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SOVIET GEOTHERMAL ELECTRIC POWER
ENGINEERING - REPORT 2

V. A. Stevovich

Informatics, Incorporated

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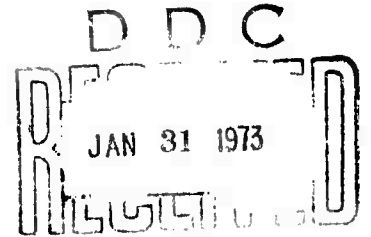
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INTRODUCTION

This report provides information on Soviet geothermal research and engineering associated with the design, construction, and maintenance of geothermal power plants and related facilities.

Besides a general outline of geothermal characteristics, emphasis in this report is on Soviet geothermal research and development, including engineering data on existing power plants, as well as those under construction and in the planning stages.

A number of interesting papers on Soviet geothermal research and development were presented at the United Nations Symposium on the Development and Utilization of Geothermal Resources, held in Pisa, Italy, in 1970. Unfortunately, as of this writing, Volume 2, Part 2 of the Symposium Proceedings, evidently containing all the Soviet papers, has not yet been published. However, many of the Soviet papers were reviewed individually in the Rapporteurs' General Reports of the eleven sections of the Symposium, presently available in "proof" form and soon to be published as Volume 1 of the Symposium Proceedings. The Proceedings of the Symposium are being published as Special Issue 2 of the journal Geothermics, Volume 2, Part 1 of which is already available.

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I. GENERAL ASPECTS OF GEOTHERMY AND GEOTHERMAL ENGINEERING

A. General

Natural surface manifestations of geothermal energy, such as hot pools, steam vents, geysers, mud volcanos, and mineral-thermal springs, have been known for a long time, but the broader significance of their economic potential has come under consideration only in recent years.

The economic potential of this energy was first recognized in Italy, where the first steam well was drilled at Larderello in 1904, and a total of 384.1 MW (1969) of electric power has been generated by natural steam [24]. New Zealand was the second country to utilize geothermal resources, and it already has a capacity of about 200 MW of electric power. Domestic and industrial heating by geothermal heat was initiated in Iceland in 1925, and over 100,000 people now live in houses heated in this manner.

Encouraged by progress in these countries, exploration and development programs were initiated in Burma, Chile, Colombia, El Salvador, Ethiopia, Guatemala, Japan, Kenya, Mexico, Nicaragua, Turkey, the Soviet Union, and United States. With growing interest in this natural source of energy, many more countries are expected to conduct exploratory work in the near future.

There are several projects within the framework of the Flowshare program which propose utilizing nuclear explosions for the recovery of natural gas and geothermal energy from dry geothermal anomalies. The Flowshare concept suggests the use of nuclear devices fired deep in natural hot rock to create a large cavity filled with fractured rock from which the sensible heat* can be removed. The removal of heat would be

*) Sensible heat is the heat involved in cooling a piece of any material like rock or water through a given temperature range. It is different, for example, from evaporation or fusion; it is the heat capacity itself that is removed.

accomplished through a closed-cycle flow of injected water or other coolants. This flow cycle (cavity - steam turbine - condenser - cavity) also will provide a slurry of various metal ores and chemicals, and a geothermal plant may develop into an unique base for the generation of electric power and the extraction of various marketable chemicals. Sites for such plants are possible wherever dry, hot geothermal anomalies are found. In this way, favorable geological formations can be selected in order to eliminate or substantially reduce the impurities in the natural steam system. In addition, this approach would greatly reduce the need to rely on the rare simultaneous occurrences of a number of geological factors necessary to produce geothermal steam of the required quality and quantity. From the practical point of view, geothermal energy represents only a very slight fraction of the internal heat of the Earth. The amount of the thermal heat of the Earth is at least 10^{33} cal and is more than ten times the caloric value of all exploitable fossil energy in the Earth and the nuclear energy of fissionable materials obtainable by mining. In fact, geothermal energy is essentially nuclear energy from a large natural nuclear reactor situated in the crust and mantle of the Earth [25]. Several optimistic experts, foresee future exploitation of the mantle, with highly advanced equipment, to tap geothermal energy almost anywhere on the Earth.

Economically significant concentrations of geothermal energy occur in local "hot spots" where high temperatures (70 to 340° C) are found in porous rock containing water or steam [26]. Such concentrations of extractable heat are known as geothermal reservoirs and are found either in regions of recent volcanism or in the deep areas of sedimentary basins. Based on geological exploration, the entire circum-Pacific belt, the African Rift System, the Lesser Antilles, Iceland, and the Italian-Aegean belt are areas of great geothermal significance. There appears to be an interrelation between the chemistry of lava erupted in these

zones and the frequency of areas with geothermal activities. Most, if not all, high temperature areas show a close connection with eruptive centers that have produced silicic lava or tephra in great amounts. However, manifestations of geothermal anomalies through natural fissures of permeable volcanic rock are noted at much shallower depths with temperature of 300°C at a few decimeters depth, and far higher temperatures (up to about 700°C) have been recorded in shallow holes drilled to depths of 27 meters [26].

The energy in a geothermal reservoir consists of heat stored largely in rocks and, to a lesser extent, of liquid water or steam stored in pores and fractures. The water and steam provide the means by which the heat from deep sources is transferred by convection to depths shallow enough to be tapped by drilling. They also serve as agents by which the geothermal heat escapes through conduction at the surface in the form of hot springs or fumaroles. For a geothermal reservoir to be of appreciable economic potential for exploitation, it must have:

- o relatively high temperature (66 to 210°C);
- o depth shallow enough to permit drilling (about 4000 meters or less);
- o sufficient rock permeability to allow the heat transfer agents (water and/or steam) to flow continuously at a high rate; and
- o sufficient water for recharge to maintain uninterrupted production.

B. Geothermal Prospecting

Several prospecting methods with novel approaches are still in testing and evaluation stages. However, the measurements of temperature gradients and heat flow rates are still the basic and most direct methods in geothermal prospecting. Geophysical surveying by electrical resistivity

methods for shallow- and medium-depth sites also is a present practice [27]. In general, the electrical resistivity methods have proven very reliable in geothermal prospecting, because of the direct relationship between the fluid and rock temperature on one hand, and electric conductivity on the other. They owe their effectiveness to the fact that the resistivity of water decreases noticeably as its temperature and content of ionized salts (e. g., sodium chloride) increases. Prospecting by the resistivity method can be hampered by several geological parameters such as: porosity, high fluid salinity, cementation, and clay content. However, through the effective application of common geological techniques, it is possible at times to isolate electrical resistivity changes due to temperature alone, and to calculate the geothermal gradients [27].

Airborne infrared sensing equipment is a relatively recent development in geothermal prospecting. Multiband photography (visible and infrared spectrum) and microwave radiometry are used to depict the anomalous spectral reflectance associated with hydrothermal alteration zones. The data obtained are correlated with ground control through detailed thermometric, gravimetric, and subsurface heat flow mapping. There are some factors influencing the quality of infrared records, such as solar radiation, diurnal variation of surface temperature, wind, fog or condensation, degree of emissivity, flight altitude, ground velocity and instrument characteristics. Direct measurements of temperature made on the ground are more accurate, but the airborne infrared method promises to be useful in reconnaissance surveys to detect large thermal anomalies within arid, unexplored, or inaccessible areas.

In general, prospecting methods for geothermal resources fall into two classes:

Direct methods which probe the subsurface temperature fields by thermal, electronic, chemical, and microseismic techniques, and

Indirect methods which are mainly applied to structural problems and include seismic, gravimetric, and magnetic techniques.

These methods are substantially similar to those applied in the fields of hydrology, hydrogeology, and prospecting for oil, natural gas, and minerals.

Drilling methods and equipment for tapping endogenous fluids and steam are very much the same as those used in the oil drilling industry. Generally, drilling rigs for geothermal wells have a medium depth capability, since steam producing layers are usually at shallower depths than oil-bearing layers [28]. However, the blowout preventive equipment on steam wells must handle much higher temperatures at the wellhead. Difficulties in geothermal drilling arise when mud is lost into the rocks, although this can be prevented by chocking the channels in the rock with material specially introduced into the drilling mud. The spacing of wells can be very close, as little as 10 meters in fields drawing on hot water through fractures in the reservoir rocks; when drawing on steam, a spacing of 200 meters appears to be optimum.

The drilling cost of geothermal wells comprises, certain fixed costs associated with the preparation and setting up of drilling equipment. The average cost per meter for a 1000 meter well is \$98, though costs as high as \$172 per meter have been reported during the first phase of drilling in a new geothermal field.

C. Generation of Electric Power

Geothermal electric power is viewed by geothermal experts as a possible rival to hydroelectric power and, in the long run, even nuclear power. The volume of water needed for the cooling of a conventional thermal power plant is becoming an important factor in the construction of new plants. Fossil fuel plants waste about two-thirds of the heat contained in steam and nuclear plants, about 75 percent. The volume of water needed for these plants in the United States by 1980 has been estimated at one-sixth of its surface drainage runoff. Geothermal plants, on the other hand, do not require external sources of cooling water except for the initial charging of the system. Geothermal electric power is very profitable in regions where neither fossil fuels nor hydroelectric resources are available. Even if they are available, geothermal electric power offers considerable savings because there is no fuel cost, and capital investment and maintenance are considerably lower, when compared with conventional power plants of the same capacity. It is estimated that the cost of geothermal power ranges between 3.2 and 4.9 mills per kWh for dry steam fields and amounts to about 60 percent of the cost of electric power obtained from fossil fuel. The costs in fields producing a mixture of steam and water may be higher, but they are still competitive with conventional power plants.

The manufacturing of geothermal generating components presents no special engineering difficulties and plant reliability has generally been very high for an average 90 to 98% load factor.

The generation of geothermal electric power in recent years has shown quantitative progress, rather than spectacular advances in new techniques. Several design refinements in turbines, condensers, and rotary exhausters, together with automatic or semiautomatic operation,

have brought considerable improvement in overall plant efficiency. In order to obtain some useful energy at an early stage of well development, present practice calls for the use of a small portable turbo-generator unit (not over 1000 kw capacity), which is quickly coupled to the first producing well and supplies electric power for immediate local use. Upon the installation of a permanent unit, the portable unit is then removed for subsequent use elsewhere.

The major problems in geothermal engineering are corrosion and scaling caused by transmission and collection of geothermal fluids. Corrosion in pipelines is most severe when oxygen gains access to the system and cooling towers as a result of the oxidation of hydrogen sulphide contained in the condenser. The deposition of silica scale may occur because of a temperature drop in the geothermal fluids; the deposition of carbonate scale, on the other hand, occurs when the pH changes in response to the escape of dissolved gas as pressure is reduced. The exclusion of air from the system can prevent corrosion. The deposition of silica and carbonate scale can be controlled either by maintaining carbon dioxide in solution by pressurizing the fluid, or by allowing deposition in specially constructed settling tanks from which it can easily be removed. Investigations on corrosion by geothermal fluids, steam, and condensates indicate that the martensitic stainless steels and copper-base or nickel-base alloys are very susceptible to corrosion. However, the austenitic stainless steels, ferritic stainless steel, and lead-clad carbon steel exhibit high resistance to corrosion [29].

D. Multipurpose Utilization

Geothermal resources are entering a new phase of more intensive development through multipurpose exploitation. Most of the possible uses, whether of low or high temperature sources, appear to be economically

viable and some offer great advantage in cost and convenience. Besides generating electric power, geothermal energy has broad application in the following areas: heating, hot water supply, food processing (drying, sterilization, refrigeration), chemical processing (drying of minerals, brine and syrup extraction, plastics manufacture, petroleum refining, fermentation or distillation of agricultural products, extraction of liquid oxygen and nitrogen for metallurgy), swimming pools and bath facilities, balneology, heating of soil, hot-spring irrigation, hothousing-greenhousing, construction, and the mining of gold placers during winter months and in permafrost and frozen-ground areas.

