plyazh (Yuzhno-Kurilsk).

All of these sites are in regions of recent volcanism which are characterized by dramatic surface thermal manifestations.

The locations of several major hydrothermal areas on the Kamchatka peninsula are shown in Fig. 1. The major population center of the area, Petropavlovsk-Kamchatskiy, is within 75 km (47 mi) of several of these geothermal prospects. By and large the resources are of low-to-moderate temperature and are situated in relatively shallow reservoirs (< 1 km). Some typical temperature profiles

are shown in Fig. 2. The highest bottom-hole temperatures have been found at the Pauzhetka site, e.g., about 200°C (392°F) at 400 m (1312 ft.).

It is known that at least two geothermal power plants have been in operation in Russia and that several others have been mentioned as either under construction or in planning. These include the flash-steam plant at Pauzhetka, the binary plant at Paratunka, the multiple-flash steam plant under construction at Bolshoye-Bannoye, and the steam plants proposed for Makhachkala and Yuzhno-Kurilsk. Each of these will be discussed in the sections which follow.

2. Pauzhetka

Approximately 20-25 wells have been drilled at the Pauzhetka geothermal area. These each produce roughly 36 t/h (79,000 lbm/h) of steam and liquid. The geofluid is a mixture of liquid and vapor having a dryness fraction of about 9%. The wellhead pressure lies between 196 - 392 kPa (28 - 57 lbf/in²). The fluid carries 1000 - 3400 ppm of total dissolved solids, of which about 250 ppm is silica. The noncondensable gases amount to slightly more than 0.05% (by weight) of the geofluid mixture (or 0.6% of the steam) with the bulk of the gases being CO₂ (92%), and the rest being mainly H₂S (4%) and NH₃ (3%) [Tikhonov and Dvorov, 1970]. The composition of the geothermal liquid from a typical well at Pauzhetka (well No. 4) is given below [Vakin, et al, 1970]:

Cl = 1633 ppm,	Na = 986 ppm,	H ₂ SiO ₃ = 216 ppm,	K = 105 ppm,	SO ₄ = 78 ppm,
Ca = 52 ppm,	CO ₃ = 22 ppm,	HCO ₃ = 4 ppm,	Mg = 3.5 ppm,	NH ₄ = 0.6 ppm
TDS = 3448 ppm,		T _{dh} = 195°C (383°F), pH = 8.2.		

At present, a separated-steam plant of 5 MW capacity is in operation at Pauzhetka. The plant is owned and operated by the Kamchatka Electricity Production and Distribution Administration. The plant began production in 1967. About 9 wells are required to supply the station. The steam piping from the wells to the power house ranges in diameter from 210 - 370 mm (8.25 - 14.5 in) and totals 1.3 km (4300 ft) in length. The steam pipes are made of carbon steel.

The design of the plant is simple and straightforward; a flow diagram is given in Fig. 3. Cyclone separators with mist eliminators in the upper part yield steam of approximately 0.995 dryness fraction. The 5 MW output is obtained by means of two 2.5 MW turbines arranged in tandem. The machines were manufactured by the Thermal Turbine Machine Construction Plant at Kuluga, and are situated in a turbine room that has a floor area of $33 \times 9 = 297 \text{ m}^2$ ($108 \times 30 = 3200 \text{ ft}^2$). The condensers are of the direct-contact type, made of stainless steel, with 11 m^3 (389 ft^3) of steam volume, and are fitted with 118 nozzles through which the cooling water is sprayed.

A summary of the technical particulars for the unit may be found in Table 1 [Naymanov, 1970]. On the basis of the data in Table 1 and assuming a geofluid wellhead dryness fraction of 9%, the plant would have a resource utilization efficiency of 54% and would consume 56 kg/kW·h (123 lbm/kW·h). However, values as low as 5% have been reported for the geofluid dryness fraction [Tikhonov and Dvorov, 1970], and this would reflect a much lower utilization efficiency, i.e., 28%. The actual value probably lies somewhere between these limits.

