# HYDROGEOTHERMAL RESOURCES OF RUSSIA

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**KEY WORDS**

Hydrogeothermal resources, direct use, Russia

**ABSTRACT**

Studying a thermal field of the Earth testifies to potent, practically inexhaustible and ecologically pure source of a thermal energy in the interior. These geothermal resources are subdivided into petrothermal and hydrogeothermal varieties, presenting thermal energy accumulated in rocks and in underground water fluids, respectively. Extraction of thermal energy from hard rocks is as yet at the stage of experiment, whereas the hydrogeothermal resources are already successfully exploited in many countries supplying electrical and thermal energy. In Russia the hydrogeothermal resources are rather well-studied. Low-potential resources of such kind are utilized predominantly for space heating in several cities and settlements on Northern Caucasus and Kamchatka with a total population of 350 000. Besides, the greenhouses of 465 000 $m^2$ in total area use terrestrial heat in some regions of Russia. The electricity is generated by some geothermal power plants (GeoPP) only in the Kamchatka Peninsula and Kuril Islands.

## 1. INTRODUCTION

The last World Geothermal Congress 2000 held in Japan [1] concluded that use of geothermal resources will be one of the main lines in energy production during the third millennium. The share of geothermal resources in energy budget of the World economy is supposed to increase at least up to 30 % or, according to the most optimistic prognosis, up to 80 %.

As known, thermal energy is evacuated from the Earth' interior by two modes: conductive heat flow due to thermal conductivity of rocks and advective heat output by volcanic and hydrothermal activity.

Conductive heat flow is characterized by considerable regional variations. Polyak and Smirnov [2] showed that the density of the average (background) heat flow makes 45, 55 and 70 mW/$м^2$ in Precambrian, Paleozoic and Mesozoic units, respectively, and reaches 90 mW/$м^2$ in areas Cenozoic volcanism, i.e. heat flow increases as age of tectono-magmatic activity decreases. Global heat loss is evaluated as $\sim 3\times10^7$ $MW_t$. These conclusions follow from the results of extensive regional investigations reflected on the various geothermal map: The USSR Geothermal Map [3], The maps of heat flow and abyssal temperatures in the USSR and adjacent territories [4, 5], Geothermal Atlas of Russia [6] and many others.

The studying a thermal field of the Earth testifies to potent and practically inexhaustible source of a thermal energy in the interior. These geothermal resources are subdivided into hydrogeothermal and petrothermal varieties, presenting thermal energy accumulated in underground water fluids and in rocks (including magmatic melts), respectively. The whole geothermal resources suitable for an effective utilization are estimated by the giant value - $137\times10^9$ ton of equivalent (standard) fuel, TSF. [ 7].This value is 10 times more than total substantial resources of a fossil fuel. However, 90 % of these thermal resources is accumulated by hot hard rocks. The mastering of these resources studied in some countries (USA, UK, Germany, France, Japan) and in Russia as well [ 8 ], but has not quitted from a stage of experiment.

## 2. HYDROGEOTHERMAL RESOURCES (HGTR)

Such resources, i.e. natural steam and thermal water have long been used on an commercial scale. These projects are carried out in more than 60 countries, including USA, China, Japan, Italy, France, Hungary, Iceland, Mexico, New Zealand, Philippines, etc. From 1995 to 2000 direct use of terrestrial heat has increased approximately by 44 %; therefore, it is supposed to grow up $100 \times 10^9$ $KW_t$-hour in 2010 and $100 \times 10^9$ $KW_t$-hour in 2020 [ 9 ].
The underground thermal fluids are rather diverse in thermal potential, chemical composition, total content of dissolved solids (TDS), water acidity-alkalinity, abundance and assortment of gases, etc.

