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100 Years of Experience in Implementation of Russian Scientific and Technical Concepts of Geothermal Heat Supply

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ABSTRACT

Projected reserves of geothermal waters in Russia are estimated at 218 m3 / sec. Proven operational reserves of 66 fields – 315.23 thousand m3 / day. The installed thermal capacity of Russian geothermal heat supply systems is 310 MW with heat output of 170 GW•h / year. Geothermal research in Russia was started in 1905 by L. A. Yachevsky, a member of the international geothermal Commission. The first geothermal well in the USSR was drilled in 1948 in Makhachkala (North Caucasus). The first laboratory in the USSR for the study of geothermal resources was established in 1954 in the city of Petropavlovsk-Kamchatsky. In 1961, the USSR Academy of Sciences established the scientific Council for geothermal research. In the USSR there were 4 main geothermal scientific schools: Moscow, Leningrad, Kiev, Dagestan. Brief results of research of each scientific school and their heads are given. Was highlighted research results of petrogeothermal technologies. In 1972 the geothermal map of the USSR was published. The results of work of 5 regional divisions of the Ministry of gas industry of the USSR on drilling and operation of geothermal fields are presented. The results of work of engineering schools of the USSR on geothermal energy and heat supply, normative documents and leaders of these schools are analyzed. For the largest geothermal region - Dagestan the analysis of scientific researches, design researches, drilling and operation is executed. The results of the work of the only Institute of geothermal problems of the Academy of Sciences of Russia (Makhachkala) are noted. The data on the second reserve of geothermal water in Russia - Chechnya are presented. The results of research and operation of 16 geothermal fields (74 wells) with a potential thermal capacity of 238 MW in the Krasnodar region are presented. Built a combined solar and geothermal system of heat supply of the Rosoviy settlement (population 1000 people). The assessment of the energy potential of the Crimea, the characteristics of 26 geothermal wells, the experience of creating 12 geothermal heat supply systems using associated methane for power supply.

INTRODUCTION

According to the World Geothermal Congress (WGC) 2015 [1] geothermal power plants (GeoPP) with total fixed capacity of 12.6 GW with annual electricity generation of 74 thousand GW/h are operated in the world. Depending on parameters of a geothermal coolant, the following main types of geothermal plants are distinguished: with one expansion of steam (separation) - 5 GW of fixed capacity, on superheated geothermal steam - 2.9 GW of fixed capacity; geothermal binary geothermal plants on low-temperature coolant – 1.8 GW. In total, 613 geothermal power plants operate in the world, including 286 binary, 167 with one separation pressure, 68 with two separation pressures. In Russia, total fixed capacity of geothermal plants is 82 MW, including 75 MW with one separation pressure, 5 MW with back pressure, 2 binary.

According to the latest data, fixed thermal capacity of geothermal heat supply systems in the world amounted to 70.3 GW in production of thermal energy of 163 TW.h/y. From 2010 to 2014, 2218 geothermal wells were drilled in 42 countries, including 38.7% to heat supply and 8.6 % to combined heat and power supply. The world is dominated in geothermal heat supply systems with heat pumps: 70,95 % of fixed capacity, 55,3 % of released heat energy. The structure of GTP of the world with heat pumps is characterized by the following indicators of fixed capacity / annual output of thermal energy, % geothermal heat pumps – 70,95/55,3; pools – 13,0/20,31; heating – 10,74/15,01; others – 5,31/9,38. Structure of GTP without heat pumps respectively: heating – 44,74/45,43; greenhouses – 36,98/33,58; others – 9,32/10,84 [2].

Geothermal heat supply is in second place in the world after solar, from all renewable energy sources. Drilling of geothermal wells and development of mines differ significantly from gas and oil. Volumes of geothermal water re-injection are multiple of those used in oil production. Geological, hydrogeological, thermal and physical characteristics of geothermal fields determine specialization of respective disciplines. Development and construction of ground-based geothermal heating systems should take into account stable temperatures, high flow rates, complex chemical and gas composition of a geothermal coolant. According to the source of heat, there are deep (over 400 m) and surface geothermal heat supply systems. For the first, the source of energy is the heat of the Earth's magma, for the second – accumulated solar heat and deep heat of the Earth.

RUSSIAN GEOTHERMAL RESOURCES

Russia has huge reserves of geothermal energy in the Caucasus, Western and Eastern Siberia, Kamchatka, the Kuril Islands, Sakhalin, the Far East with estimated total flow rate of 218 m^3/sec.[3]. The resource base of geothermics of the USSR has been systematically studied since 1954. The geothermal map of the USSR was compiled due to the basis of the research data of geologists, hydrogeologists, mining thermal physicists [4, 5]. The general scheme of geothermal water resources development in the USSR has not been completed for a number of reasons [6]. Geothermal map of Russia is presented in the book [7] (Fig. 1). The results of testing of hundreds of thousands of drilled oil, gas and geothermal wells allow predicting geothermal resources of Russian regions with sufficient degree of reliability. According to data [8] 66 geothermal mines with temperatures at the wellhead from 40 ° C to 300 ° C with operational reserves of 315.23 thousand m^3/day were explored at a rate of 52.6 thousand m^3/day in 11 regions of Russia (Dagestan, Chechnya, Krasnodar Territory, Stavropol Territory, Adygea, Karachay–Cherkessia, Kabardino-Balkaria, Kamchatka, Sakhalin, Chukotka, Magadan region). Results of researches and operation of geothermal deposits made by the Ministry of Gas Industry of the USSR were summarized in the regulations of development of geothermal deposits [9]. At present time the fixed capacity of Russian systems of geothermal heat supply (GHS) amounts 310 MW and with released heat supply is 170 GW h/year [8].