The separation of heavy water from ordinary water is a high energy-consuming process, and geothermal steam is considered as the most favorable source. It has been estimated that the manufacturing cost of heavy water by the ion exchange method and geothermal steam is 10 to 15 percent cheaper than by heat derived from natural gas or by exhaust steam from conventional turbines [30].

There are opinions that geothermal fluids could serve not only as the "raw material" of water, but also as a source of heat which could be used either for the self-distillation of contaminated hot waters or for the desalination of sea or brackish waters. However, at this time, it is too early to predict the outcome of various studies on water desalination for agricultural use, but there are indications that geothermal energy is the cheapest available for this purpose [16, 31].

II. SOVIET GEOTHERMAL RESEARCH AND ENGINEERING

A. Historic Background Information

Geothermal research in Russia started in the first half of the 18th century with several scientific expeditions engaged in measuring terrestrial temperatures in various mines in the Urals, Siberia, Altay, Volga region, and in the Far East. In 1906, scientist A. N. Ogil'vi developed a method for geothermal prospecting and exploitation of mineral waters. This method was applied also in prospecting for minerals, primarily oil and balneological waters. Information on terrestrial heat played an important role in the early evolution of geological science in Russia [1].

In 1910, the first Geothermal Commission of the Russian Geographic Society was organized and is credited with the collection of data on soil temperatures in permafrost zones and geothermal anomalies in the Caucasus.

After the revolution, geothermal research was given practical and scientific attention in national industrialization plans, though on a rather moderate scale and at a slow pace. In 1929, the first Geothermal Laboratory of the Central Scientific Research Institute for Geological Exploration was established to assume responsibility for geothermal research in the search for new natural resources. In the late 1930's, systematic thermometric observations were being conducted at several permafrost stations (operated by the Permafrost Institute of the USSR Academy of Sciences), with primary emphasis on the thermophysical constants of specific regions and large reservoirs.

Prior to World War II, intensive surveying and mapping of geothermal fields over a network of test wells was initiated, but was soon interrupted by the war.

In the early 1940's, by merging hydrological and geothermal doctrines, research was directed toward the development and exploitation of mineral and thermal springs. The most outstanding work of this period, Geothermal Characteristics of the Caucasus, provided a new interpretation of the origin and distribution of therapeutic waters, terrestrial temperature, conditions for the formation and evolution of geothermy, depth of thermal flow, variations of heat gradients, and formation of ground waters [1, 2].

The All-Union Conference on Geothermy, held in Moscow in March 1956, stressed the great need for broader basic and applied research.

In 1963, the Plenum of the Central Committee of the Communist Party enacted a resolution, in a drive for overall expansion of the chemical industry, to intensify research on and the utilization of geothermal resources, primarily on Kamchatka, and subsequently in the Caucasus, Siberia, and other regions of the Soviet Union. To coordinate these activities, the Earth Sciences Section of the USSR Academy of Sciences (established in 1961) was reorganized in January 1964 into the Scientific Council for Geothermal Research under the USSR Academy of Sciences [1]. This Council was strictly an administrative body, as all geothermal research was conducted and financed by various institutes, laboratories, universities, and several branches of the Academy of Sciences. Many valuable studies and collected works on geothermy and related subjects were published by the All-Union Scientific Research Institute for Geology and Engineering Geology, the Ministry of Geology, the Geological Institute, the USSR Academy of Sciences and its various branches, the Laboratory for Hydrogeological Problems imeni F. P. Savarensky, the Institute of Volcanology, and many others.

Presently, geothermal resources are considered as a new branch of the national economy. The Ministry of the Gas Industry has established several organizations and prospecting expeditions for broader development of geothermal resources in general, and multi-purpose exploitation of hot water and steam in particular. In connection with these, considerable activity is underway in Dagestan, the Chechen-Ingush ASSR, the Georgian SSR, Kabardino-Balkar, northern Osetiya, Stavropol', Krasnodarskiy Kray, Kazakhstan, and Kamchatka Oblast, while activities in the Caucasus and Kurile and Sakhalin Islands will be stepped up. To meet increasing demands for hot water, heating, and hothouse-greenhouse facilities, the Ministry's goal for the current Five-Year Plan (1971-1975) is to drill over 10000 meters of additional geothermal test wells.

Since 1967, the utilization of geothermal water in the USSR has increased about 16 times. Several towns and industries have been supplied with hot water and heating, and the largest hothouse-greenhouse complex, completed at Paratunka in 1971, provides year-around fresh vegetables (previously imported from Vladivostok) to Petropavlovsk-Kamchatskiy and the surrounding area.

It has been estimated that the geothermal resources of the Soviet Union have a daily capacity of 22 million cubic meters of hot water* and 430,000 tons of steam. If fully utilized, this would save about 40 million tons of conventional fuel annually. The annual output set for 1975 is to produce about 15 million cubic meters of hot water and 470,000 tons of steam.

* One of the world's largest reservoirs of hot water, extending over an area of about 3 million square kilometers, is situated in western Siberia.

However, the development of geothermal resources is under the control of the Main Gas Production Administration of the Ministry of the Gas Industry, where a special Geothermy Department was established in 1963. The above Administration is primarily concerned with the extraction of natural gas, while geothermal resource development appears to be a secondary issue. The existence of this situation would not appear to be conducive to the fulfillment of the projected goals [3].

There is evidence, corroborated by several Soviet geothermal research scientists, that the economic benefits to accrue from geothermal resources have been somewhat ignored and not revealed to the public as being comparatively cheaper than conventional resources, such as gas, oil, coal, or peat. For example, on Kamchatka the geothermal heat is 6 to 15 times cheaper than heat produced by conventional thermal plants. Many geothermal experts are of the opinion that geothermal development cannot thrive as a separate discipline as long as it is subordinate to the gas industry. They further believe that now is the time for the establishment of a special organization which would be responsible for the promotion and development of this growing branch of the national economy [3]

B. Trends in Geothermal Research

In spite of all the organizational changes and complexities of geothermal research, Soviet basic and applied research in geothermy has achieved considerable results for both the scientific world and the Soviet national economy. In general, this research is concerned with broad theoretical investigations, improvement of equipment and methods, and more intensive field exploration and prospecting [2].

In the last two decades, the hydrogeological deep drilling activities have contributed to the development of the new science of hydrogeothermy, which was applied to regional projects in the exploration and mapping of the geothermal characteristics of the USSR, ground water table, oil-bearing areas, and coal regions in the Donbas and other areas [1].

In 1967, the Aerial Surveying Laboratory of the USSR Ministry of Geology conducted the first exploratory survey on Kamchatka peninsula to determine the possibility of utilizing aerial infrared mapping techniques in studying volcanos and thermal anomalies. This survey concentrated primarily on the thermal characteristics of geysers and fumaroles, hot and warm springs, mud volcanos, mud pots, thermal streams and lakes, and other areas with thermal anomalies. The data obtained were correlated with field data and were used for mapping geothermal areas under consideration for development of their geothermal resources [4].

The Soviets have published a number of studies covering diverse subjects relating to various geothermal systems*. Included among several subjects in these studies are: the measurement of the Moon's heat flow; the practical utilization of terrestrial heat; and the possible utilization of ground waters with low enthalpy**, found in great quantities in the Soviet Union. Based on regional synthesis of geothermal data, it is concluded that continental drift, which has separated the European platform from the Siberian platform, is manifested in the formation of a wide

* A geothermal system is part of the earth's crust that contains a source of heat (regional heat flow or local igneous intrusion) and the rocks and water affected by that heat. Geothermal systems that involve circulating waters are also called hydrothermal systems. A hot spring area is the surface manifestation of a geothermal system [14].

** Enthalpy, a quantity associated with a thermodynamic system expressed as the internal energy of a system plus the product of the pressure and volume of the system, having the property that during an isobaric process, the change in the quantity is equal to the heat transferred during the process. Also called heat content or total heat.

tectonic depression. The Soviets postulate that in the continental interior, the thermal energy released from the deepest part of the Earth (left uncovered by drift movements) is not dissipated by the cooling effect of oceans (which would come to occupy dislocated areas) and the energy thus maintains itself over a long period of time, creating regions with high geothermal anomalies [5].

The sources of water and the nature of geological formations constitute a basis for determining the location and type of geothermal systems, which can be categorized as either an "open system" or a "buried system". The open systems are fed from the surface and are open throughout their extent [46]. To these types are related some manifestations observed at several volcanos in the more elevated areas of Kamchatka. The buried systems are those which utilize fossil waters or waters released by sediments under geostatic pressure. A similar situation is verified in the Caucasus where attempts have been made to utilize depleted oil deposit sites by injecting water into certain wells and extracting hot water from adjacent wells. Presently, such water is being used for industrial and agricultural purposes [6].

A different situation exists in the Georgian SSR, where there are more than fifty groups of thermal springs with temperatures ranging between 35 and 105° C, and with a total yield of more than 1000 liters per second. Although quite complex, the hydrogeological conditions in the Georgian SSR come within the scheme of ground hydrology. Water circulation in some cases is at relatively deep horizons where the heat flow varies from moderate values for the Georgian Block (0.68 - 1.22 microcal/cm³ sec) to rather high values in the Adzhar region (1.49 - 2.03 microcal/cm³ sec) [7]. However, considering the situation in Kamchatka as a whole, and the Pauzhetka system in particular, there are indications that the cold, thermal, and hyperthermal waters are hydraulically

interconnected. In consequence, the piezometric levels of the Kamchatka thermal waters, measured in wells of the region's geothermal system, agree with the static levels of the local cold waters [8]. This interference phenomenon between the cold descending flow and the hot portion of the system, results in a general decrease in the temperature of the extracted fluids, and in an increase of water quantity drawn to the surface from the wells. Flashing occurs only near the well bottom or actually inside the well thus creating scales which obstruct the fracture and reduce the diameter of the well, causing considerable reductions in yield and in some cases, an actual stoppage.

In specific cases, there is the possibility that a system has an almost direct connection between the recharge and discharge areas. This opinion has been supported by a recent Soviet study [9] which has shed new light on the origins of geothermal water. Field data, collected over various areas, on the chemical components, isotopes, and organic material in geothermal waters, including the hydrothermy of recent volcanism, indicate regional characteristics and continuity of such waters in the upper hydrogeosphere. The interpretation of the data obtained is based on geotectonic, lithologic-facial, geothermal, and geochemical characteristics of the system under consideration. It is concluded that the basic sources of water, mineral salts, gases, and organic material in thermal waters are the result of atmospheric precipitation and filtered sea water.

Considerable attention is given to the condensation of steam in contact with the coldest levels of the reservoir top, particularly with those levels which correspond to the peripheral parts of the production areas. Regular observations conducted over many years on Kamchatka,

indicate that hydrothermal activity was unaffected by exploitation. However, a different picture is seen for the Pauzhetka wells where, through exploitation, a considerable decrease in the piezometric levels (and hence in hydrostatic pressure) has been observed. It is noteworthy that, during test drilling of the Pauzhetka deposit, a sharp decrease in piezometric level was accompanied by the transformation of a constantly boiling spring into a geyser with reduced output from 10 l/sec to 0.6 l/sec. With the termination of test drilling and the restoration of piezometric level, the former constant discharge was resumed. This transformation, involving hydrodynamic variations in the hydrothermal water system, shows conclusively that geysers and boiling springs share the same nature, and also that geysers are a special type of boiling spring. A decrease in hydrostatic pressure in areas with low piezometric level gives more intensive steam separation and thus, more surface steam discharge [10]. This correlates with the fact that, at the Pauzhetka site, the surface thermal manifestations are not the result of changes in the temperature of the water-bearing complex. The above described examples demonstrate that geothermal systems must be classified and evaluated according to their types and potentials in order to predict the characteristics which they will display after a certain period of use. It is therefore important to broaden the base of experience and knowledge in forecasting the various modifications of a producing geothermal system and to predict the production time under varying conditions. Soviet scientists stress the great importance of models based on numerical, analog, or experimental methods, in the study of geothermal systems. Heat and mass transfer, important components of a hydrothermal system, are the bases of a Soviet attempt to create a mathematical model of a selected system.