### 2.1. High-potential HGTR

The most high-temperature hydrothermal systems are located in zones of high heat flow, i.e. in tectonically mobile belts of the earth crust, where recent volcanism and magmatic activity manifest itself. More than 100 hydrothermal systems with temperature 180-240°C (somewhere more than 300 and even 400°C) were found out in these regions on the depths of 1-2 km.
The phase state of a fluid in a hydrothermal reservoir is stipulated by a relation of intensity of thermal and water recharge of the reservoir. Dry steam predominates in highly heated and weakly permeable rocks when water recharge does not replenish hydrothermal discharge.
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Systems located in more permeable aquifers contain mainly liquid water. It can boil in bore holes, and its part (from 13 to 25 wt %) transforms into vapor phase (saturated steam). Such water-dominated systems are known in Iceland, New Zealand, Japan, as well as in Kurile-Kamchatka province of Russia (Geyser Valley, Nizhne-Koshelev, Bol'she-Bannoe, Hot Beach and some other fields). Temperature in such systems on the depth of 1-2 km varies from 180 $^oC$ up to critical values (375$^oC$).

### 2.2. Low-potential HGTR

Such thermal waters are subdivided into two groups differ each other in conditions of thermal energy supply: 1) heated in a regional geotemperature field and 2) formed in abnormal geothermal conditions under an effect of magmatic (volcanic) processes. The first group is presented by the predominantly stratal waters of large artesian basins and intermountaine depressions, the second group includes the hydrothermal systems confined to separate volcano-tectonic depressions (calderas and grabens) and fissure zones.
Low-potential HGTR are applied mainly for so-called direct use of thermal energy. Modes of their use vary depending on temperature, pressure and fluid composition. These modes are the following: space heating of apartment houses and industrial buildings, agriculture (greenhouses

heating), cattle breeding and fish-farming, drying of grain, tea, algas, wood, some industrial productions (wool washing, paper production,), extraction of valuable dissolved components, improvement of oil-bearing reservoir recovery, thawing of frozen ground, balneological and recreational use (geothermal baths and swimming pools).

Nowadays, the global resources of systems with lower temperatures provide direct use of terrestrial heat in amounts of 51 × $10^9$ $KW_t$-hour for space heating of appartment houses and industrial buildings, industrial processes, agriculture and many other purposes in 25 countries, especially in China, Japan, USA, Iceland. From 1995 to 2000 direct use of terrestrial heat has increased approximately by 44 %; therefore, it is supposed to grow up 100 × $10^9$ $KW_t$-hour in 2010 and 200 × $10^9$ $KW_t$-hour in 2020 [ 9 ].

## 3. LOW-POTENTIAL HGTR OF RUSSIA

### 3.1. Distribution and reserves

The hydrogeothermal resources of Russia are rather well-studied (Fig. 1). The investigators from All-Union Research Institute on Hydrogeology and Engineering Geology (VSEGINGEO) in 1983 compiled "Atlas of thermal waters resources in the USSR" added with the explanatory note and containing 17 maps, including two maps of thermal waters and their potential stores (both in the scale of 1:10 000 000) and the maps of exploitation reserves of thermal waters in the main water-bearing complexes of the most promising districts (Western Siberia, Cis-Caucasia, Kamchatka, Kuril Isls.) in the scales of 1:5 000 000 and 1:1 500 000 [ 10, 15] (Fig.1).