Power from the plant is transmitted to the town of Pauzhetka, the Ozernovsk fishing combine, and the collective farm at Krasnyy Truzhenik. The power line carries electricity at 35 kV and is 30 km (19 mi) long [ARPA, 1972].

The geothermal liquid which is separated at the wellheads is discharged into the Pauzhetka River at a temperature of 110°C (230°F) and at a rate of 100 kg/s (220 lbm/s). There were plans to make use of this hot fluid for the heating of greenhouses although it is not known whether such plans have been implemented as yet [Tikhonov and Dvorov, 1970]. The same authors also reported that the cost of electricity from the Pauzhetka geothermo-electric station is less by a factor of 10 to 15 than electricity generated by diesel power plants on the Kamchatka peninsula.

Although it has been reported that there were intentions to expand the capacity of the plant to 12.5 MW, and eventually to 20 MW, these intentions remain unfulfilled at present [ARPA, 1972]. The ultimate potential of the Pauzhetka reservoir has been estimated at between 50 and 70 MW of electrical power [Tikhonov and Dvorov, 1970].

3. Paratunka

The Paratunka geothermal power plant was an ambitious attempt at providing a form of total-energy system, albeit on a rather limited scale. The power plant was a binary-fluid cycle which employed refrigerant-12 as the working fluid in conjunction with geothermal waters at temperatures as low as 81°C (178°F). The power from the plant served a small village and several soviet state farms. Furthermore, the geothermal water, after leaving the power house and having been cooled to 45°C (113°F) in the plant's heat exchangers, was put to use to heat the soil in a series of greenhouses. Finally, the cooling water leaving the condensers of the power plant was used to water the plants in the greenhouses. It is not possible to use the waters of the Paratunka River directly for this purpose because of their low temperature of 5 - 7°C (41 - 45°F).

It is generally acknowledged that the Paratunka plant was the first binary geothermal pilot plant to generate electricity, having begun operations in 1967. Although the plant apparently operated successfully for several years, it has been reported recently [Smith, 1978] that the power station has been closed and dismantled because of difficulties with leaks in the refrigerant-12 piping. Furthermore, the properties of refrigerant-12 are not ideally suited for geothermal applications [Naymanov, 1970]. Nevertheless, it is instructive to examine the details of the Paratunka plant.

The geothermal hot water is obtained from a number of shallow wells located about 1.5 km (0.9 mi) from the plant site. The wells range in depth from 302 - 604 m (991 - 1982 ft), and in diameter from 127 - 200 mm (5 - 7.875 in) [ARPA, 1972]. Eight wells were completed in 1964 before construction got underway on the plant; six wells were used to supply the plant with about 280 t/h (617×10^3 lbm/h) of hot water [Moskvicheva and Popov, 1970]. One well was kept on reserve. The composition of the geothermal water from a typical well (Stredne-Paratunka well No. 2) is given below [Vakin, et al, 1970]:

$\text{SO}_4 = 556$ ppm, $\text{Na} = 206$ ppm, $\text{Ca} = 71$ ppm, $\text{Cl} = 39$ ppm,

$\text{H}_2\text{SiO}_3 = 32$ ppm, $\text{CO}_3 = 19$ ppm, $\text{K} = 10$ ppm, $\text{F} = 2$ ppm.

$\text{TDS} = 935$ ppm, $T_{\text{dh}} = 90^\circ\text{C}$ (194°F), $\text{pH} = 9.0$.

A simplified flow diagram of the power plant is given in Fig. 4. The technical specifications are listed in Table 2. The values given in the table are the actual values achieved during the tests reported by Moskvicheva and Popov [1970]. In certain respects, these differ from the design values. For example, the hot water inlet temperature should have been

90°C (194°F), the cooling water from the Paratunka River should have been 5°C (41°F), and the condensation temperature of the refrigerant-12 should have been 15°C (59°F), instead of 81.5°C (178.7°F), 6 - 8°C (42.8 - 46.4°F), and 32°C (89.6°F), respectively. It should be noted, moreover, that the performance data quoted in the above reference leads to a negative pinch-point temperature difference in the geofluid/refrigerant-12 heat exchanger, a result which is prohibited by the laws of thermodynamics. This casts doubts on the validity of the data as reported.