Presently, the classifications of geothermal fields are based on chemical or thermodynamic criteria. There are proposals by several scientists that classification should be based also on geological criteria.

However, some Soviet scientists differ with the present classification system of geothermal fields and suggest a dual classification of occurrence of thermal waters based on tectonic setting and type of heat source. Other proposals suggest the use of geological age, as well as tectonic environment.

Based on the above classifications, Soviet scientists conclude that water having moderate to high thermal potential and in large quantities, can only be found in Cenozoic folded regions, in older regions reactivated in the Cenozoic age, and in the interiors of Paleozoic platforms. In addition, they distinguish between waters occurring in "fissure/veins" and those in permeable stratigraphic horizons called "stratal" deposits. The exploitable ratio is approximately 1 to 20, respectively [11]. Based on the above geological differences, the thermal gradient, depending on the tectonic structure of the region, varies from formation to formation. For example, in the western region of the Georgian SSR, the 50° C isotherm ranges in depth from 2000 meters near the Black Sea coast, and only 800 meters inland averages 1400 meters overall. This gives a maximum gradient of about 42° C/km, and an average gradient of only 21° C/km. In the eastern region of the Georgian SSR, the gradient ranges between 27 and 40° C/km. In general, the temperature gradients in these basins are from one and a half to two times the world average, making it possible to extract water at 80 to 100° C from relatively shallow depths over extensive areas. Geothermal fields found in platforms and foredeep areas are generally characterized by a normal heat flow, and they have geothermal gradients close to the world average [12]. The thermal gradients in the Ciscaucasus foredeep average about 30° C/km, and thermal waters ranging in temperature from 47 to 86° C are used extensively for balneological purposes, hothousing, and the dairy industry [6].

The occurrence of exploitable waters at a depth of 2 kilometers in the platform areas of the USSR, has been established in the West Siberian lowland ($60 - 80^{\circ}\text{C}$) and in the Turana lowland, east of the Caspian Sea, ($65 - 95^{\circ}\text{C}$) [5].

In early 1972, during intensive field research on geothermal gradients, heat flow, and coefficient of conductivity in the area of the Koryak-Avachin and Paratunka depressions, the Soviets obtained conclusive data that the volume and distribution of anomalous heat flow rapidly attenuates near hydrothermal systems or magma chambers. This has been considered as a valuable indicator in prospecting for geothermal waters with the exploratory thermal corings [13].

Geochemistry has an important role in solving various problems connected with geothermal resource development, such as evaluation of reservoir energy reserve, reservoir depletion, power plant design, corrosion, scale formation, and effluent disposal. The following chemical indicators of subsurface temperatures in hot water systems is in broad use for evaluating reservoir potential [14]:

Indicator	Comments
1) SiO_2 content	Best of indicators; assumes quartz equilibrium at high temperature with no dilution or precipitation after cooling.
2) Na/K	Generally significant for ratios between 20/1 to 8/1 and for some systems outside these limits.
3) Ca and HCO_3 contents	Qualitatively useful for near-neutral waters; solubility of CaCO_3 inversely related to subsurface temperatures.

Indicator	Comments
4) Mg; Mg/Ca	Low values indicate high subsurface temperature, and vice versa.
5) Cl dilution	Assumes dilution of lower-Cl springs by cold water, permitting calculation of subsurface temperatures from required mixing ratios with highest Cl waters.
6) Na/Ca	High ratios may indicate high temperatures but not for high-Ca brines; less direct than 3?
7) Cl/HCO ₂ +CO ₃	Highest ratios in related waters indicate highest subsurface temperatures and vice versa.
8) Cl/F	High ratios may indicate high temperatures but Ca content (as controlled by pH and CO ₃ ²⁻ contents) prevents quantitative application.
9) H ₂ /other gases	High ratios qualitatively indicate high temperatures.
10) Sinter deposits	Reliable indicator of subsurface temperatures (now of formerly) > 180° C.
11) Travertine deposits	Strong indicator of low subsurface temperatures unless bicarbonate waters have contacted limestone after cooling.

Based on the chemical analysis and measured subsurface temperatures from several drill holes, Table I shows data summarized for several Soviet geothermal areas presently under exploitation or in the final planning stage.

TABLE I. Indicated and Observed Subsurface Temperatures in Explored USSR Geothermal Areas [14].

Area	SiO ₂ content, ppm	Na/K ratio atomic	T _{SiO₂} , °C	T _{Na/K} , °C	T _{Max.} , °C observed	Comments
Pauzhetka, Spring P. 1 (~100°C) Well 4	166 302	23.2 16.0	164 194	~156 193	195	VAKIN ET AL [8]
Uzon-Geyzernyy Geyser Velikan (~100°C)	294	16.9	200	187		VAKIN ET AL [8]
Bol'she-Bannaya Spring 4 (~100°C) Well 35	165 223	20.7 22.0	163 177	~167 ~161	171	VAKIN ET AL [8]
Paratunka Spring (42.5°C) Well 2	62 25	63.1 35.0	111 70(?)	~83 ~123	106	VAKIN ET AL [8]

The above data are fundamental for designing geothermal electric power plant of respective capacity and for selecting corrosion resistive material.

Abundant textual and graphical data on geothermy have contributed extensively to present Soviet geothermal engineering activities in the Crimea, Caucasus, Soviet Central Asia, western and eastern Siberia, and the Far East, including Kamchatka peninsula and the Kurile Islands.

C. Geothermal Development

In the spring of 1941, the Soviet botanist Tatyana Ustinova made a major geographical discovery of powerful geysers in the southeastern part of the Kamchatka peninsula. Before that time, geysers were known only in Iceland, New Zealand, and the United States. Ustinova's discovery was to a certain extent a sensation, for in the middle of the 20th century, such a discovery is not frequent [15].

The first practical utilization of geothermal energy in Kamchatka started at the peninsula's southern tip near the large fish-processing plant at Ozernovskiy. Here, in the Pauzhetka river valley, between the Kambal'nyy and Koshelev volcanos, a vast territory of self-discharging hot water and steam vents (see Fig. 1) became the site of the Soviet Union's first geothermal electric power station. Although,



Fig. 1. Geysers in the Ozernaya River Valley (Kamchatka).

its capacity was not great, this project began a new chapter in Soviet power engineering and the development of the Soviet Far East [15].

In general, a long delay between the prospecting phase and the ultimate generation of electric power is common to all geothermal plants. In many cases, a delay of five years or more noticeably increases the capital cost of geothermal energy and it becomes a very serious obstacle to procuring the large amount of capital required for the exploration [16].

During the last nine years, the installed capacity, of geothermal power in the world increased from 385.7 MW in 1961 to 860.0 MW, (projected for 1971), which is considered to be a very slow growth rate. Several projects scheduled for completion in the next few years will increase the world output to over 1000 MW. It seems a very large development, but it is very small fraction of the power produced by various countries considering the enormous reserves of the global geothermal resources. Selection of power plant size is the most difficult decision for geothermal plant planners. The cost per kw decreases when the size of plant increases; however, a large plant requires more producing wells and a longer time for completion [16].

The Paratunka power plant (USSR), the first freon*-operated plant in the world, offers convincing evidence that a power plant using natural hot water below the boiling point may offer a convenient solution. This type of geothermal power plant can be designed and built within the framework of existing engineering knowledge, technology, and construction capabilities; no revolutionary new design or new methods are required. A freon or isobutane hot-water plant may be designed and constructed without major innovations within existing production technology. In this regard, very large reservoirs of hot water above 80° C exist in many countries and can be easily harnessed by present technology [16].

* Freon (trademark), any of a class of liquid fluorinated hydrocarbons used chiefly as a refrigerants such as the colorless and odorless gas dichloride-fluoromethane. Also used as propellants for aerosols.

Geothermal developments in the Soviet Union, for the most part, have followed an original pattern, differing significantly from the development patterns of other countries. In a recent study, it is estimated that 50 - 60% of the Soviet Union has deposits of thermal waters which are available for economically effective use. The use potential of these deposits are comparable to the coal, oil, gas, and peat resources of the Soviet Union taken together. The thermal water reserves of the USSR at depths between 1000 and 3500 meters, with temperatures ranging between 50 and 130° C, have an estimated output of 7.9 million cubic meters daily. About 70% of these thermal waters are at depths between 1000 and 1500 meters [17].

Presently, there are eleven geothermal facilities in operation in the Soviet Union, with a total amount of consumed heat at 200 Gcal/hr, or about the equivalent of 125,000 tons of conventional fuel. An increase of at least 10 times this figure is forecast for the end of 1980 [18].

The basic factors governing the technical feasibility of utilizing geothermal waters are: temperature potential, discharge rate, depth of occurrence, pressure, chemical composition (mineralization, hardness, content of free carbon dioxide and hydrogen sulfide), and the amount of organic material and suspensions [19].

The economic expediency in utilizing geothermal waters depends on the geographic location of the source, accessibility and the condition of roads, the overall economic development of the region, and the availability of other types of energy resources. Based on hydrogeological and geothermal characteristics, the Soviet Union is subdivided into nine regions having different priorities and prospects for geothermal resource development [19].

To meet the technical-economic criteria, the engineering requirements for practical exploitation of a geothermal site in various regions and for different industrial applications are given in Table 2 below.

Table 2[19, 20].

Type of utilization	Temperature, °C	Daily output, m ³	Depth of water-bearing horizon, m	Mineralization, g/l
Production of electric power by direct steam cycle	100	10,000	3,100	2 - 4(50)*
Production of electric power by intermediate low-boiling agent (freon, isobutane, etc.)	60 - 90	2,500	2,500	50
Heat supply for populated places	70 - 90	1,000	2,500	2(50)*
Refrigeration	70	500	1,500	50
Hot-water supply	40 - 60	1,000	1,500	1(50)*
Hothousing - greenhousing	40 - 70	500	1,500	10(50)*
Thermal irrigation	25 - 40	250	1,000	2
Heating of soil (for agriculture)**	25 - 50	500	1,500	50
Thawing of frozen soil***	25 - 50	250	3,000	50
Swimming pools & baths	25 - 40	250	1,000	50

* Figure in parentheses indicates permissible mineralization for geothermal plants with heat exchangers.

** During winter months or in permafrost regions.

*** Mining in winter months, in permafrost, or in the Arctic region.

It is estimated that there are over 150 areas and groups of individual springs with temperatures above 40° C. Some 19 of these have near-boiling temperatures, and about 40 have temperatures ranging between 60 and 90° C. The total discharge from springs having temperatures above 40° C is estimated as being over 140,000 cubic meters per second, with a heat equivalent of 10 billion kilo-calories daily. Recent research and prospecting activities in various Soviet republics foresee a complete inventory of geothermal resources as a contribution towards their more intensive utilization for heating, electric power, and other applications. The following are some of the major future developments planned for various republics and areas [21, 22]:

Ukrainian SSR. Utilization of all thermal waters with various temperatures (70-80° C) and different degrees of mineralization for experimental-industrial installations.

Moldavian SSR. Pilot projects contemplate the use of thermal waters with different degrees of mineralization for agriculture, with new wells to be drilled near the towns of Kishinev, Ungen, and Bendery.