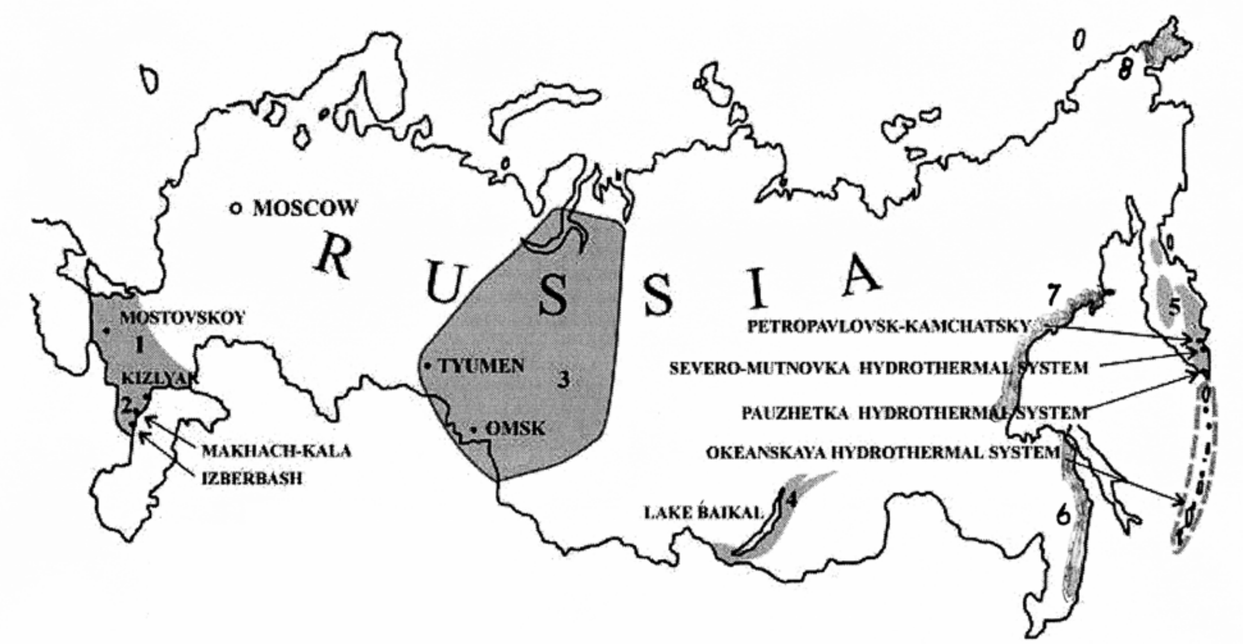


**Fig. 1. Perspectives for geothermal resources utilizing in Russia**

(1) Alpine province of the Northern Caucasus, (2) Scythian Plate of the Northern Caucasus, (3) Western Siberia, (4) Baikal region, (5) Kuril-Kamchatka region, (6) Far East region, (7) and (8) Okhotsk-Chukotka volcanic belt.

Geothermal resources siutable for (1) space heating by means of heat pumps, (2) «direct use» (space heating of apartment houses and industrial buildings, greenhouses heating, fish and animal farming, agricultural drying, industrial process heat, for extract of chemical builders, rise of blow-down recovery of seams, defrosting of frozen rocks, improvement of oil-bearing reservoir recovery, frozen overburden thawing, extract of usefull dissolved components, bathing and swimming) as well as for exploitation of heat pumps and electric power generation on binary-cycle GeoPP using low-boiling actuating fluid; (3) «direct use» and electric power generation on GeoPP of both binary-cycle and direct steam-water cycle on high-temperature hydrothermal systems.

According to the VSEGINGEO data, at the cheapest way of thermal waters extraction (at natural flowing), one can extract $1.4 \times 10^6$ м$^3$/day of waters with temperature from 40 up to 140 °C and TDS up to 100 000 ppm, and thermal effect of their use will amount $25.9 \times 10^6$ Gcal/year. Extraction of such water can be increased by the use of exhaust pumps up to $19.1 \times 10^6$ m$^3$/day that will provide the output of $230.3 \times 10^6$ Gcal/year.