Nevertheless, the efficiency of the energy conversion system may be determined in terms of the amount of hot water required for a given output. Figure 5 shows the hot water flow rate as a function of the gross power output. It may be seen that the actual fluid consumption was roughly 65% higher than the design value at 680 kW because of the 8.5 - 9°C shortfall in geofluid temperature. In fact, the actual fluid requirement exceeded the calculated value by about 9% at the actual temperature. The specific hot water consumption at maximum load (680 kW) was about 412 kg/kW·h (908 lbm/kW·h). This converts to a geothermal resource utilization efficiency of 23% (gross), or 15% (net) when 110 kW for the cooling water pump and 130 kW for the two refrigerant-12 circulating pumps is subtracted from the gross output. The turbo-expander reached an isentropic efficiency of 82% at full load, two percentage points below the design value.

The turbine-generator, three preheaters, the boiler/superheater, two condensers, and the associated auxiliary equipment were located in a machine hall which was 12 m wide, 24 m long and 8 m high (39 × 79 × 26 ft). A photograph of the turbine-generator is shown in Fig. 6.

The specific installed cost of the plant has been reported to be four times that of the other Soviet geothermal power plant which is located at

Pauzhetka. The high cost of Paratunka was attributed to the small size of the unit, the costs associated with the development of the unique halocarbon turbo-expander, and with the installation of the piping system to supply the adjacent greenhouse facilities [ARPA, 1972].

4. Bolshoye-Bannoye

It was reported in 1965 [ARPA, 1972] that a sophisticated, multiple-flash geothermal power plant was under construction at Bolshoye-Bannoye. Only twenty wells had been completed and the rate of construction was slow. It is not known whether or not the plant has been completed or in operation.

It was to have a rated output of 8 MW, and use two 2.5 MW low-pressure turbines and four 750 kW very-low-pressure turbines. A flow diagram for the plant is shown in Fig. 7. A mixture of geothermal steam and hot water from a number of wells is fed to a series of separators at a pressure of 152 kPa (22 lbf/in²). By the time the separated steam reaches the low-pressure turbines, the pressure has fallen to 101 kPa (14.7 lbf/in²). An intermediate flash tank generates additional steam at one atmosphere for the low-pressure turbines from the hot water which was separated at the wellheads. The remaining hot water is first collected in a receiver and then flashed successively to produce three streams of subatmospheric steam for use in a set of four multiple-admission turbines. The liquid effluent from the final flasher must be pumped back to atmospheric pressure for disposal.

Vakin, et al, [1970] reported the composition of the geothermal liquid from a typical well in the Bolshoye-Bannoye region (well No. 35) as follows:

SO₄ = 532 ppm, Na = 324 ppm, H₂SiO₃ = 290 ppm, Cl = 127 ppm, HCO₃ = 42.7 ppm,
CO₃ = 37.2 ppm, K = 25 ppm, Ca = 23 ppm, As = 0.12 ppm, NH₄ = 0.1 ppm
TDS = 1400 ppm, pH = 8.7.

Based upon the exergy of the geofluid at the wellhead and the indicated geofluid flow rate and power output, the plant would have a gross geothermal resource utilization efficiency of 35%, or a specific geofluid consumption of 90 kg/kW·h (198 lbm/kW·h). The quality of the geofluid mixture at the wellhead would be about 7 percent. The cost of electricity from the plant was estimated to be about one-sixth the cost of electricity from conventional sources serving the city of Petropavlovsk-Kamchatskiy [ARPA, 1972].

5. Makhachkala

A 12 MW flash-steam geothermal plant has been proposed to satisfy the electrical and heating requirements of the town of Makhachkala in the Dagestan ASSR. It is estimated that a total geofluid discharge of about 100 t/h (220×10^3 lbm/h) will be required to supply the plant. Very deep wells of the order of 4 - 4.5 km (2.5 - 2.8 mi) are needed in order to tap waters of 160°C (320°F) temperature. Water at 120°C (248°F) may be obtained from wells 2.5 - 3 km (1.6 - 1.9 mi) in depth. No other technical details on this plant have been made available.