Crimea. Drilling is in progress at Dzhankoy, Feodosiya and Novoselovo, where surface manifestations of thermal water are present, but where additional surveying is required to determine daily discharge, chemical composition, and temperature.

Georgian SSR. Thermal waters will be used in growing citrus, tea, and grapes, as well as for resort centers in the areas of Pitsunda, Zugdidi, Alazan, and others. At Tbilisi, it is proposed to obtain thermal water for experimental-industrial installations.

Northern Caucasus. Plans call for tapping thermal waters having various degrees of mineralization (10-50 g/l) and temperatures (60-100° C) for agriculture purposes, as well as for heating the towns Cherkassk, Armavir, and Nal'chik.

Azerbaydzhan SSR. Exploratory drilling is planned for Lenkoran and Masallinsk areas in hopes of providing thermal waters at temperatures ranging between 50 and 60° C for heating and hot-housing complexes which will serve the European part of the Soviet Union. Presently, at Istisu, thermal water (54.5° C at the surface and 64° C at 50 m) is being used for balneological purposes.

Armenian SSR. Near the cities of Yerevan, Nalband, and Ankavana, prospecting work is scheduled to tap thermal waters with estimated temperatures ranging between 70 and 75° C.

Dagestan ASSR. Near the town of Makhachkala, drilling to a depth of 4500 meters is in progress to reach steam-water layers for a planned experimental-industrial geothermal electric station. Near the town of Berekey there is a highly mineralized hot water and steam well (see Fig. 2) with a capacity of 70,000 cubic meters daily and a temperature at the surface of 57° C. It is estimated that this well can produce about $94.54 \cdot 10^{10}$ kcal of hot water annually, which is equivalent to 94,535 tons of fuel oil or 107,456 tons of coal [23].

(see Fig. 2 next page)

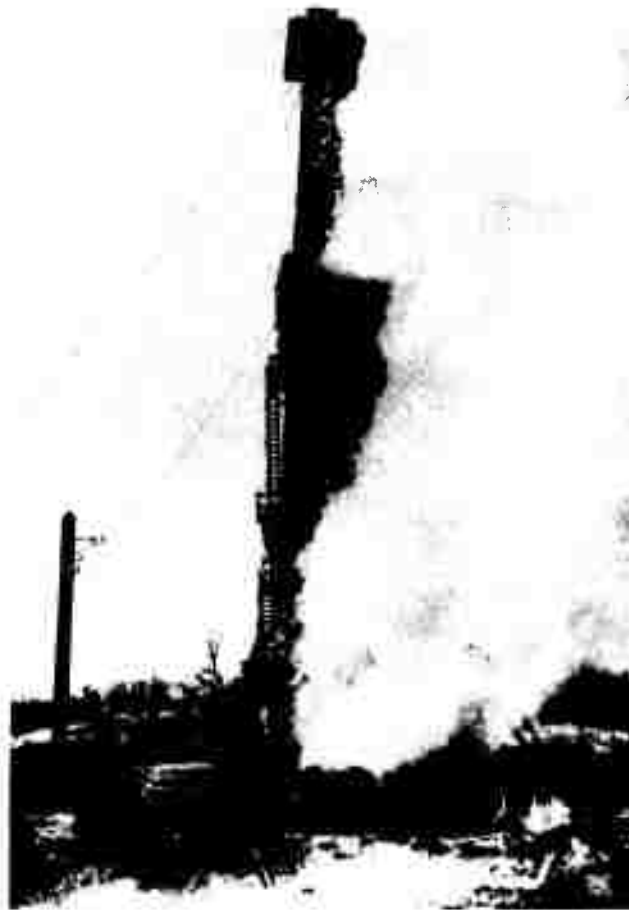


Fig. 2. Hot Water and Steam at Well No. 3 near Berekey.

Kazakh SSR. Extensive prospecting is being conducted to determine regional thermal water characteristics (pressure, discharge, chemical composition, temperature, depth and capacity of water-bearing horizons), especially in the regions of Chimkent, Turkestan, Turgay, and northern Pavlodar Oblast, for ultimate agricultural applications in arid and semiarid regions.

Uzbek SSR. Extensive exploratory works are in the areas of Tashkent and Fergana.

Kirgiz SSR. Prospecting is planned for the Przheval'sk area to develop thermal water resources for space heating. In the Issyk-Kul' lake region, additional drillings will be conducted to determine balneological capabilities and in particular, space heating potential for several resort centers under construction.

Tadzhik SSR. Near the city of Dushanbe, several drill sites for thermal waters are planned, to provide heating and air-conditioning to the city. At the resort centers of Khodzha-Obi-Garm, Obi-Garm, and Khabatag, the plans to increase output of thermal water and steam for balneological and heating purposes are in the final stage.

Western Siberia. To promote balneological resort centers, extensive drilling for thermal waters, ranging in temperature between 50 and 90° C with mineralization between 10 to 30 g/l, is in the planning stage.

Chukchi Peninsula. Exploratory drillings on Chukchi peninsula and in the coastal permafrost region bordering the Sea of Okhotsk will assist in studying the technical-economic indices of thermal waters for space heating, vegetable farming, and resort centers. Near the towns of Talaya and Motykleysk (about 125 km west of Magadan) exploratory drilling is in the preparatory stage, with the ultimate goal of obtaining fresh and low-salinity thermal waters for resort centers.

Under primary consideration for the production of electric power are the areas of Yevpatoriya, Nal'chik, Tbilisi, Tobol'sk, Tashkent,

Bol'she-Bannaya, Pauzhetka and Sredne-Paratunka on the Kamchatka peninsula, Goryachiy Plyazh on Kunashir Island, Paramushir Island, and Chaplino on the Chukchi peninsula [21]. *

In 1964, it was proposed that all exploratory and producing wells be reevaluated regarding their equipment status, water table, and water parameters. Areas under primary consideration are: western Siberia, the Tersko-Kumsk area, the Azov-Kuban' artesian basin, the steppe area of Crimea, the Ciscarpathian depression, the Dneprovsk-Donets basin, the Pechora artesian basin, the Kura depression and the adjacent region of the Apsheron peninsula, the artesian basins of the Georgian and Armenian SSR's, the North Caspian depression, northern Ustyurt, southern Mangyshlak trough, and the Sakhalin and Yakutsk artesian basins [21].

It is assumed that these evaluations will contribute to increasing the output of existing geothermal wells, reduce expenses for new exploratory projects, and assist in the discovery of potential deep terrestrial heat-flow sites. In addition, this survey of existing geothermal wells would serve to update regional and national geothermal resource data [21].

To achieve the above goals, it has been proposed by several Soviet scientists, geologists, and geothermy specialists, that the following steps be taken:

- To compile a map at 1:2,500,000 scale which would represent the quantitative characteristics of the exploitable thermal water reserves in the USSR. This map should be compiled by the Geological Institute of the USSR Academy of Sciences and the All-Union Scientific Research Institute of Hydrogeology and Engineering Geology.

*) Additional data on geothermal sources in the above republics and regions and their chemical compositions, temperatures, discharges, mineralization, gaseous components, and development potential for various areas of the national economy, are outlined in "Recent Soviet Investigations in Geothermy", Report 1, May 1972.

● To request that the Geological Institute develop a theoretical basis for the formation of thermal waters.

● To develop procedures for the research and exploitation of geothermal waters, and to develop well technology and methods for the complete testing of thermal waters encountered while drilling for oil and gas. These activities should be conducted by the Balneological Institute of the Moscow State University and the All-Union Scientific Research Institute of Hydrogeology and Engineering Geology.

● To request full participation from the State Commission on the Natural Resources of the USSR, in defining basic conditions and requirements for thermal waters.

● To request the All-Union Scientific Research Institute of Hydrogeology and Engineering Geology to develop and provide basic economic estimates as guidelines for effective exploitation of thermal waters with varying temperatures and ratios of mineralization, and for various geographic areas [21].

III. SOVIET GEOTHERMAL ELECTRIC POWER GENERATION

A. General

The enormous USSR reserves of geothermal waters having temperatures between 30 and 180° C could be utilized for purposes vital to the national economy, other than the generating of electric power [32]. The most efficient way is to use a low boiling heat carrier as a second working fluid. In this line, the experimental freon turbine power station represents a revolutionary innovation and appears to hold great promise for future Soviet geothermal power development and engineering [13].

The following are some highlights of Soviet engineering efforts toward solving some problems in geothermal power generation.

The Soviets have conducted extensive studies on the corrosion effects of geothermal waters on metals and alloys having various degrees of corrosion resistance, such as steel, chrome-nickel steel, gray iron, galvanized steel, copper, and brass. It has been established that for geothermal water containing soluble hydrogen sulfide or carbon dioxide, at a temperature of 70° C, the corrosion rate of low-carbon steel increases by about 25 to 30 times; with the water aerated and at a temperature of about 55° C, corrosion increases only by 10 times. To capitalize on this, the geothermal water is not used directly from the well, but is collected in an open reservoir for aeration, and is then fed into the heating system [33].

The Electric Welding Institute imeni Ye. O. Paton of the Ukrainian Academy of Sciences has developed several types of cavitation and heat-resistant austenitic steels, characterized by high weldability and stability through work hardening [34]

Soviets use low-level turbines with external barometric condensers, while other countries use high-level turbines placed above the condensers.

The extraction of noncondensable gases from the condenser is achieved by water ejectors, while some countries use steam ejectors, rotary exhausts, and reciprocating pumps.

Regarding the steam-control method, the steam is maintained at a constant pressure by blowing off variable quantities to waste, instead of allowing the steam to float to some extent by throttling at the turbine and thus reduce possible blow-offs [35]. The turbine's stop valve pressures, at the first point of feed from the field (i. e. excluding turbines fed from the exhaust from other turbines or flash steam), are generally very low [36].

As the first phase in the utilization of geothermal resources, the Soviets are presently concerned with the construction of small capacity geothermal electric power stations and heat-supply systems [12].

An advanced idea, originated by the Institute of Thermal Power Engineering of the Ukrainian Academy of Sciences and supported by the Design Institute of the Thermal Electric Station Planning Enterprise, to design a very large geothermal power station for a highly superheated mixture of water and steam from a depth ranging between 7 and 10 kilometers, is under serious consideration. The basic concept of this plan is to pump the surface water into the well and then lift it heated to 300-400° C by the porous masses of the earth's interior. Such a method holds promise for building in the future a power plant of up to 10 million kilowatts capacity [15].

B. Current Operations

1. Paratunka Geothermal Electric Power Station

The Paratunka geothermal electric station is the first station in the world to operate on freon.

The Thermal Physics Institute of the Siberian Branch of the USSR Academy of Sciences, after extensive research designed a turbo-unit called Shatura HEPP-5. A prototype model of this freon unit of 340 kw was constructed and tested. Another unit, the UEF90/65, designed on the same principles, was assembled and shipped to Sredne Paratunka thermal springs for subsequent testing. After construction of the pumping station and the pipeline system, this plant was completed in September 1967. A series of tests demonstrated that this power plant operates satisfactorily using thermal water with a 81.5°C temperature, instead of the design temperature of 90°C [16].

The operating principles of this plant, schematically shown in Figure 3, are as follows: the liquid freon, preheated by the thermal water (temperature 83°C), boils and overheats to 55°C at an absolute

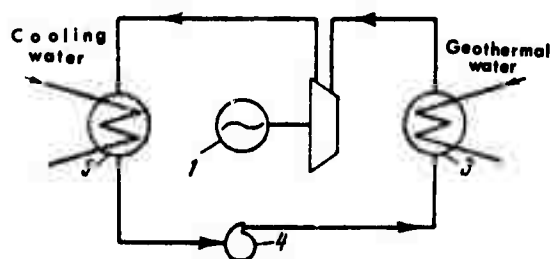


Fig. 3. Schematic of the Energy Cycle for the Paratunka Geothermal Electric Station [37].