It should be remembered that extraction of heat from such waters (brines) of a high TDS dictates their re-injection to avoid an environment pollution. The utilization of 5% from the geological reserves of such brines will allow to extract about $834\times10^6$ Gcal/yr, saving $119\times10^6$ TSF. Potential exploitable reserves of the brines and heat energy amount to $5315\times10^6$ m$^3$/day and $66.5\times10^9$ Gcal/yr, respectively, if the pressure in reservoir remains constant due to reinjection of wastewater. The experts from VSEGINGEO showed that 66 deposits of natural heat carriers were already prospected in Russia [Вартанян и др., 1999], including 4 high-potential hydrogeothermal systems those contain total geological reserves of thermal water and natural steam were estimated as $268,2\times10^3$ m$^3$/day and $40,7\times10^3$ t/day, respectively. 33 deposits exploited nowadays provide the consumption of thermal water at a rate of $27,747\times10^6$ m$^3$/y corresponding to $1,458\times10^6$ Gcal/y, or $291,7\times10^3$TSF per year.

## 3.2. Utilization

Tables 1 and 2 characterize the modern scales of direct use of thermal waters in Russia. Approximately half of extracted resources are applied for greenhouses heating, third part for space heating of houses and industrial buildings and about 13 % for industrial processes. Besides, these resources are used in about 150 health resorts and 40 factories for bottling mineral water.

**Table 1. Direct use of geothermal resources in different regions of Russia on December 31, 2002.**

| Regioins | Type[1)] | Maximal use | | | Power[2)] ($MW_t$) | Mean annual use | | |
|---|---|---|---|---|---|---|---|---|
| | | Flow rate, (kg/s) | temperature (°C) | | | Ave. flow rate, (kg/s) | Energy use[3)] (TJ/year) | Capacity factor[4)] |
| | | | inlet | out-put | | | | |
| KURIL–KAMCHATKA REGION | | | | | | | | |
| Kamchatka | **HBG** | 532 | 85 | 30 | 122 | 372 | 2 701 | 0.7 |
| Kurils (Kunashir Isl.) | H | | | | 20 | | | |
| NORTHERN CAUCASUS *Scythian plate* | | | | | | | | |
| Krasnodar Territory | IAFHBG | 370 | 80 | 30 | 77 | 222 | 1 465 | 0.6 |
| Stavropol Territory | AHG | 60 | 100 | 30 | 18 | 36 | 335 | 0.6 |
| Adygei Republic | AH | 49 | 80 | 30 | 10 | 25 | 162 | 0.5 |
| *Cis-Caucasian foredeeps* | | | | | | | | |
| Kabarda-Balkar Rep. | **G** | 70 | 70 | 30 | 2 | 6 | 33 | 0.5 |
| Dagestan Republik | IHBG | 339 | 80 | 30 | 71 | 203 | 1 340 | 0.5 |
| Karachai-Cherkess Rep. | **O** | 25 | 65 | 30 | 4 | 13 | 58 | 0.5 |
| Northern Ossetia Rep. | O | 21 | 60 | 30 | 3 | 10 | 41 | 0.5 |
| In total | | >1 466 | | | 327 | > 888 | > 6 135 | |

Note: [1)] I = Industrial process heat, A = Agriculture drying (grain, fruit, vegetables), F = Fish and animal farming, H = Space heating and district heating (other than heat pumps), B = Bathing and swimming (including balneology), G = Greenhouse and soil heating, O = hot water supply

[2)] Capacity ($MW_t$) = Max. flow rate (kg/s) × [inlet temp. (°C) - outlet temp. (°C)] × 0.004184
[3)] Energy use (TJ/yr) =Ave. flow rate (kg/s) × [inlet temp. (°C) - outlet temp. (°C)] × 0.1319
[4)] Capacity factor = [Annual energy use (TJ/yr) × 0.03171] / Capacity ($MW_t$)

**Table 2. Direct use of Russia' geothermal resources for different purposes on 31 December 2002**

| Use | Installed capacity[1)] ($MW_t$) | Annual energy use[2)] (TJ/yr=$10^{12}$ J/yr) | Capacity factor[3)] |
|---|---|---|---|
| Space heating[4)] | 110 | 2 185 | 0.63 |
| Greenhouse heating | 160 | 3 279 | 0.65 |
| Fish and animal farming | 4 | 63 | 0.5 |
| Agricultural drying[5)] | 4 | 69 | 0.55 |
| Industrial process heat[6)] | 25 | 473 | 0.6 |
| Bathing and swimming[7)] | 4 | 63 | 0.5 |
| TOTAL | 307 | 6 132 | |