6. Yuzhno-Kurilsk

A geothermal power plant of about 5 - 6 MW capacity has been proposed for the Goryachy Playazh geothermal area on Kumashir Island of the Kurile Island group, about 8 km (5 mi) from the town of Yuzhno-Kurilsk. The plant will be designed to use geofluids at 130°C (266°F). Numerous surface thermal manifestations exist in the Guryachy Playazh region, with several steam vents having temperatures of 100 - 130°C (212 - 266°F).

7. Conclusion

Beneath the surface of Siberia lies the largest known reservoir of geothermal hot water. This area is, however, sparsely populated, and besides, the temperature of the water is not high enough at presently drillable depths to permit the efficient production of electricity. This resource will likely be developed for domestic heating and agricultural purposes where it is feasible to do so.

With regard to the geothermal power plants in the Soviet Union, it is generally true that information is difficult to obtain, and once obtained, is difficult to confirm. The bulk of the information on which this report is based appeared in papers which appeared in the 1970 United Nations Symposium on the Development and Utilization of Geothermal Resources, Pisa, Italy.

It is known, however, that the Soviet research and development effort in geothermal energy has included the design, construction, and testing of a so-called "total-flow" turbine to make use of the total geofluid mixture as it emerges from the wellhead [Naymanov, 1970]. Recently, a report was issued which indicated that a plant of 50 - 70 MW capacity will soon be constructed at Nizhne-Koleshevskaya [ECPE, 1977], but no additional data were included. The same source also reported that plans are underway to tap the Avachinski volcano on the Kamchatka peninsula at a depth of 3.5 km (11,500 ft) in the hope of establishing a resource which might supply a 5000 MW geothermal plant for 500 years.

It seems that the Soviet Union intends to exploit its geothermal resources in such a way as to provide an efficient match between the characteristics of their relatively low-temperature hydrothermal fluids and the requirements of the selected applications, such as domestic space heating, agricultural soil heating, or electric power production.

References

Note: The following reference is cited several times:

Proceedings of the United Nations Symposium on the Development and Utilization of Geothermal Resources, Sept. 22 - Oct. 1, 1970, Pisa, Italy; Geothermics, Spec. Issue 2, Vols. 1 and 2, Pergamon Press, Inc., New York, 1970. (Referred to as Pisa-1970, hereafter).

ARPA, 1972, "Soviet Geothermal Electric Power Engineering", Report 2, ARPA Order No. 1622-3, Informatics, Inc., Rockville, MD.

ECPE, 1977, "5000 MW Geothermal Power Plant?", Energy in Countries with Planned Economics, Vol. 1, No. 4, Dec. 14.

Kutateladze, S. S., Moskvicheva, V. N. and Petin, Yu. M., 1975, "Applications of Low-Temperature Heat Carriers in Geothermal Energetics for Use as a Secondary Energy Source in Industry", Proc. Second U.N. Symp. on Dev. and Use of Geoth. Resources, San Francisco, CA., May 22-29, 1975, Vol. 3, pp. 2031-2035, U.S. Government Printing Office, Wash., D.C., 1976.

Makarenko, F. A., Mavritsky, B. F., Lokshin, B. A. and Konov, V. I., 1970, "Geothermal Resources on the USSR and Prospects for Their Practical Use", Pisa-1970, Vol. 2, pp. 1086-1091.

Moskvicheva, V. N. and Popov, A. E., 1970, "Geothermal Power Plant on the Paratunka River", Pisa-1970, Vol. 2, pp. 1567-1571.

Naymanov, O. S., 1970, "A Pilot Geothermoelectric Power Station in Pauzhetka, Kamchatka", Pisa-1970, Vol. 2, pp. 1560-1566.

Smith, R. A., 1978, "Soviet Failure", Geothermal Report, Vol. VII, No. 24, Dec. 15, p. 3.