1 - Generator; 2 - turbine; 3 - main boiler;
4 - pump; 5 - condenser

pressure of 13.8 atmospheres in the main boiler (3) consisting of three preheaters, boilers, and superheaters. The freon steam, preheated up to 65°C , enters the radial freon-turbine (2) where it expands, reaching the required condensation pressure for the operation of the turbine. The turbine is connected to a T2-75-2 generator (1). From the turbine, the freon steam enters two tube-type condensers (5), where it is cooled by cold water (15°C), at an absolute pressure of 5 atmospheres. From the condensers, the liquid freon flows into the line receiver and is returned again to the main boiler by the centrifugal pumps (4XGV-GE-40-5 model) [37].

This plant has a receiving charge-discharge unit consisting of two receivers having a capacity of 6 cubic meters each, and two AK-FV-6 piston-type freon compressor-condenser units designed for the removal of freon from the system, the resupply of freon, and the refilling of the system with freon after installation or maintenance [37].

The maximum consumption of geothermal water (including water used to heat the station) is 289 cubic meters per hour while the consumption of water for cooling is 1520 cubic meters per hour. In selecting the site for a power plant, besides the existing geothermal waters, the volume of water available for cooling cycles is also of considerable importance [37].

The distance between the geothermal wells and the station is about 1000 meters. With the completion of the power station building in late 1964, eight geothermal wells had been finished, ranging in depth between 302 and 604 meters with the diameters ranging between 123 and 200 millimeters. At the wellhead, the thermal water attains a head of 30 meters [37].

The discharge of free-flow thermal water at each wellhead was registered at about 18 liters per second, and the average temperature was 83.7°C . To eliminate head decrease (about 0.55 liter per second per meter), booster-pumps were installed in order to maintain the required operating head [37].

To provide thermal water of the required 81 liters per second discharge, six wells are used with one well in reserve. Water for cooling is brought from the Paratunka river into the pumping station by two suction pipes; from here it is pumped through pressure pipes into the power station [37].

The Paratunka station consists of two units. In the main unit is the machine hall (see Fig. 4), and in the annex is the control panel,



Fig. 4. The Machine Hall of the Paratunka Geothermal Electric Station [22].

machine shop, chemical laboratory, equipment and mercury rooms, ventilation chamber, and utility room. For the first two years, the annex unit was used as an experimental laboratory by the Thermal Physics Institute [37].

The machine hall (see Fig. 5) is 12 meters wide, 24 meters long, and 8 meters high, while the annex is 12x12 meters, with a height of 3.6 to 4.0 meters [37].

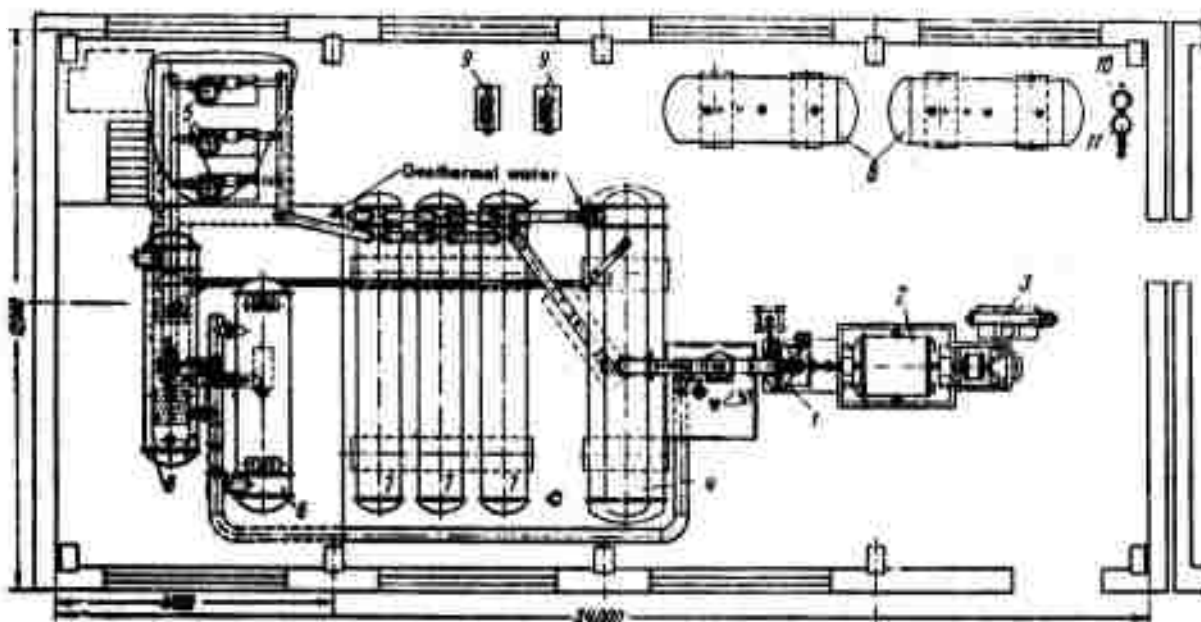


Fig. 5. Plan of the Machine Hall of the Paratunka Geothermal Electric Station (dimensions in mm) [37].

- 1- Turbine; 2- generator with exciter; 3- generator lubrication system; 4- boiler; 5- freon pump;
- 6- condenser; 7- preheater; 8- freon-line receiver;
- 9- compressor-condenser unit; 10- freon filter;
- 11- freon drier.

The electric station has the following technical-economic characteristics:

- installed capacity 750 kw*
- consumption of electric energy by the power station 35%
- cost of 1 kw of installed capacity 1600 rubles (1967)

The high cost of the installed capacity (4 times higher than that of the Pauzhetka geothermal electric power station operating on a steam-water mixture) is explained by the comparatively small capacity of the station and the excessive construction of pipes and other installations for the supply of thermal waters to neighboring hothousing-greenhousing facilities. In addition, the final cost included all expenses in connection with planning, construction and testing of the freon turbo-unit (Shatura HEPP-5) [37].

According to this same source [37], there were plans to construct a similar geothermal electric station with a 25 MW capacity near the town of Petropavlovsk-Kamchatskiy.

*) In a recent source [38], the installed capacity is given as 1000 kw.

2. Pauzhetka Geothermal Electric Power Station

The Pauzhetka geothermal electric station (see Fig. 6), located in the Pauzhetka river valley, was commissioned in July 1967.



Fig. 6. Pauzhetka Geothermal Electric Power Station [19].

In the Pauzhetka river valley, during 1965, 22 wells were drilled to a maximum depth of 800 meters, the average depth being 300 meters. The highest temperature recorded at the surface was 187°C , with the average temperature at 170°C . Surface pressures ranged between 2.2 and 6.7 atmospheres, with mineralization between 3 and 3.5 grams per liter. Average discharge capacity of the hot water-steam mixture has been estimated at 170 kilograms per second [19, 22].

According to original design estimates, this station was to operate on steam-hot water mixture with a natural heat capacity of 170 kcal/kg at the surface obtainable from wells 100 to 400 meters deep, and was to have the following technical-economic indices [39, 40]:

Initiating capacity	5 MW
Total discharge of wells	500 tons per hour
Hours in operation	7000 annually
Annual production of electric energy	35 million kw/hr
Annual loss of heat	25,000 Gcal
Cost of one kw of intalled capacity	400 rubles
Cost per kw/hr	0.65 kopeck
Electricity consummed by station	10%*
Efficiency factor of the station (net)	9.2%
Operating personnel	21 (10)
Staff coefficient	4 men per 1000 kw

In the first stage of construction (1966), an initiating capacity of 3 MW was to be produced by two turbines operating with a pressure of 1.2 atmospheres and utilizing seven geothermal wells. An eighth well was used for research and as a reserve well [40].

In the second stage of the construction (1967), by drilling two additional wells, a considerable increase in discharge and pressure was to be obtained. Increased pressure from 1.2 to 2.0 atmospheres consequently was to increase the capacity of the station to 5 MW, which is the current figure for the station. Below is a schematic outline of

*) The 1963 estimate [39] was 1.6%

the Pauzhetka geothermal station (see Fig. 7).

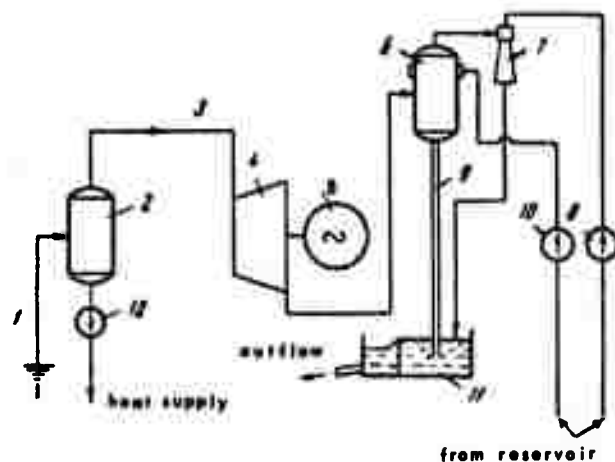


Fig. 7. Schematic of the 5 MW Pauzhetka Geothermal Electric Power Station [40].

1- Geothermal well; 2- separator; 3- steam pipe;
4- turbine; 5- generator; 6- mixing condenser;
7- water-jet ejector; 8- ejector pump; 9- barometric
tube; 10- cool water pump; 11- outflow of hot water.

The third stage of construction, planned 1968, to increase the capacity of the station to 12.5 MW in 1968, did not materialize.

A schematic outline of the Pauzhetka geothermal electric power station with a planned [40] capacity of 12.5 MW is given below (see Fig. 8). Besides the unfulfilled plans for expansion of this station up to 12.5 MW, there reportedly have been other, additional plans to bring this station up to a final capacity of 20 MW.

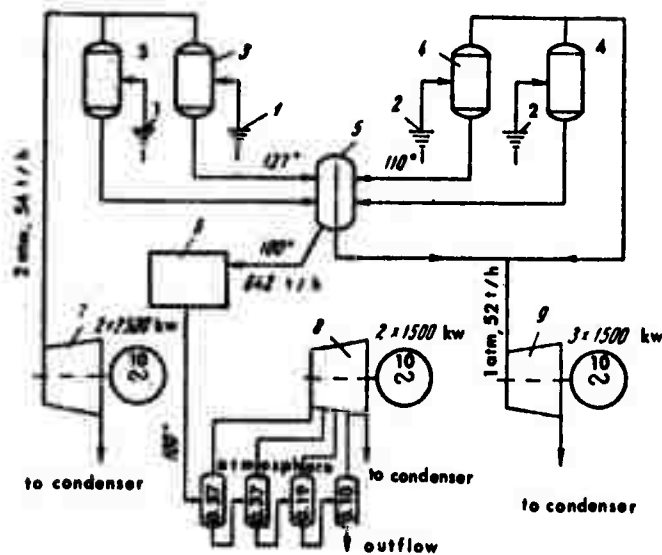


Fig. 8. Planned Arrangement of the Pauzhetka Geothermal Electric Station with a Capacity of 12.5 MW [40].

1- Wells with 2.5 atm; 2- wells with 1.5 atm;
 3- separators with 2.5 atm; 4- separators with 1.5 atm;
 5- expander for 1 atm; 6- hot water storage tank;
 7- 2 turbines (each 2500 kw at 2 atm); 8- 2 vacuum turbines (each 1500 kw); 9- 3 turbines (each 1500 kw at 1 atm); 10- generators.