Note:
[1)] Installed capacity (thermal power)($MW_t$) = Max. flow rate (kg/s) × [inlet temp. (°C) - outlet temp. (°C)] × 0.004184
[2)] Annual energy use (TJ/yr) = Ave. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] × 0.1319
[3)] Capacity factor = [Annual energy use (TJ/yr) × 0.03171] / Capacity ($MW_t$)
[4)] Includes district heating
[5)] Includes drying or dehydration of grains, fruits and vegetables
[6)] Excludes drying and dehydration
[7)] Includes balneology

In the ***Northern Caucasus*** thermal waters form multi-layered artesian basins enclosed within the Mesozoic–Cenozoic sedimentary cover of Alpine foredeeps and Scythian Plate. TDS and temperature of these water vary in wide ranges. These parameters change from 500 to 65 000 ppm and from 70 to 100°C at the depth of 1–2 km in foredeeps, whereas in the plate their values vary from 1000 to 200 000 ppm and from 50 °C to 170 °C at the depth of 4-5 km.

In *Daghestan Republic*, the thermal water is used mainly for space and district heating [12,13].

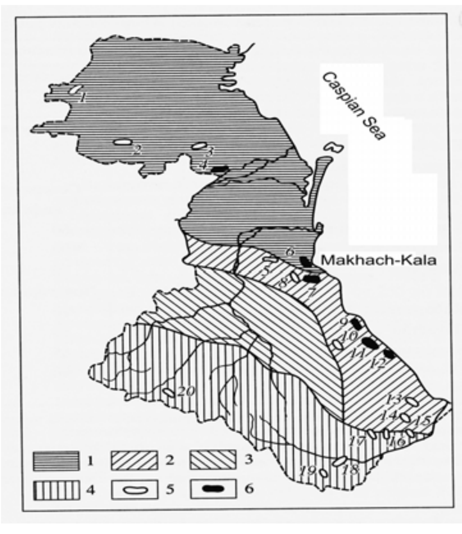


**Fig. 2. A review map of hydrogeothermal fields and promizing areas of Dagestan according to M.K. Kurbanov and Yu.G. Sheikhov (see [12]).**
1 – Quarternary sediments, 2 – Neogen, 3 – Cretaceous, 4 – Jurassic; 5 – promizing areas; 6 – hydrogeothermal fields. Geothermal anomalies enumerated on the map: 1 – Bazhigan, 2 – Terekli-Mekteb, 3 – Tarumovra, 4 – Kizlyar, 5 – Isti-Su, 6 – Makhachkala; 7 – Talgi, 8 – Zauzenbash, 9 – Izberbash, 10 – Salgabak, 11 – Kayakent, 12 – Berikei, 13 – Belidzhi, 14 – Choshmenzil, 15 – Gilyar, 16 – Adzhinour, 17 – Rychal-Su, 18 – Akhty, 19 – Khnov, 20 – Khzan-Or.

Such systems completely satisfy the thermal needs of Izberbash, Terekly-Mekteb, Chervlenye Buruny and Tarumovka towns and partially Makhach-Kala, Kizlyar and Kayakent towns (Fig.2). The total square of indoors heated by thermal waters makes up $280\times10^3$ $m^2$. About 300 000 inhabitants use hot water supply. Besides, the sizable geothermal greenhouse enterprises are located near Makhachkala (Ternair) and Kizlyar. The thermal waters are also utilized for heating cow and pig farms and poultry yards as well as in a few resorts (hydropathic establishments).