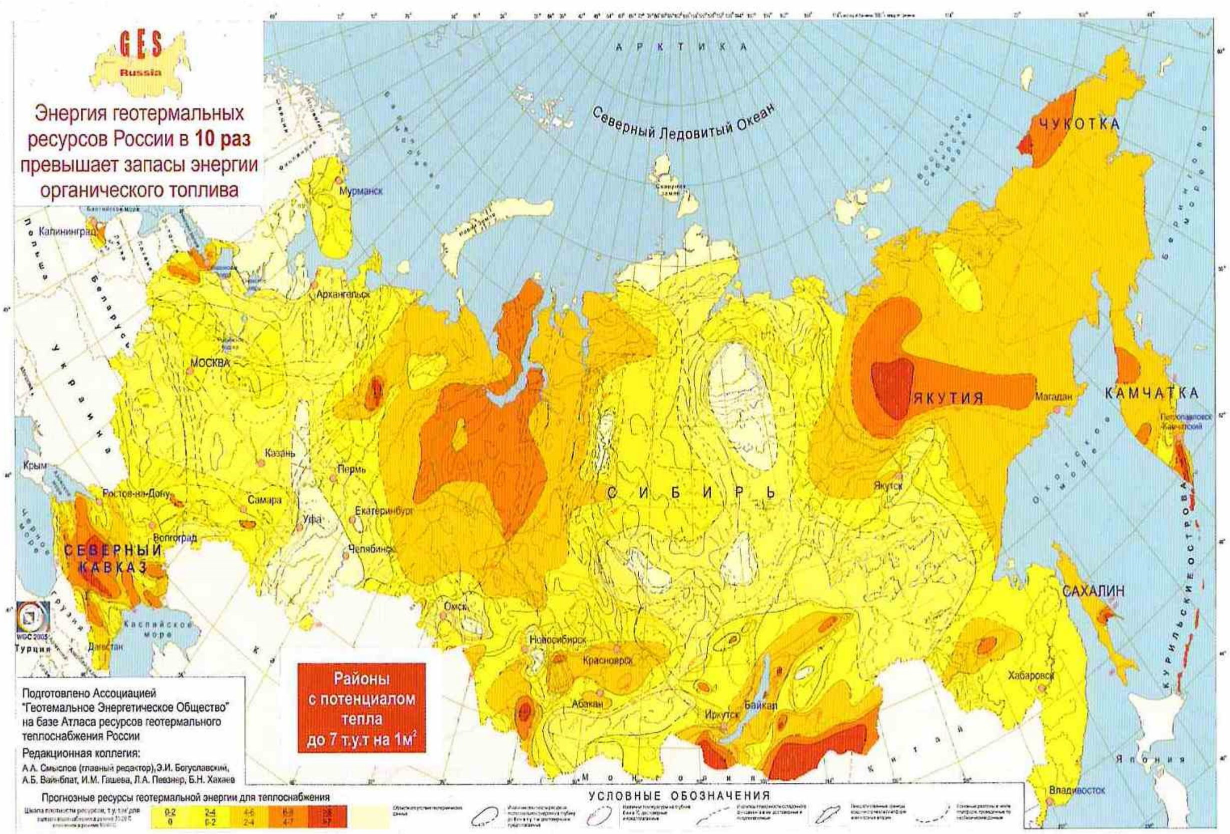

Figure 1 – Map of geothermal resources

SCIENTIFIC SCHOOLS AND CONCEPTS

Geothermics as a science is inseparably connected with geology and hydrogeology. Geothermal conditions of depths are also investigated in the exploration and production of minerals, oil and gas. The first geologist in Russia who systematically investigated geothermal problems was a talented and outstanding man L. A. Yachevsky (1858-1916). In 1905 he published articles on geothermics and became a member of the International Geothermal Commission. In 1910, on his initiative, the permanent Geothermal Commission of the Russian Geographical Society was organized.