The main building is 4400 cubic meters in size and is connected to the wells by pipes having a total length of 1.3 kilometers. The machine hall floor space is 33 by 9 meters, and the control room is housed in a 4-meter-wide auxiliary building. The MK-2.5 turbines were manufactured by the Thermal Turbine Machine Construction Plant at Kaluga.

The Pauzhetka geothermal electric station supplies electricity over a 30-km-long, 35 kv power line from a 5600 kv transformer to the Ozernovsk fishing combine, the "Krasnyy Truzhenik" collective farm, and the village of Pauzhetka [22].

The production cost of electricity at Pauzhetka has been estimated at 0.55 kopeck per kw/hr (1963) [39], 0.65 kopeck per kw/hr (1965) [40], and 7.2 US mills per kw/hr (1970) [41]. Considering the size of the plant and its remote location, the last figure given seems to be a very satisfactory one, and it will undoubtedly be much less when the plant is expanded. The Soviets claim that it is 30% cheaper than any alternative means of power supplied in the same area, and it has been estimated that this station will pay for itself within 3 to 4 years of operation [19].

C. Future Programs

Besides the existing geothermal power stations, there are several prospective sites for the construction of additional geothermal power stations. For instance, in the Tersko-Kumsk artesian basin (towns of Makhachkala, Khasavyurt, Kizlyar, and others) geothermal waters have been found at depths of 2500 - 3000 meters, with temperatures of about 120° C and discharge capacity ranging between 1500 and 3000 cubic meters daily. The pressures range between 5 and 10 atmospheres, with mineralization less than 2.5 grams per liter [19].

There are also several regions being considered for the future construction of geothermal power stations utilizing low-temperature geothermal waters [19].

Additional potential sites for low-temperature geothermal power stations utilizing fissure waters are located in the northeastern USSR; i.e. the Mogoy'sk and Uakitsk hot springs (Buryat ASSR), and the Mechigmen, Sinyavina, and Chaplino hot springs in the Chukotskiy (Chukchi) National'nyy Okrug [19].

Below are available data on several geothermal power stations planned for construction in the near future.

1. Bol'she-Bannaya Geothermal Electric Power Station.

The construction of this station, about 60 kilometers from the town of Petropavlovsk-Kamchatskiy, has been under consideration since 1965. At present, only 20 geothermal wells have been drilled, with only minor construction activities under way at the site (see Fig. 9).

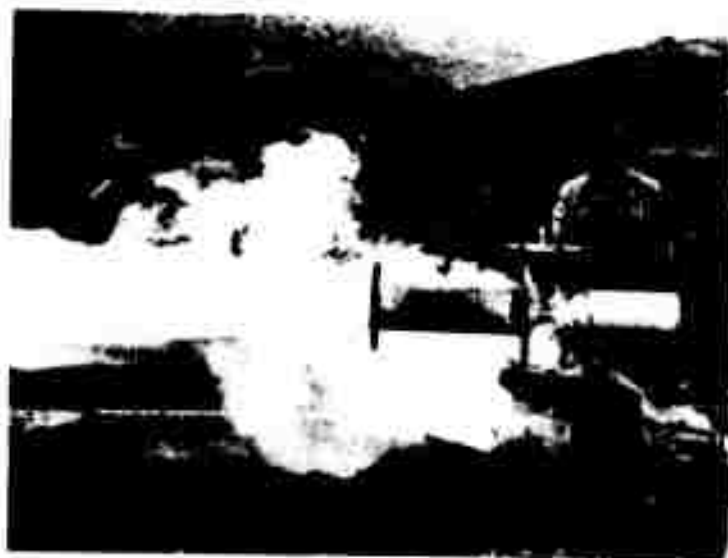


Fig. 9. High-Pressure Steam-Hot Water Well of the Future Bol'she-Bannaya Geothermal Power Station.

During exploratory work in 1965, some wells produced about 73 kilograms per second of steam-hot water mixture with an average heat capacity of 150 kcal/kg at natural discharge. With additional wells, there is a possibility of increasing the volume up to 200 kilograms per second. It is estimated that this volume will warrant the operation of an electric station with an 8MW capacity [40].

Below is a schematic layout of the first stage for the proposed power station (see Fig. 10). All wells will be directly connected to the

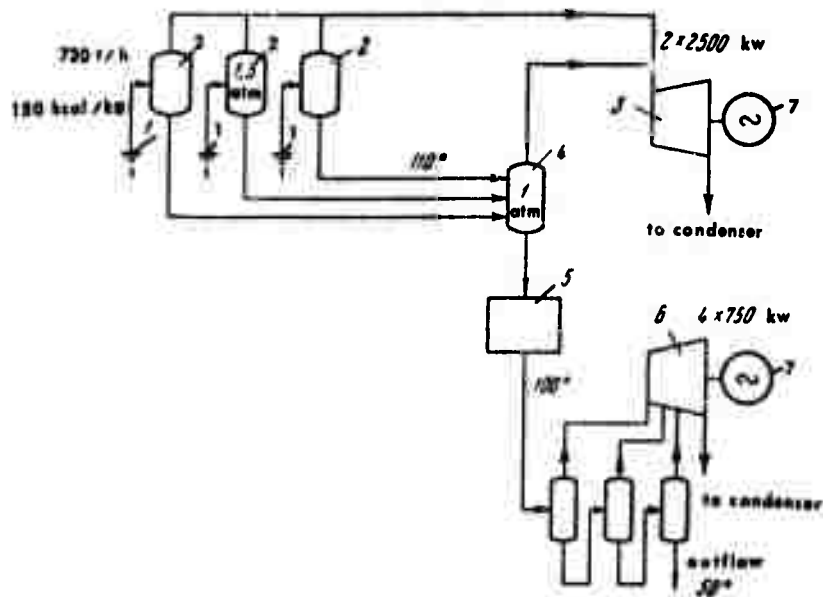


Fig. 10. Schematic of the First Stage of Construction of the Bol'she-Bannaya Geothermal Power Station for 8MW Capacity [40].

1- Wells at 1.5 atm.; 2- separators at 1.5 atm.; 3- 2 turbines (each 2,500 kw at 1 atm.); 4- expander at 1 atm.; 5- hot water storage tank; 6- 4 vacuum turbines (each 750 kw); 7- generators.

separators (2). Steam with pressure between 1 and 1.2 atmospheres will be channeled into the turbines (3), while the hot water will be channeled into the expander (4) in order to reach the required pressure of one atmosphere. From the expander (4), hot water (100°C) will enter the hot-water storage tank (5) and then the vacuum turbines (6) [40].

Based on Soviet estimates [40], the cost of the station will be about 2.5 million rubles. The initiating capacity of 8MW is rated as minimal, since the station will start operation with a steam-hot water mixture of only 200 kilograms per second discharge. To increase the capacity, the use of low-boiling agents (freon, isobutane, and others) are under consideration. In this way, it is expected to increase the output by about 50%, and by operating with a steam-hot water mixture of over 200 kilograms per second discharge rate, the station will have a capacity of 12 MW. By fully utilizing the available resources (estimated at 400 kilograms per second of steam-hot water mixture), the capacity of the station eventually can be increased to 24 MW [40].

The cost of electricity is estimated at 2 to 2.5 kopecks per kw/hr, representing one-sixth to one-seventh of the prevailing cost in the city of Petropavlovsk-Kamchatskiy.

However, the existing 20 wells represent only 50% of the geothermal resources required for the operation of a station with 24 MW capacity, and additional prospecting drilling is needed to provide the necessary volume. The construction cost of this plant constitutes an additional problem, and the construction probably will not progress as planned.

2. Makhachkala Geothermal Electric Power Station

This geothermal power station, designed by the Dagestan Branch of the USSR Academy of Sciences and the Design Institute of the Thermal Electric Station Planning Enterprise, in the first stage of development will have an initiating capacity of 12 MW. There are indications that this station will be expanded to yield a much larger capacity, but for the

present no definite data are available regarding the exact capacity and the date of completion [15, 22]. In this region, at a depth between 2500 and 3000 meters, the geothermal waters attain a temperature of 120°C , with the discharge ranging between 1500 and 3000 cubic meters per day at a pressure of 5 to 10 atmospheres; mineralization is not more than 2.5 grams per liter. To reach geothermal waters with temperatures above 160°C , deep drilling to a depth of 4000 to 4500 meters has been in progress since 1965. These prospecting activities are related to Soviet plans for increasing the production capacity of this station [19]. As part of this prospecting, at Berekey, near the town of Makhachkala in the Dagestan ASSR (see Fig. 2), drilling to a depth of 4500 meters to reach the steam-hot water mixture is in progress. During the drilling, a highly mineralized steam-hot water mixture was obtained (from an undisclosed depth), with an estimated discharge capacity of 70,000 cubic meters daily, having a temperature of 57°C at the surface. The Soviets expect to tap about $94.54 \cdot 10^{10}$ kcal hot water annually, which is equivalent to 94,535 tons of fuel oil, or 107,456 tons of coal [21, 23].

The Makhachkala station is designed for geothermal water with a natural heat capacity of 160 kcal/kg at the surface, obtainable from depths ranging between 4000 and 4500 meters, to satisfy the electricity and heat requirements of the town of Makhachkala. The estimated technical-economic data for this station are summarized as follows [39]:

Total discharge of wells	100 tons per hour
Initiating capacity	12 MW
Number of hours in operation	8000 annually
Annual production of electric energy	96 million kw/hr
Annual loss of heat	100,00 Gcal
Electricity consumed by the station	5%
Staff coefficient	2 men per 1000 kw

3. Yuzhno-Kuril'sk Geothermal Electric Power Station.

The Yuzhno-Kuril'sk geothermal power station on Kunashir Island (Kurile Island group), will have an initiating capacity of 5-6 MW. The station, to be erected at the Goryachiy Plyazh site about 8 kilometers from the town of Yuzhno-Kuril'sk, will operate on geothermal water at a temperature of 130°C . There are also several steam-producing vents at this site, having temperatures ranging between 100 and 130°C [19].

The discharge rate of the steam-hot water mixture is not high, estimated at 1.5 kilograms per second. However, data presented by the Institute of Volcanology of the Siberian Branch of the USSR Academy of Sciences indicate that the average discharge volume is actually much larger (given as 77 kilograms per second) with a total caloric value of 36 Gcal per hour. The minimum caloric value has been estimated at 130 kcal per kilogram. In January 1965, the Sakhalin Geological Administration started several drillings at the site, but at present no additional technical data are available regarding the progress and the purpose of this activity [40].

The Goryachiy Plyazh area, abundant with geothermal surface manifestations, is being considered for exploitation for space heating, agriculture and other purposes, in addition to the generation of electric power. The Thermal Physics Institute of the Siberian Branch of the USSR Academy of Sciences presently is studying the technical-economic aspects of the construction of this station [42].

Additional future developments of considerable importance have been planned for the following sites [40]:

The Verkhne-Koshchevsk fumaroles, are located about 22 kilometers southeast of the village of Ozernoye.

The Severo-Kambal'nyy fumaroles, are located about 10 - 12 kilometers from the Pauzhetka station. By preliminary estimates, the discharge volume is put at 100 tons per hour of dry steam which has high energy potential. It has been estimated that one ton of hot water at a temperature of 100°C can produce 4 kw/hr of energy, while one ton of dry steam can produce about 100 kw/hr, i. e., a 25-fold increase in output of electricity, as compared with hot water.

The Zhirovskiy geothermal springs have not been studied in detail and, consequently, their data are limited. It is estimated that the discharge rate is about 15 kilograms per second, and the steam mixture has a temperature of 100°C at the surface. During 1968-1970, some prospecting and research activities were to take place for the purpose of producing a number of wells having a total length of 19,000 meters. From these activities, it has been established that the maximum temperature ranges between 100 and 130°C , with the natural heat capacity between 25 and 60 million calories per second with a production capacity of about 36 MW.