The total exploitation reserves of thermal water in Daghestan makes up $278\times10^3$ $m^3$/day at natural flowing and ~$400\times10^3$ $m^3$/day at re-injection of waste fluids. Such an output of geothermal energy is eqivalent to annual consumption of $600\times10^3$ TSF [14]. The main exploitation reserves of water with temperature of 40-107°C and TDS from 1500 to 27000 ppm are situated in the Northern Daghestan. During the last 40 years twelf large deposits of thermal water were found out in this region, 130 boreholes were prepared for exploitation. Nowaday, however, 15 % of the known reserves of thermal waters are only used in Daghestan [14].

The ***West-Siberian plate*** also contains thermal waters suitable for direct use. They form a huge artesian basin in sedimentary cover of the plate spread over $3\times10^6$ $km^2$. The resources of these waters on the depth up to 3 km, where temperature and TDS vary from 35 to 75 $^o$C and from 1 up to 25 g/kg, respectively, were estimated in 180 $m^3$/s [15]. Up to now, however, these geothermal resources are used on a very insignificant scale. Thermal waters provide the space heating for some buildings in Tyumen and Omsk cities and some small settlements. Besides, the thermal waters are applied for fish farming, extracting J and Br, as well as for heating oil-bearing beds to enhance oil recovery. The production rate of thermal water used for oil recovery is evaluated as 10-15 $\times10^6$ $m^3$/day [11].

There are many thermal springs in the ***Baikal Rift zone***. Up to now, their waters are locally used for space heating of separate buildings and small resorts as well as for bathing and swimming. In the future, the thermal springs located along the Baikal-Amur railway could be probably used more intensively.

Hydrogeothermal manifestations are known in the rather young ***Okhotsk-Chukotka volcanic belt*** as well: e.g., springs Talaya, Sytygan-Sylba, Berenda, Motyklei in Magadan district, Chaplino, Senyavinskie, Kukun'(Lorino), Neshkan, Dezhnev in Chukchi Peninsula, as well as in other parts of the ***Russian Far East*** (Shmakovka, etc.). Some of them were formerly supply hot water to local hydropathics and greenhouses (Nalaya, Chaplino, Lorino) and could be a base for more extensive geothermal development.

Geothermal resourses available in the ***Kuril-Kamchatka region*** of the recent volcanism are considered as an object for top-priority use.

In *Kamchatka Peninsula* there are about 150 thermal spring groups of mainly Cl-Na water with TDS = 1000-5000 ppm and 11 high-temperature hydrothermal systems (Fig. 3). They are confined to volcano-tectonic depressions (grabens and calderas) serving as reservoirs for intergranular and fissure-circulating thermal fluids. Low-potential HGTR of Kamchatka can provide the heat consumption of 1345 $MW_t$ during 100 years at least (by [16]). The parameters of the low-potential hydrothermal reservoirs of Kamchatka being in exploitation an recommended for prospecting work, are cited in Table 3. Table 4 characterizes the high-temperature systems of Kamchatka except those located in the Kronoka preserve (Geyser Valley, Uzon, Semyachik). Such systems could be provide the electric power generation up to 1130 $MW_e$ (by [16]). At present time, however, only two of them (Pauzhetka and Mutnovka) are partially mastered for electric power generation. The first Russian Pauzhetka GeoPP has installed capacity of 11 $MW_e$. Two GeoPP with total installed capacity of 62 $MW_e$ are in operation on Mutnovka system (see a special paper by O.A. Povarov with co-authors in the same volume).