After the Great Patriotic War, the department of geothermics was organized in the Ministry of Geology of the USSR, and in 1949 the first geothermal well was drilled in Makhachkala, which gave an industrial flow of hot water. The history of geothermal researches in Kamchatka is figuratively described by V. I. Belousov (born in 1936) [10]. On its website (http://sites.google.com/site/geobelousov), he posted unique documents on the history of geothermics in the world, the USSR, Kamchatka. In his opinion, the history of geothermics of Kamchatka began in 1948, when A. A. Gaivoronsky, a thermal engineer of the designing-budget Bureau of Glavsakhalinrybprom (1903-1971), addressed to Stalin with a proposal for the development of geothermics on Kamchatka. With the support of academician Mikhail Viktorovich Kirpichev (1878-1955), an outstanding thermal engineer and a founder of the Soviet scientific school of boiler construction, Chairman of the government of the USSR V.M. Molotov gave an order on starting of geothermal researches in Kamchatka. In 1954, there was developed the laboratory for study of geothermal resources of the Institute of Volcanology of the USSR, and in 1956 the first two exploration wells were drilled in Petropavlovsk-Kamchatsky. In 1966, in Kamchatka, 300 km south to Petropavlovsk-Kamchatsky there was developed the Pauzhetskaya geothermal power plant (GeoPP), the first in the USSR, capacity of 5 MW with turbines of the Kaluga turbine plant (KTP). Currently, this geothermal plant is a guaranteed supplier of electricity of 4 villages of Ust-Bolsheretsky district with two turbines with capacity of 6 MW, produced in the USSR in 1940 and 2000. In 2014 there was built the only 2.4 MW binary geotherrmal plant in Russia. The second in the USSR after Pauzhetskaya –Paratunskaya GeoPP was built in 1967 in 70 km from Petropavlovsk-Kamchatsky near the village of Termalniy. For the first time in the world, according to the idea of the academician S. S. Kutateladze (1914-1986), this plant used an intermediate easily boiling working fluid – freon, which turned into steam and rotated a turbine with capacity of 600 kW at geothermal water temperature of 85 ° C. The construction and testing of the plant was supervised by a student of S. S. Kutateladze, Ph.D. V. N. Moskvicheva. The results of the work of the geothermal plant during 2000 hours confirmed its designing characteristics. Currently, the equipment of the station has been dismantled. On the Kuril Island Kunashir at the foot of the volcano there was established a geothermal power plant "Omega" (KTP) with capacity of 500 kW in 1993, and in 2003 there was developed the Mendeleevskaya GeoPP with power plants "Tuman-2A" (KTP) with capacity in 3.6

MW, geothermal heat supply station in 18 MW and geothermal heat pipeline in the village of Goryachy Klyuch with length of 9 km. Currently, the reconstruction of the geothermal plant with the installation of equipment of the company "ORMAT" (USA) is being made. In 1999, in 110 km from Petropavlovsk-Kamchatsky under the leadership of PhD in Engineering O.A. Povarov there was built the Verkhne-Mutnovskaya GeoPP with capacity of 12 MW with turbines "Tuman 4 K" (KTP). A specific feature of this station was the modularity of the design, which allowed to build it in the shortest possible time, as well as the use of air capacitors. Based on the successful experience of the Verkhne-Mutnovskaya GeoPP operation in 2003 there was built the most powerful in Russia Mutnovskaya GeoPP with capacity of 50 MW with two turbines K-25-06 (KTP).

Table 1: Characteristics of exploited Russian GeoEP

№	Title, location	Fixed capacity	Year of construction	Scheme of GeoEP	Comments
1	Pauzhetskaya South of Kamchatka	12,0	1966	single circuit with one separation, mixing condenser	virtual capacity 5 MWt
2	Verkhne-Mutnovskaya, Petropavlovsk-Kamchatsky district	12,0	1999	single circuit with double separation, air condenser	moduled
3	Mutnovskaya, Petropavlovsk-Kamchatsky district	50	2002	single circuit with double separation, air condenser	

In 1956 there was developed the laboratory of hydrogeological problems named after S.V. Savarensky in Moscow (F. A. Makarenko), laboratory of geothermics of the Institute of Earth's physics in Moscow (I. D. Dergunov), laboratory of hydrogeological and geothermal studies of the Institute of Geology of Dagestan branch of the USSR Academy of Sciences in Makhachkala (S. A. Jamalov). The research results were discussed by the Academy of Sciences of the USSR in 1956 at the first all-Union Meeting on Geothermics in Moscow. In 1961 to coordinate researches, the USSR Academy of Sciences organized a commission on hydrogeology and geothermics, which was transformed into a Scientific Council for geothermal researches headed by academician A. N. Tikhonov in 1964. In 1963, the government of the USSR adopted a resolution "On the development of works on the use of Earth's deep heat in national economy", which assigned the responsibility for the development of thermal energy of depths to the Ministry of Gas Industry of the USSR. In 1964 in Moscow the second all-Union Meeting on Geothermics was held, and at the third all-Union Meeting in 1969 in Makhachkala it was noted that geothermal heat supply in 7 cities was provided to 50 thousand people, 100 industrial enterprises and 15 hectares of greenhouses. During this period 64 organizations were engaged in geothermal researches in the USSR.

The study of geological, hydrogeological and thermophysical issues of geothermics was carried out in four main scientific schools: Moscow, Leningrad, Kiev and Dagestan. As a result of researches of Geological Institute of the USSR Academy of Sciences (F. A. Makarenko, V. I. Kononov, M. D. Khutorsky, V. I. Dvorov), the joint Institute of Earth's physics of the USSR Academy of Sciences (I. D. Dergunov, E. A. Lyubimov) there were determined the main perspective geothermal deposits of the country.