IV. OTHER APPLICATIONS OF GEOTHERMAL RESOURCES

Geothermal resources are also being considered for diverse exploitation and most possible uses, whether of low- or high-temperature sources, appear to be economically viable with great advantages to domestic and industrial development.

In the USSR, hot water is found in over 20 percent of the nation, although the present explored potential amounts only to 1 percent. It has been estimated that during 1970, the total fuel cost saving arising from the use of hot geothermal waters amounted to one million dollars. By 1980, this saving is expected to be approximately 10 million dollars [43].

Besides generating electric power, geothermal energy has broad application in several fields of the national economy. There are presently many engineering projects of varying scale and purpose in various stages of completion across the USSR, and describing all of them would be beyond the scope of this study. Therefore, only the major projects of basic interest to the respective fields will be outlined in order to illustrate the degree and magnitude of multipurpose exploitation of geothermal resources in the USSR.

A. Domestic and Industrial Applications

1. Heating

The largest user of geothermal energy for heating is the Soviet Union, where consumption of low-temperature waters from thermal springs or drill holes represents an annual savings of about 15 million tons of conventional fuel. A ten times greater saving is expected by 1980. It is estimated that 50 to 60 percent of the USSR territory contains

thermal waters which are economically exploitable, with the total heat value being comparable with the total coal, oil and peat resources of the country [17].

Considering the annual heating demand, several Soviet scientists have investigated the possibility of using geothermal water for district heating in conjunction with fossil fuel boilers operating during peak heating months. They stress the importance of seasonal demands on the overall geothermal load factor and also indicate the limitations which apply to the direct use of cooler waters for heating. To overcome the low temperature disadvantage, the Soviets are stressing the great potential of the lithium-bromide absorption machine operated with geothermal energy as a heat pump for winter heating and air conditioning in the summer [43].

The economic use of thermal water depends on the selection of appropriate heating systems, the discharge capacities of wells, and the temperature and chemical composition of the waters [19].

In case the chemical compositions are beyond permissible limits, before entering the heating system the thermal water should be channeled through a degasifier and heat exchanger. In the heat exchanger, the thermal water releases its heat into low-mineralized and chemically nonaggressive water, and then is used for the heating system. For highly mineralized thermal waters, a centrifugal separator is required to separate the steam from water before it is introduced into the heating system. In general, geothermal water should not have more than 0.1 mg/l of oxygen, 5 mg/l of sediments, and 700 mg-equiv/l of hardness (carbonate residuals)[19].

Regarding heating systems, among most interesting is that used by the town of Paratunka, Kamchatka, to heat three 48-unit apartment houses. The maximum load is 0.55 Gcal/l, and geothermal water at 80° C is used for heating both the tap water and the apartments. A conventional radiator system or radiant heating with pipes embedded in the floors or ceilings is used, and the heating system is designed for a temperature drop from 80 to 40° C. Utilizing a heat pump, part of the 40° C return water can be reheated to 60° C by extracting heat from the remainder of the return water, which in turn is cooled to 10° C. The 60° C water is mixed with the 80° C geothermal water. The temperature of this mixture can be increased as desired by an electrical peak heating unit. Increased loads during cold spells can also be met by increasing the heat extraction from the geothermal water with the heat pump [45].

Pipelining of hot water will improve the present poor heating conditions of Petropavlovsk-Kamchatskiy, where only about 30 percent of its households have individual steam heating. The town is supplied with heat from the Paratunka geothermal fields, a distance of 45 to 65 kilometers, by different means (see Fig. 11).



Fig. 11. Insulated Pipes for Heating of Petropavlovsk-Kamchatskiy [42].

In the town of Makhachkala and adjacent areas, utilization of geothermal waters for heating of domestic and industrial space was initiated 24 years ago following the discovery of thermal waters as a result of oil prospecting. From about 100 oil wells, having depths between 1200 and 1500 meters, 40 wells produce hot water at 60 to 70° C utilized for heating about 9,000 square meters of domestic and industrial space. The capacity of the wells has been estimated at 2000 cubic meters daily, with plans being considered to increase the heating capacity to 10,000 cubic meters daily [42].

At the town of Groznyy, the Caucasus Special Geothermal Directorate (Ministry of Gas Industry) recently commissioned two powerful geothermal wells which will be utilized for heating of the town, replacing the present heating system operating on gas which during the winter months proved to be insufficient [42].

The largest single heating system in the USSR serves three districts of the town of Cherkassk with about 19,000 inhabitants [45].

Presently, several towns are under consideration for heating by geothermal waters, such as Armavir, Poti, Gudermes, Nal'chik, Tyumen, Tobol'sk, Arshan, Tsaishi, Fergana, Chartak, and many others [34].

2. Hot Water Supply

Hot water from geothermal springs and wells with moderate temperatures and of required chemical composition are being used extensively for domestic, industrial, and other hot-water supply. To meet required specifications, the chemical compositions of geothermal water should not exceed 1 g/l of dry residuals, 0.5 g/l of sulfate, 0.35

g/l of chloride, and 7 mg-equiv/l of average hardness. Besides the required clarity, taste, and odor, the content of heavy metal salts, radioactive elements and other contaminants should be within the established norms. In addition, the content of lead should not exceed 0.1 mg/l, while arsenic, fluorine, copper, and zinc should not exceed 0.5, 1.5, 3.0 and 5.0 mg/l, respectively [19].

Hot water supply systems are constructed using conventional techniques and equipment and, in many cases, in conjunction with heating systems.

3. Permafrost - Mining and Construction

The Soviets foresee future large-scale use of geothermal waters in mine heating to facilitate the exploitation of mineral resources in permafrost, frozen soil, and regions subject to long and severe winters [47].

In Magadan Oblast', the main gold mining region in the Soviet Union, scientists are studying methods for year-round hydraulic placer mining with geothermal waters. Similar methods are under consideration in the mining of diamonds, lead and other minerals abundant in the Taymyr, Yakutia, Kolyma, and Chukotsk regions [19].

A study conducted by the Leningrad Mining Institute indicates that for this type of mining, the thermal water should have a temperature between 20 and 30° C and a minimum discharge of 250 cubic meters per hour [19].

There are two ways to obtain geothermal waters for the above purposes [19]:

- by direct tapping of thermal waters with a temperature above 25°C , regardless of the degree of mineralization;

- by injecting cold water into deep, specially drilled wells, where it will be heated above 25°C by the deep regional geothermal (dry heat) field. It has been estimated that one such well can produce 400-500 cubic meters per hour of thermal water at $20-80^{\circ}\text{C}$ for a duration of 10 to 30 years, i.e., the equivalent of 2-20 million kcal/h capacity.

Possibilities also exist for utilizing geothermal waters for various types of construction in permafrost and frozen soil. Applied thermal water creates a hot slurry which, through gravity, penetrates into the frozen soil and facilitates drilling of holes for pillars and other foundation components.

4. Refrigeration and Air Conditioning

Geothermal waters are a very cheap source for refrigeration and air conditioning in domestic, public and industrial installations, with great savings of over hundreds of thousands kilowatts of electric energy possible. Geothermal waters with temperatures above 13°C provide better results for year-round air conditioning applications. Thermal waters of 70°C require special conversion equipment. To obtain temperatures above 0°C , special lithium-bromide machines are in use, and for temperatures below zero, the ammonia-water machines are appropriate.

Below is a schematic diagram (see Fig. 12) of a lithium-bromide absorption unit. This unit was designed by the Thermophysical

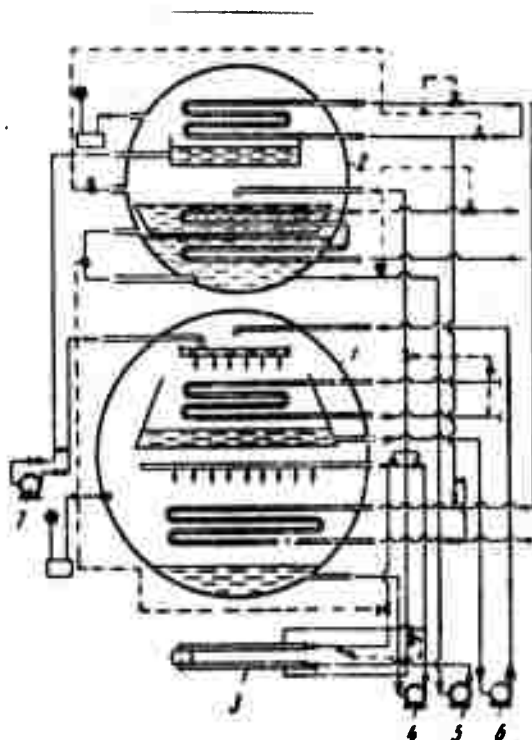


Fig. 12. Schematic of a Lithium-Bromide Absorption Unit [48].

- 1 - Absorber-evaporator;
- 2 - generator-condenser;
- 3 - heat exchanger;
- 4 - 7 - pumps.

Institute of Siberian Branch of the USSR Academy of Sciences and was tested at the Chernigov Synthetic Fiber Plant. It operates on thermal water with a temperature ranging between 85 and 120° C. This unit has a capacity of 2.5 Gcal/hr, is manufactured in the USSR, and is in great demand for refrigeration in various chemical industries such as synthetic rubber, ammonia and at metallurgical plants. The arrangement and operation characteristics of the unit are similar to units used in other countries [48].

Tabulated data on cooling-heating requirements are given in Table 2 (p.24).

5. Swimming Pools and Baths.

Thermal waters for swimming pools and baths should have a temperature between 25 and 40° C and mineralization not exceeding 50 grams per liter. The thermal waters can be obtained chiefly from a geothermal well, geothermal electric station or geothermal heating system [19].

Below is an outdoor swimming pool utilizing geothermal water from one of the wells in Paratunka river valley (see Fig. 13).

(see Fig. 13 next page)



Fig. 13. Outdoor Geothermal Swimming Pool in the Paratunka River Valley [42].

Near the town of Nal'chik, there are five geothermal wells ranging in depth between 1600 and 2840 meters with a free-flow discharge capacity of 9000 cubic meters daily at temperatures between 50 and 80° C, and mineralization of 0.6 to 78 grams per liter. Presently, only one well with a temperature of 80° C is supplying several swimming

pools with thermal waters. The 80°C temperature is cooled to the required temperature of 25 to 40°C [49].

At present, there are many towns and resort centers utilizing thermal waters for the above purposes, and only a few have been mentioned here.

B. Agricultural Applications

Agricultural use of geothermal waters for hotbed and hothouse cultivation of vegetables has increased considerably in recent years. It has been estimated, that one hectare (2.47 acres) of heated soil will produce year-round vegetables for a town with a population of 10,000, and for a town of 100,000 about 10 hectares will be required. The norms for above acreage are based on standards established by the Food Institute of the USSR Academy of Medical Sciences assuming an annual per capita consumption of about 146 kilograms (400 grams daily) of the fresh vegetables grown in hotbeds or hothouses. It is desirable, that 25% of the above quota should be naturally grown vegetables [50].

In general, the water temperature varies according to the type of farming, geographic location, and season. A temperature of 60°C is required for hothousing in winter and 50°C in spring; for heated hotbeds, a temperature of 40°C is required, while for heating of soil (sheltered or unsheltered), 30°C temperatures are appropriate. The thermal water for heating of shielded soil (by glass plates, plastics, or wooden boards) should have natural heat capacity of $2.5 \cdot 10^6$ cal/hr, a temperature between 35 and 40°C , and a head of at least 10-15 meters at the surface. Heating soil by the shielding method is said to be 4 to 5 times cheaper than by hothousing installations. This method has been used in Kamchatka, Kazakhstan and the Caucasus foreland, and has proven to be very economical [19].