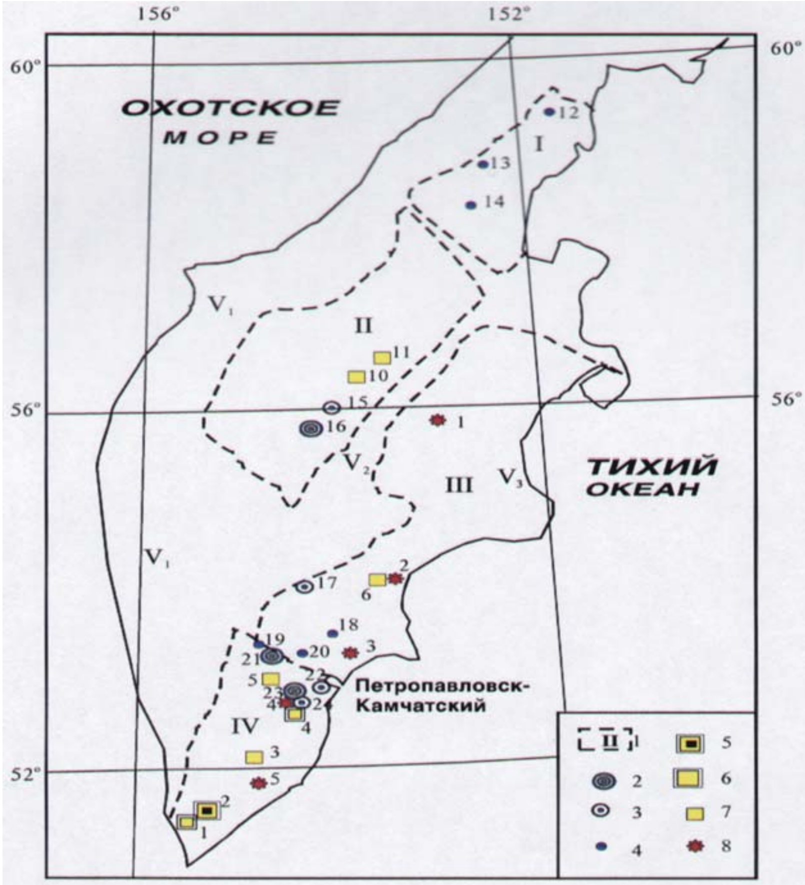


**Fig. 3. Map of geothermal deposits exploited and recommended for prospecting ( by [16] )**

1 – geothermal provinces (I – Northerh, II – Median, III – Eastern, IV – Southern, V – province of large structural depressions); 2-4 – low-potential deposits (T< 150°C, see cipher indices in Table 3): 2 – exploited; 3 – prospected; 4 – recommended for prospecting; 5-7 – high-potential deposits (see cipher indices in Table 4): 5 – exploited; 6 – prospected; 7 – recommended for prospecting; 8 – some volcanoes and calderas (1 – Tolbachik, 2 – Little Semyachik, 3 – Avacha, 4 – Gorely, 5 – Ksudach)

There are numerous thermal springs in the *Kurile Islands*, but now low-potential HGTR of the archipelago are not practically used because of its low occupation. At the same time, two small GeoPP are in operation in the Kurils' Kunashir Isl. and Iturup Isl. with installed capacity of 2.6 $MW_e$ and 6 $MW_e$, respectively.

Despite the abundance of geothermal resources, the Kurile-Kamchatka region needs badly in electric and thermal energy.