They used to accompany by tectonic faults at the boundaries of plates on which hot magma achieved to the surface of the Earth. In 1972 the geothermal map of the USSR was published (ed. by F. A. Makarenko – 1906-1984). Researches of conditions and motions of underground waters from areas of supply to areas of discharge and modeling of geothermal mines have been performed by hydrogeologists of the Institute VSEGINGEO (PhD Mavritsky B. F., Shpak A. A.) [11]. Mining engineers-physicists were engaged in studies of heat transfer from magmatic foci to rocks, changes in thermal regime of water-saturated rocks in selection and injection of geothermal water in rock massifs. In the USSR the leader of using heat of dry rocks (petrogeothermics) was the founder of the Leningrad scientific school of geothermics, PhD in Mathematics Yu. D. Dyadkin (1929-2002). At the Leningrad Mining Institute (LMI), he developed theoretical and experimental bases for the use of deep heat of the Earth [12], participated in the development of the geothermal Atlas of the USSR [11]. In 1970 he played an important role in the development of geothermal researches and he was organized the problematic scientific-research institute of mining thermal physics in LMI. The worthy successor of Yu. D. Dyadkin and the leader of the Russian geothermics was Doctor of Technical Sciences E. I. Boguslavsky (born in 1934) and he described the results of studies of geothermal and petrogeothermal deposits in his monograph "Development of thermal energy of depths". At the same time, the problems, from mathematical modeling of thermal transfer processes in rocks to economy of geothermal heat supply were analyzed. Currently, this is the only most informative book in Russia.

Kiev geothermal school was founded by Doctor of Technical Sciences O. A. Kremnev (1919-1987). Together with Doctor of Technical Sciences A.V. Shurchkov, he investigated the creation of petrogeothermal systems in porous rocks [13], geothermal circulation systems, technical and economic assessment of creation of geothermal heat supply systems with construction of nomograms for determining the thermal power of a well depending on depth, temperature and flow rate, costs of drilling [14]. The successor and a chief specialist of geothermics in Ukraine currently is Doctor of Technical Sciences Yu. P. Morozov (born in 1943). In his latest book "Extraction of geothermal resources and accumulation of heat in underground aquifers" [15] generalized experience of geothermics of Kiev scientific school. In world practice, petrogeothermal systems had limited application. The main problem is instability of rock fracturing and, accordingly, well flow rates. In the USSR there was a negative experience of creating such a system in Tyrnyauz (Kabardino-Balkaria). At the depth of 3.7 km, the temperature of rocks was 200 ° C and the pressure of water injection was 60 MPa. The experiment was stopped after the accident [16].

DRILLING AND OPERATION OF WELLS

In accordance with the Decree of the Government of the USSR in 1963 the drilling of wells and the construction of geothermal mines in the USSR were carried out by the Ministry of Gas Industry. From 1966 to 1981, it organized 5 regional offices for the use of deep heat of the Earth: Caucasian (Makhachkala), North Caucasian (Grozny), Kuban (Armavir), Georgian (Tbilisi), Kamchatka (Petropavlovsk-Kamchatsky). The task of offices included drilling of new geothermal wells, re-equipment of oil and gas wells, mine development, production and sale of geothermal water. In 1981, on the basis of departments supplemented by the Institute VNIPI geotherm in Makhachkala there was organized the NGA “Souzburgeotermia” on which balance there were 250 geothermal wells. The first operational normative document (Rules of development of deposits of thermal waters) was developed by the Ministry of Gas Industry of the USSR in 1985. Current rules of mine development of thermal waters PB 07-599-03 were approved in 2003.

DESIGNING OF GEOTHERMAL HEAT SUPPLY IN THE USSR

Since 1965 the projects of geothermal heating systems have performed by the central scientific research Institute of experimental designing of engineering equipment. The book of the USSR leading specialist on geothermal heat supply PhD. B. A. Lokshin (1937-1970) “Use of geothermal water for heating” [17] has not lost relevance to date. B.A. Lokshin firstly introduced the notion of coefficient geothermal heat supply efficiency, worked out the first designing regulatory document of the USSR “Instruction on complex use of geothermal waters for thermal supply of constructions”, VSN 36-77. A great contribution to geothermal heating made the main supervisor of B. A. Lokshin, PhD A. Z. Iwyansky (1925-2006). Their worthy successor was PhD. V. I. Krasikov (born in 1949). He developed the rules of designing VSN 56-87 “Geothermal heat supply of dwellings and public constructions” [18]. This research institute worked out the projects of geothermal heat supply in Makhachkala, Kaspiisk, Izberbash, Ternair, Cherkessk, Grozny, Tobolsk, tens of projects of geothermal heat supply of different objects were made. Under guidance of V.I. Krasikov there were worked out the projects of geothermal heat supply of Ust-Labinsk and the settlement Rozoviy of Krasnodar Territory, the city Vranje in Serbia.

GEOTHERMAL ENERGETICS IN THE USSR

Until 1985, the design of geothermal power and heat supply systems was also carried out by the Novosibirsk branch of the Institute “Teploelektroproekt”, which developed the schemes of geothermal power supply of Tyumen region, Petropavlovsk-Kamchatsky and Yuzhno-Sakhalinsk.

In the USSR, the main organization of the Ministry of Energetics of our country, the coordinator of all works on geothermics through the State Committee on science and technology of the USSR was the Energy Institute named after G. M. Krzhizhanovsky, where since 1962 the laboratory of geothermal energy and the Dagestan branch of the Institute had operated. Among the works of this Institute there should be noted the coordination of works on creation of the Mutnovskaya GeoPP (approval of reserves, preparation of feasibility study of construction), the same for the Oceanic geothermal heat supply on the island of Iturup (Kuril Islands), Kayasulinskaya in Stavropol Territory (drilling of wells, mining tests, technical plant design), creation of geothermal heating systems in Kamchatka, Dagestan, Georgia. PhD V. A. Vasiliev headed the laboratory of geothermal energy and the Institute of power engineering. [19].