The temperature of water used for heating soil and for thermal irrigation should be above 25°C . For thermal irrigation, the mineralization should not exceed 2 grams per liter [19].

In 1970, it was reported [19], that the largest hothousing complex in the world, at Sredne-Paratunka springs, was being completed and would cover an area of 60,000 square meters. Production in the initial stage is expected to be 900 to 1000 tons of fresh vegetables annually and the final production goal is set at 2000 tons annually.

Another hothousing complex in the planning stage is in the Pauzhetka thermal springs region, which will cover an area of 150,000 square meters and will have an estimated annual production capacity of 1800 tons of fresh vegetables.

Near the town of Makhachkala there are several hothousing complexes (see Figs 14 and 15), with moderate production capacity. However, to



Fig. 14. Hothousing Complex Near the Town of Makhachkala [22].

increase the supply of fresh vegetables to the town of Makhachkala and adjacent areas, several hothousing projects are in the planning stages or nearing completion (see Fig. 15). It has been estimated



Fig. 15. Hothousing Project (near completion) in the Vicinity of Makhachkala [19].

that the production capacity of hothousing complexes in this area will amount 3000 tons annually. Also in the planning stages, are several hothousing projects near the towns of Khasavyurt, Groznyy, Stavropol', and Tobol'sk [19].

Agricultural use of geothermal water is being considered also in Sakhalin Oblast', especially in the Kurile Islands, the Yakutsk ASSR, and Magadan Oblast', where the Soviets appear to be confronted with the immediate problem of a geothermal resources survey. On the other hand, in Lorino and vicinity (Magadan Oblast') geothermal resources are already being utilized for hothousing, but on a rather moderate scale.

C. Medical and Health Applications

Over the years, thermal water has been used by clinics, hospitals, and health resorts in many countries for therapeutic purposes.*

Out of 1500 hot water springs in the Soviet Union, over 340 are utilized exclusively by sanatoriums, hospitals, and health resorts. In addition, there are 86 mineral water bottling plants presently in operation [53].

Based on medical research and empirical experience, geothermal waters and their chemical components have a significant healing influence on various human maladies. The basic indicators for the therapeutic value of thermal waters are: mineralization, ion content, gas saturation, gaseous components, content of specific biologically active components (CO_2 , H_2S , As, Fe, Br, I, H_2SiO_3), radioactivity (Rn), hydrogen ion concentration (pH), and water temperature. To be considered for balneological use, the thermal water should meet the following norms: overall mineralization 2 g/l, content of soluble CO_2 - 0.5 g/l (for external application, 1.4 g/l), content of H_2S - 10 mg/l, As - 0.7 mg/l, Fe - 20 mg/l, Br - 25 mg/l, I - 5 mg/l, H_2SiO_3 - 50 mg/l, and Rn - 5 m μ Curie/l. However, the above-stated content of As, Fe, Br and I pertain to therapeutic drinking water with an overall mineralization of 10 g/l [19].

Various therapeutic treatment and health resort facilities using low-temperature springs have been developed in the Soviet Union, especially in the Soviet Far East. The largest balneological resort center, near the town of Nal'chik, utilizes one geothermal well having a temperature of 80° C [49].

*) The first health resort in Russia was established in 1714, in Karelia.

In the bed of dry Duzkan lake, near the town of Chardzhou (Turkmen SSR) there are many thermal water holes utilized by the local people for balneological treatment [51].



Fig. 16. Thermal Water Holes in the Bed of Dry Duzkan Lake.

Considerable therapeutic value has been attributed to the Garm-Chashma thermal springs (see Fig. 17) in the Anderob river valley near the town of Khorog (Tadzhik SSR). Several years ago, a balneological sanatorium was built, with an additional two presently in the planning stage.

(see Fig. 17 next page)



Fig. 17. The Garm-Chashma Thermal Spring, Near the Town of Khorog.

The hot springs area in the southern part of Kamchatka Oblast' has developed considerably with modern facilities for medical treatment and recuperation. There are sanatoriums with good medical treatment facilities at Nachiki and Paratunka.

Recently, several hot spring areas have been developed for medical treatment, such as:

Magadan Oblast'. The Talaya hot springs have a well-equipped sanatorium, and the recently discovered Novoye Chaplino hot springs are in the development stage for medical treatment. Hot springs near the town of Lorino are being used for medical treatment and recuperation [52].

Sakhalin Oblast'. Hot springs have been discovered sporadically on the main island. For instance, at the town of Sinegorsk there is a large medical treatment facility, and the hot springs in the vicinity of Dagi have been utilized as health resorts [52].

However, several hot spring areas are in the planning stage for development in the near future as balneological, medical and health centers [52].

Geothermal waters with their therapeutic potentials have been regarded as very valuable to the national economy and to the population's health.

The Hydrogeological and Hydrophysical Institute of the Kazakh Academy of Sciences recently published a comprehensive study emphasizing the curative value of geothermal and mineral waters. The study indicates that therapeutically valuable elements, such as radon, iron, hydrogen sulfide, and iodine-bromine have been found in thermal waters of southern Kazakhstan, in the Mangyshlak peninsula, and the Sary-Arki desert [55].

The Ministry of the Food Industry, in cooperation with the Central Scientific Research Institute for Balneology and Physiotherapy (Ministry of Health) is accelerating the production of bottled mineral waters. It has been estimated that the production capacity is over 1.5 billion bottles annually. During the current five-year plan (1971-1975) several large bottling plants are to be built and production is to be increased by about 2.4 times. One plant under consideration will have a capacity of 250 million bottles annually.

About 80% of the resources presently being utilized are located in the northern Caucasus, the Ukraine, and Transcaucasia. A considerable increase in bottling has been achieved in Soviet Central Asia, Chita and Kemerovo Oblast's, and Kamchatka peninsula. Presently, about 80 new mineral water sources are recommended for immediate exploitation.

D. Geothermal Byproducts

Geothermal waters are enriched with about 80 different chemical elements, which can be extracted either coincident to the purification processes of thermal waters intended for geothermal electric power stations and other facilities, or specifically for the chemical industry [19, 23].

The extraction of sodium and magnesium sulphates, iodine, and bromide from geothermal waters has been carried out in the Soviet Union. For example, in the Kashkadar'insk artesian basin (Uzbek SSR) from only one exploratory well, about 2,700 tons of salts (mostly potassium chloride), 9 tons of bromine, and about 100 kilograms of iodine have been extracted in one year [22, 54].

Recently, the Soviets announced that techniques for the extraction of boron, alkali and alkali-earth metals, and trace elements are being developed [54].

Frequently, hot and superheated geothermal waters contain large amounts of salt, iodine, bromine, naphthenic acid (mixture of cycloparaffin acids), boron, strontium, lithium, fluorine, and other rare elements, which can be extracted easily for the chemical industry [23].

The potential benefits from extracting chemical elements from highly mineralized geothermal waters can be demonstrated with actual data as follows:

(1) Near the town of Berekey, Dagestan ASSR, during prospecting drilling, well no. 3 (see Fig. 2) produced a fountain of highly mineralized

water (brine) with a discharge capacity of 70,000 cubic meters daily. Considering the discharge volume and the amount of chemical elements, it has been calculated that in one year such a well could produce [23]:

<u>Elements</u>	<u>Tons</u>
NaCl	1,470,000
KCl	30,000
CaCl ₂	30,000
BaCl ₂	14,300
MgCl ₂	24,300
SrCl ₂	277
various trace elements	<u>6,704</u>
Total of obtained elements:	1,575,581 tons

(2) During prospecting drilling in the oil region of Datykh, Chechen-Ingush ASSR, well no. 6 produced a highly mineralized water (brine) fountain having a discharge capacity of 40,000 cubic meters daily. It has been calculated that annually, this well can produce [23]:

<u>Elements</u>	<u>Tons</u>
NaCl	636,690
CaCl ₂	78,930
MgCl ₂	80,000
MgSo ₄	4,000
various trace elements	<u>2,240</u>
Total of obtained elements:	802,370 tons

The geothermal waters of the Cheleken peninsula annually produce about 300 to 360 tons of lead, 48 to 50 tons of zinc, 24 to 35 tons of copper, and several other components valuable for chemical industry [19].

The western Siberian and Irkutsk basins are prospective sites for the extraction of iodine, bromine, and several other elements. In addition, the Kamchatka peninsula and the Kurile Islands are considered as potential regions for the extraction of bromine, rubidium, cesium, lithium and arsenic from available superheated water and steam [19].

Near the town of Zhigalovo, Irkutsk Oblast', during prospecting drilling, a well 1125 meters deep produced highly mineralized geothermal water with brine density of 0.4 g/cm^3 and the soluble salts at 600 grams per liter. This high content of salts represents a very valuable raw material for the various chemical products for which eastern Siberia has a great need. However, the exploitation of these valuable minerals is still in the early stage, and considerable work has to be done to achieve production on an industrial scale [23].

V EQUIPMENT AND INSTRUMENTS

The drilling equipment and instruments for the exploitation of endogenous fluids are very much the same as used in the oil industry. Experience gained by the oil industry has been applied in geothermal drilling with minor changes in the methods, machinery, and instruments.

The standard rotary rigs are used for wet geothermal drilling, and as a rule they are for medium-depth penetration, since steam producing wells are usually less deep than those producing oil. Therefore, this particular use calls for some specific adjustments and minor modifications [28].

During the last decade, no great changes have become apparent in the design of drilling equipment. However, the Soviets designed their own separator with rather marginal improvement over those used by other countries, and the blowout preventer (on the base of wellhead connection) has been slightly modified to withstand the higher pressure [35]. The Soviets did not experience any blowouts during exploratory drillings, although they anticipated the possibilities in 1958 during drilling of the first rotary borehole in the Pauzhetka region [15].

Regarding the power plants and prime movers for drilling rigs, diesel engines and the direct-current electrical motors have been considered. The diesel engine is used primarily in the strictly exploratory phase, when electric power distribution points are at a considerable distance from drilling site. The electrical motor may prove highly economical in the subsequent stage, when a power generating plant is already in operation and may easily supply the drilling site [28].

To exploit deep dry geothermal resources, Soviet scientists have suggested a long-range project to drill wells to a depth of 10 kilometers and create large subterranean "boilers" which would supply a steam-hot water mixture for a geothermal electric station of more than 1 million kilowatts capacity.

The designers of the Uralmash Plant (Ural Heavy Machinery Plant), Sverdlovsk, RSFSR, have developed plans for a drilling installation called "Uralmash 15,000," which will be capable of drilling to a depth of 15,000 meters. The entire complex of the "Uralmash-15,000" consists of a power plant, an engine room, and a pumping station. This installation will have a derrick over 60 meters high, with elevators for cargo and operators. The superdeep drill-holes may be bored either by turbine or rotary methods [56].

In geothermal investigations, the instruments for measuring heat flow, thermal conductivity variations, thermal gradients, chemical composition of water, and other elements of geothermy, are the same as those used in standard geological exploration and hydrogeological engineering.

The Soviets have developed an instrument used for evaluating such physical parameters as thermal conductivity, permeability, and heat flux in rock under dry or wet conditions. The method involves heating and pressurizing the center of blocks of different types of rock with or without addition of liquid solutions. Quite large blocks are used, up to tens of cubic meters, with internal temperatures up to $1,000^{\circ}\text{C}$. Temperature and pressure gradients are measured in the walls by probes [57]. Additional technical and graphical data are lacking.

The Technical Thermophysics Institute of the Ukrainian Academy of Sciences has developed a series of instruments for measuring heat flux over a broad range; however, technical and graphical data on these instruments are presently insufficient [12].

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