**Table 3. Parameters of the low-potential hydrothermal reservoirs of Kamchatka (by [16])**

| # # on Fig.3 | Thermal springs | Heat output, $MW_t$ | T, oC in springs (measur.) | T, oC, in reservoir (estimated) | Reservoir volume, $km^3$ | Reserves of heat in reservoir, $10^{18}$ J | State of mastering |
|---|---|---|---|---|---|---|---|
| 1 | Nachiki | 4.2 | 81 | 106 | 2.2 ± 0.7 | 0,63 ± 0,19 | drilled |
| 12 | Tymlat | 5,0 | 47,.5 | 115 | 3,7 ± 1,1 | 1,1.5 ± 0,34 | |
| 13 | Palana | 7,5 | 95,0 | 105 | 9,7 ± 2,9 | 2,75 ± 0,8 | |
| 14 | Rusakovskie | 57,8 | 76,5 | 90 | 15,0 ± 4,5 | 3,64 ± 1,1 | |
| 15 | Anavgai | 7,4 | 52,0 | 115 | 2,2 ± 0,7 | 0,68 ± 0,2 | drilled |
| 16 | Esso | 4,4 | 65,0 | 104 | 4,5 ± 1,3 | 1,26 ± 0,38 | mastered |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 17 | Pushchino | 1.5 | 46,0 | 110 | 3“7^1.1 | 1,1 ± 0,33 | drilled |
| 18 | Nalycheva | 9,4 | 75,0 | 143* | 16,5 ± 4,9 | 6,37 ± 1,9 | |
| 19 | Malka | 9,4 | 83,0 | 128* | 3,7 ± 1,1 | 1,28 ± 0,33 | drilled |
| 20 | Pinachevo | 0,8 | 12,5 | 53,5 (meas.) 95 (estim.) | 2,2 ± 0,7 | 0,56 ± 0,17 | drilled |
| 22 | Yuzhno-berezhnye | 0,2 | 20,0 | 90 | 3,0 ± 0,9 | 0,73 ± 0,22 | drilled |
| 23 | Paratunka | 8,2 | 81,5 | 110 | 15,0 ± 4,.5 | 4,46 ± 1,34 | mastered |
| 24 | Upper Paratunka | 20,6 | 70,5 | 110 | 13,5 ± 4,0 | 4,01 ± 1,2 | drilled |

**Table 4. Parameters of the high-potential hydrothermal reservoirs of Kamchatka ( by [16])**

| # # on Fig.3 | Hydrothermal systems | Heat output, $MW_t$ | Phase state of heat carrier on the earth surface | Average T, $^oC$, in reservoir, ($T_{max}$ in holes) | Reservoir volume, $km^3$ | Reserves of heat in reservoir, $10^{18}$ J | Maximal electric power, $MW_e$ |
|---|---|---|---|---|---|---|---|
| 1 | Koshelev | 314 | Superheated and saturated steam | 220 | 37.5±11.2 | 22,27±6,7 | 215 ± 64 |
| 1a | Lower Koshelev | 104 | | 220 (240) | 17,5±5,2 | 10,4±3,11 | 100 ± 30 |
| 2 | Pauzhetka | 104 | saturated steam and water | 200 (220) | 45±13,5 | 25,8±7,73 | 186±56 |
| 3 | Khodutka | 122 | water, 88 $^oC$ | 200 | 30±9 | 16,2±4,8 | 117±35 |
| 4 | Mutnovka | 546 | Superheated and saturated steam | 220 | 80±24 | 47,5±14,2 | 460±138 |
| 4a | Northern Mutnovka | 129 | | 220 (301) | 30±9 | 17,82±5,3 | 172±52 |
| 5 | Bol’she-Bannaya | 79 | boiling water | 200 (171) | 15±4,5 | 8,1±2,43 | 58±17 |
| 6 | Karymskaya | 146 | | 58±17 | 200 | 37,5±11,2 | 146±44 |
| 10 | Apapel’ | 17 | | 200 | | | |
| 11 | Kireuna | 24.5 | | 200 | 17,5±5,2 | 9,45±2,83 | 68±20 |

## 4. CONCLUSIONS

The last World Geothermal Congress 2000 held in Japan [1] has demonstrated that development and use of geothermal resources goes everywhere much faster than that in Russia. Our country, however, possess the vast and rather well-studied geothermal resources. Their use instead fossil fuel to obtain electric and thermal energy has indisputable ecological advantages and, as the world experience shown, is very profitable. Geothermal development is especially promising in Kurile-Kamchatka region. Thermal waters with lower temperature and higher salinity in the Northern Caucasus and Western Siberia should be utilized by means of binary-cycled installations. The lowest-potential geothermal resources could be used with the help of “heat pump” technology.

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