GEOTHERMAL ENERGETICS IN RUSSIA

In the 1990s the scientific and geothermal engineering school was created by the outstanding specialist in turbine construction, a great organizer, PhD, professor O. A. Povarov (1938-2006). Three times state prize winner Oleg Alekseevich organized the research and training center of geothermal energy at the Moscow Power Institute in 1992. In 1994 O. A. Povarov created the JSC “Geotherm”, where he was a research supervisor, vice-president of the company. Under difficult economic conditions of 1990s, under the leadership of O. A. Povarov, new geothermal turbines, separators and other equipment were developed for the most powerful 50 MW Mutnovskaya geothermal power plant in Russia, which was put into operation in 2003 (Fig. 2). O. A. Povarov's work on the creation of geothermal energy was continued by his students, including Doctor of Technical Sciences G.V. Tomarov (born in 1957), PhD A. I. Nikolsky (born in 1945), PhD V. N. Semenov (born in 1948), PhD. A. A. Shipkov (born in 1975) [20]. In 2003, for the first time in Russia, the creative team headed by O. A. Povarov was awarded the state prize of the Russian Federation for fundamental researches in the field of geothermal energy and the creation of geothermal plants on their basis. Many years of experience in researches, development of equipment and creation of Russian geothermal power plants have been summarized and presented in the only Russian monograph on this problem “Geothermal energy”. The scientists of the JSC “Nauka”, JSC “Geoterm–M”, JSC “Geoterm”, “GeoMEI” developed the projects of geothermal heating projects, including feasibility study of geothermal heating cities of Labinsk, Ust-Labinsk, Anapa, Apsheronsk, Goryachiy Klyuch, village of Mostovskoy, settlement Rozoviy of Krasnodar Territory with capacity of 5 MW in the field of geothermal heating.

SURFACE GEOTHERMICS

In Russia the researches on surface geothermics were launched in 1990s of the last century at the St. Petersburg State Mining University under the leadership of Dr. Boguslavsky. There were researched the survey maps of temperature distribution at depths of 40, 100, 200 m of the whole country, as well as the assessment of surface geothermic resources throughout the country. The joint influence of landscape-climatic, hydrogeological factors on the one hand and geothermal properties of rocks on the other hand were investigated. Yu. P. Morozov, Doctor of Technical Sciences, was engaged into study of thermal regime of wells up to 400 m in depth in Kiev [15]. Doctor of Technical Sciences A. B. Alkhasov carried out comprehensive studies, including thermal regimes of surface geothermics in Makhachkala Institute of geothermic problems. There were developed the methods of determining the coolant’s temperature at output in a well, optimal discharge of a coolant in a well, distance between wells and rates of layer heating regime restoration [16]. A distinctive feature of researches of Doctor of Technical Sciences P. Vasilyev (born in 1955) is the study of heat exchange in rocks, taking into account the phase transition of the liquid state, as well as a large number of constructed objects in Central Russia using surface geothermic wells with heat pumps [21.22].