Tikhonov, A. N. and Dvorcev, I. M., 1970, "Development of Research and Utilization of Geothermal Resources in the USSR", Pisa-1970, Vol. 2, pp. 1072-1078.

Vakin, E. A., Polak, B. G., Sugrobov, V. M., Erlikh, E. N., Belousov, V. I.
and Pilipenko, G. F., 1970, "Recent Hydrothermal Systems of Kamchatka",
Pisa-1970, Vol. 2, pp. 1116-1133.

Table 1

Technical specifications for Pauzhetka geothermal power plant

Year of start-up 1967

Turbine data:

Type Tandem-compound, single-flow

Rated capacity 2×2.5 MW

Steam inlet pressure 28.4 lbf/in^2

Steam inlet temperature 260.6°F

Noncondensable gas content 0.6% by weight of steam

Exhaust pressure 0.87-2.32 in Hg

Steam flow rate 59.5×10^3 lbm/h

Condenser data:

Type Direct-contact, barometric

Gas extractor data:

Type Water jet ejector

Water impeller power 170 kW

Heat rejection system:

Type Once-through, Pauzhetka River

Table 2

Technical specifications for Paratunka geothermal power plant

Year of start-up 1967 (now dismantled)

Turbine data:

Type Radial outflow

Rated capacity 680 KW

Maximum capacity 750 KW

Secondary working fluid Dichlorodifluoromethane, CCl_2F_2 (Ref-12)

Ref-12 inlet pressure 202.7 lbf/in²

Ref-12 inlet temperature 149°F

Ref-12 exhaust pressure 113.8 lbf/in²

Ref-12 exhaust temperature ~105°F

Ref-12 mass flow rate $\sim 640 \times 10^3$ lbm/h

Geothermal fluid data:

Inlet pressure 42.6 lbf/in²

Inlet temperature 178.7°F

Outlet temperature ~113°F

Hot water flow rate 617×10^3 lbm/h

Condenser data:

Type Surface type, shell and tube

Cooling water inlet temperature. . 43-46°F

Cooling water outlet temperature . 55-58°F

Cooling water flow rate 3.307×10^6 lbm/h

Heat rejection system:

Type Once-through, Paratunka River

Water pump power 110 KW

Figure captions

Figure 1. Location of hydrothermal areas on Kamchatka Peninsula , USSR

[after Vakin, et al, 1970].

Key: 1-Kireunsky; 2-Uzon-Geyserny; 3-Semyachinsky; 4-Nalychevsky;
5-Bolshoye-Bannoye; 6-Paratunka; 7-Zhirovshy; 8-Severo, Mutnovsky;
9-Khodutkinsky; 10-Pauzhetka, 11-Koshelevsky; 12-Petropavlovsk-Kamchatskiy.

Figure 2. Temperature profiles in wells in Kamchatka region [after Vakin, et al, 1970].

Key: 1,2-Paratunka wells No. GK-11, GK-3; 3,4-Bolshoye-Bannoye wells No. GK-2, GK-38; 5,6-Pauzhetka wells No. R-1, R-13; 7-Hydrostatic boiling curve.

Figure 3. Flow diagram for Pauzhetka flash-steam geothermal power plant [after ARPA, 1970].

Key: S-separator; T-G-turbo-generator; C-condenser; E-water-jet ejector.

Figure 4. Flow diagram for Paratunka binary geothermal power plant. Key:

1 - 2 -hot water inlet-outlet; H1, H2, H3-heaters; E-evaporator;
SH-super heater; T-G-turbo-generator; C1, C2-condensers; R-receiver;
P-pump.

Figure 5. Performance characteristics of Paratunka binary plant: hot water consumption as a function of gross power output, actual versus calculated [after Moskvicheva and Popov, 1970].

Figure 6. Paratunka turbo-generator unit [Moskvicheva and Popov, 1970].

Figure 7. Flow diagram for proposed multiple-flash plant at Bolshoye-Bannoye [after ARPA, 1972].

FIGURE 1

FIGURE 2

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7