Figure 2- Mutnovskaya geothermal power plant

GEOTHERMICS IN DAGESTAN

Dagestan's contribution to the development of geothermics in Russia is unique. The founder of the Dagestan scientific geothermal school is a member-correspondent of the USSR Academy of Sciences, Doctor of Physical and Mathematical Sciences, Kh. I. Amirkhanov (1907-1986), who headed the Institute of Physics and the Presidium of the Dagestan branch of the USSR Academy of Sciences from 1950 to 1984. On his initiative in 1956 the laboratory of hydrogeological and geothermal researches, headed by PhD S. A. Jamalov (1903-1980), was established at the Institute of Geology [23]. In 1980, on the basis of this laboratory there was established the Institute of Geothermics of Dagestan branch of the USSR Academy of Sciences, headed by a Doctor of Physical and Mathematical Sciences V.V. Suetnov (1931-1990), who worked there until 1983. Until 1987 his successor was the Doctor of Physical and Mathematical Sciences M.K. Kurbanov (1933-2011). Colleagues noted the huge role of Doctor of Physical and Mathematical Sciences K. M. Magomedov (1936-2002) in becoming and development IPG, who headed the Institute for 15 years (1987-2002). In 2002, since founding the Director of IPG was a member of the Institute, Doctor of Physical and Mathematical Sciences A. B. Alkhasov (1952), who successfully headed the Institute for 15 years (2002-2017). Under his leadership, IPG became the main geothermal scientific organization in Russia. It consists of 101 employees, including 22 Doctors and 30 PhD. The Institute consists of 8 laboratories, including energy, geothermal energy resources, mathematical modeling of geothermal facilities, integrated development of RES. Currently, A. B. Alkhasov heads the Dagestan branch of the Russian Academy of Sciences, heads the department of renewable energy of the Dagestan State University and the scientific school "Actual problems of development of renewable energy resources named after E. E. Shpilrein. Geothermal heat supply in Dagestan started in 1949, when at the suggestion of S. A. Jamalov there were built public baths on the basis of the old oil well № 27 in the center of Makhachkala, and in 1951 – the first in the USSR specially drilled well № 160, which gave water from Karagan deposits with a flow rate of 2000 m^3/day with temperature at the mouth of 63 ° C and overpressure of 15 bars. With the first operation of this well, the great practical importance of thermal waters has been proved. Village Reduktorny, TPS and a number of other industrial facilities in Makhachkala still use this well for heating, hot water supply and bottling of mineral water. In 1953 the buildings of the Institute of Physics and Institute of Geology of the Dagestan branch of the USSR Academy of Sciences obtained power from wells № 98 and № 175. A.A. Jamalov is one of the first who offered the geothermal panel systems of heating which are simple in implementation and reliable in operation. Development of ideas of S.A. Jamalov in geothermal power supply in Dagestan was implemented by his companions and followers: Yu.I. Sultanov, G.B. Badavov, P.N. Riger, A.Sh. Meilanov, A.N. Abduldaev. In 1964 in Makhachkala there was organized the first in the USSR North-Caucasus exploitation expedition in drilling and reconstruction of oil-gas wells on thermal waters which was reorganized in Caucasus field management in use of deep heat of the Earth of the Ministry of Gas Industry of the USSR in 1966. In Dagestan there were drilled 139 thousand running meters of geothermal wells. Here, PhD Kh.Kh.Natanov first developed methods of processing geothermal water to prevent salt deposits and corrosion [24]. In 1982, in Makhachkala, the same Ministry organized the Scientific-Production Association (SPA) "Soyuzburgeotermiya" under the leadership of a prominent oil industry worker M. G. Aliyev (1928-1987). In addition to the Caucasian fisheries management, it included the Institute of Earth's deep heat use (Grozny), Kuban (Armavir), Georgian, Kamchatka fisheries management (Petropavlovsk-Kamchatsky). (SPA) "Soyuzburgeotermiya" until 1987 performed scientific, research and engineering works, development of general schemes of development of geothermal mines, drilling new geothermal wells and recovery of oil and gas wells, geothermal water production. The All-Russia scientific institute "Geotherm" developed a general scheme of development of geothermal waters of the USSR until 2000. Dagestan is the leader in production of geothermal waters in Russia. There were developed 12 deposits with reserves of 82 thousand m^3/day, more than 130 wells were drilled and restored from the liquidated oil fund. Since 1966 systems of geothermal heat supply of cities of Makhachkala, Kizlyar, Izberbash and other settlements operate successfully. More than 200 million m^3 of thermal water was extracted from depths, 10 million Gcal of thermal energy was given to consumers, more than 2 million tons were saved [16]. 4 geothermal deposits are operating now: Makhachkala – Ternairskoe (48 wells); Kizlyar (17 wells); Izberbash (16 wells); Kayakent (4 wells). The deepest (5500 m) geothermal wells in the world were drilled at Tarumov deposit (Kurbanov M. K. Hydrothermal and hydromineral resources of the East Caucasus and foothills of Caucasus. M.: Science. 2001). Temperature at depth of 5500 m is 198 ° C, at the mouth of wells is 170° C. Steam-water mixture flow rates are up to 7000 m^3/day at pressure of 7 MPa at the mouth. Each cubic meter of water contains up to 4.5 m^3 of gas. Total mineralization is up to 200 g/l. With the predominance of chlorine and sodium ions, content of lithium, rubidium, cesium, iodine, bromine, strontium is high [25]. Currently, exploitation of geothermal mines in Dagestan is dealt by the JSC "Geoekoprom". Experience of geothermal heating of Dagestan was generalized by employees of the Dagestan branch of the Institute of Power engineering (Makhachkala) in the book [26]. This is the second book in the USSR after the monograph of B. A. Lokshin [17], which has not lost its relevance to the present time. The authors noted the following problems: small degree of use of thermal potential of wells, lack of water treatment, low profitability, imperfection of geothermal heat supply schemes. There were worked out the method of assessing economic feasibility of geothermal heat supply and cost structure of thermal waters. The employee of the Dagestan branch of the Institute of Power Engineering since its foundation, the follower of Jamalov S. A., G. B. Badavov [27] currently continues to work at the Institute of geothermal problems. For the first time in the domestic practice in 1987-1989 G. M. Gaidarov developed and tested at Kizlyar and Ternair deposits the geothermal self-circulation system (SCS), in which water from the productive well entered the injection well due to the effect of thermolift-thermopress (difference of densities of geothermal water [28].

The Dagestan branch of the Institute of Power Engineering of the USSR Academy of Sciences made a significant contribution to the development of geothermal researches in Russia. IPG of Dagestan is the only Institute in the Russian Academy of Sciences dealing with the problems of geothermal energy development. Employees of the Institute published more than 40 monographs on various aspects of evaluation, study and development of geothermal resources of different energy potential.

GEOTHERMICS OF CHECHEN REPUBLIC

In the North Caucasus, according to data of Doctor of Technical Sciences A. B. Alkhasov [16], Chechen Republic is in the second place in operational reserves of geothermal mines – 65 thousand m^3/day with 14 mines. In 1994, the annual production of geothermal waters was 8.8 million m^3 per year. The unique is Khankala mine in 10 km from Grozny, where 42 geothermal wells had been drilled from 1932 to 1989. In 1967, 36 wells were operated at this place and 7 million m^3 of geothermal water was extracted per year. The XIII layer of this deposit has been in commercial operation since 1974. The uniqueness of this deposit consists of high energy characteristics (temperature at the mouth is 95 ° C, flow rate of each well up to 3000 m^3/day), low mineralization – about 2 g/l, as well as good intake capacity for reinjection. The exploitation of this deposit was carried out by the North Caucasus Department of use of the Earth's deep heat use. In 1981 for the first time in the USSR the experimental works on re-injection were carried out on this deposit. Geothermal water from 5 productive wells with temperature of 90-95 ° C after cooling in greenhouses to 35-45 ° C was pumped into 4 wells of the same layer. According to the work [29], successful reinjection had been carried out from 1981 to 1986. In 1981, the Moscow Institute developed a technical and economic report on geothermal heat supply of Grozny with reinjection of the worked off coolant.

Figure 3- Geothermal station of Khankala deposit

In 1991-1995, during the Chechen war, the geothermal heat supply system was destroyed, but the well stock is in a satisfactory condition. Revived in 2013, the Chechen geothermal scientific school was established at the Grozny State Oil Technical University named after academician M. D. Millionschikov, under the leadership of Dr. M. Sh. Mintsaev in cooperation with the State Geological Museum of the Russian Academy of Sciences named after V. I. Vernadsky in Moscow (PhD S. V. Cherkasov). In 2015 the geothermal heating system with capacity of 8.7 MW with reinjection of the worked off coolant was built on Khankala deposit for heating 3 hectares of greenhouses (Fig.3). Mathematical modeling of deposit development, optimal well designing, development of designing of the central geothermal power point ensured the successful implementation of this project [30]. A productive well at depth of 900 m with a submersible pump provides a flow rate at the mouth without a pump – 75 m^3/h, with a pump – 210 m^3/h at temperature of 95°C. At a distance of 10 m from the mouth of the productive well, the reinjection well was drilled by inclined drilling to the depth of about 1000 m. The distance between bottom holes of productive and reinjection wells was 500 m. Intake capacity of reinjection wells was: without a pump - 15÷22 m^3/h during operation of the pump - 201 m^3/h.

GEOTHERMICS OF KRASNODAR TERRITORY

Krasnodar Territory is in the second place in Russia after Dagestan in extraction and use of geothermal water. In Soviet times, the regional comprehensive interdepartmental program was implemented. Drilling of new wells was performed at the request of local administrations. In Krasnodar Territory there were explored 16 geothermal mines, where were drilled 74 wells with depth of 1700-2900 m with temperatures of 75–120 ºC and flow rates 500-4000 m^3/day. The estimated thermal capacity of these mines is 238 MW with possible production of thermal energy of 834 MWh/year and replacement of organic fuel of 103 thousand tons [31]. There was started the construction of the injection system of the Mostovskoy deposit - 17 wells (there were drilled reinjection wells and built the pumping station building, equipment was completed). With the beginning of perestroika in the country, implementation of this project was stopped. For the exploration of new geothermal mines there were used materials of initiators of geothermics – employees of the Institute "Krasnodarneft", PhD V. S. Kotova and PhD N. V. Matvienko, who carried out measurements of characteristics of thermal waters and zoning on prospects of geothermal resources on their basis of 200 oil wells in 1956-1963 [32].

At present, the company operates 12 geothermal fields, five of which were approved with reserves in 27750 m^3/day. Four geothermal fields are without users. The largest are the existing Mostovskoye field (17 wells, 75°C, 45 MW); Voznesenskoye and Yuzhno-Voznesenskoye (15 wells, 100°C, 50 MW). Mineralization of geothermal water in these deposits does not exceed 2 g/l and meets the standard of drinking water on main rates. In 1985 the annual production of geothermal water in Krasnodar Territory reached 8.5 million m^3. Dwellings of 7 settlements and 30 hectares of greenhouses were heated. The Mostovskaya system is a classic example of cascade operation of thermal potential of geothermal water. The geothermal heat carrier at first went to heating of buildings, greenhouses for cultivation of tomatoes, cucumbers, lemons. Further, at temperature of 30 °C, geothermal water was supplied to fish ponds. Heat supply of residential and social facilities in the village of Mostovskoy was provided by 3 geothermal wells with the mouth of 1500 m^3/day and with temperature 75 °C. On the basis of two of them in 1982-1987 under the leadership of Doctor of Technical Sciences V. A. Butuzov (born in 1949) there was developed and built the geothermal heat supply system with capacity of 2 MW with utilization of waste heat geothermal water heat pumps with capacity of 600 kW. This system was supplemented with peak boiler capacity of 5 MW [33]. In 1987, the Institute TSNIIEPIO (PhD. V. I. Krasikov) together with the Moscow Institute developed the scheme for long-term development of heat supply of the village Mostovskaya for 10 years, which provided the village with additional 5 wells to heat and hot water supply and development of combined heating system with peak boiler and heat pumps with total capacity of 19.7 MW. In 2004, the company "Geoterm-M" (Moscow) under the leadership of Doctor of Technical Sciences G.V.Tomarov developed a feasibility study of geothermal heat supply on the basis of 14 wells, taking into account residential and social facilities of the village, greenhouse complex, fish farming, swimming pools with total capacity of 47 MW [33].

In 2003, in accordance with the Energy Saving Program of Krasnodar Territory, geothermal energy obtained a new impetus for development. There were developed feasibility studies of geothermal heat and power supply of cities of Labinsk, Ust-Labinsk, Goryachiy Klyuch, Anapa, Apsheronsk, Mostovskaya and Rozoviy settlements. At the same time, geothermal heat supply of Labinsk (fixed heat capacity - 100 MW, electric – 2.5 MW) was examined by the World Bank. This plant is the geothermal heat supply of the city. Ust-Labinsk (fixed thermal capacity - 42 MW, electric – 2 MW) was performed on the basis of hydrogeological forecast based on materials of 27 gas wells up to 3500 m deep. In accordance with approved feasibility study of geothermal heat supply in the settlement of Rozoviy in 2012, there was developed the first stage of geothermal heat supply with heat capacity of 5 MW under the leadership of Dr. V. A. Butuzov (Fig. 4). The peculiarity of this system is the creation of a geothermal-solar system, in which a solar installation with capacity of 110 kW provides hot water for residential and social facilities with possibility of stopping the geothermal well to restore reservoir pressure in summer [35]. In Krasnodar Territory since 1961 the only in Russia Troitsky plant of extraction of iodine from geothermal water was operated. At present, its operation has stopped.

Figure 4 – geothermal station of the settlement Rozoviy

Table 2: Characteristics of Russian geothermal heat supply systems

№	Title and location of deposit	Fixed heat capacity, MWt	Year of construction	Scheme of GCS	Temperature, ºC	Comments
1	settlement Rozoviy of Krasnodar Territory, Yuzhno-Voznesenskoe deposit	5,0	2010	open	100	with solar unit
2	Kizlyar, Dagestan, Kizlyar deposit	10,0	1970	open	106	use of geothermal different layers
3	Grozny, Khankala deposit	8,7	2015	closed	95	reinjection
4	village Medvedevka, the Crimea	1,5	1993	closed	64	reinjection, use of methane

GEOTHERMICS OF THE CRIMEA

According to the Atlas of energy potential [35] geothermal resources of the Crimea are estimated at 775 thousand tons per year under the development of thermal energy in 9011 million kWh/year. Exploration works in this region started in the 1970s, 26 geothermal wells were drilled and there were built 12 heat supply systems with double wells (productive and reinjection) [36], including 5 geothermal circulation systems (GCS) in Krasnogvardeysky, 5 – in Saka and Dzhankoy districts – 2 GCS with flow rate of each well from 670 to 4925 m^3/day with temperature of 60–87ºC at depth of 1000 to 2300 m. The Institute of Technical Thermal Physics of the USSR Academy of Sciences and the Institute of renewable energy of NAS of Ukraine were engaged in the development of projects of geothermal heat supply systems of the Crimea [15]. The first GCS was built in 1986 in the village Ilyinka, Saki district. It had worked for 3 years. More than 10 years (1993-2003) the GCS with thermal capacity of 2 MW in settlement Yantarnoe of Krasnogvardeisky district had been operating. The unique geothermal system of energy and heat supply had been working from 1993 to 2017 in the village of Medvedevka in Dzhankoy district. Thermal power of the GCS – 1MW, electric power of the gas generator on separated methane from geothermal water amounted to 60 kW, peak power of the gas boiler on methane – 100 kW. The distance between productive and reinjection wells is 400 m. The reinjection pump at flow rate of 25 m^3/h provided pressure in 1.5 MPa. Currently, geothermal heat supply systems in the Crimea are not operated.

CONCLUSIONS

1. A brief review of the hundred years of experience of Russian scientific and engineering geothermal schools showed that until 1990 they were world leaders in the whole range of achievements: geological researches, modeling and exploration methods, development of the world's first binary geothermal power plants, construction of large centralized heat supply systems. The unique

Soviet model of the economy allowed to develop a wide practical use of geothermal resources on the basis of results of scientific researches.

2. After 1992, achievements of geothermal science in Russia were not in demand. Large-scale geological studies, modeling of mining development and exploration have been stopped. A single well drilling is carried out. The achievements of early 2000s in the creation of the Russian geothermal school of turbine and other geothermal equipment have not been properly developed. A unique binary power unit with a fixed capacity of 2.5 MW in Kamchatka has not yet been put into operation. The work of the only in Russia the Institute of geothermal problems of the Russian Academy of Sciences in Makhachkala is not in demand. Thousands of geothermal wells in Russia, each of which costs 60-100 million rubles in modern prices are used irrationally mainly to heat settlements and greenhouses which had been built in Soviet times.

3. In Russia since 1990s of the last century the surface geothermics using heat pumps for heat supply began to develop. There were made large-scale studies of geothermal conditions in depths up to 400 m on the territories of North Caucasus and Moscow regions. Methods have been developed and facilities have been constructed for the use of heat from surface layers of the Earth using heat pumps.

4. In modern Russian conditions for the development of geothermics firstly it is necessary to perform researches on the analysis of both Soviet and foreign experience, which can be implemented only by the RAS. The economic reasonability of development of geothermics in new Russian economic conditions must be carefully studied taken the long-term fuel and energy balance and problems of development of the Arctic territories of the country.

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