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Current trends in the development of geothermal resources

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Abstract. Based on the analysis of publications in world journals, as well as a generalization of the experience of developing domestic geothermal fields, current trends in the development of geothermal resources are shown. The key trend is considered to be the transition from subsidized to commercial projects, which increases the relevance of research in areas that have a significant impact on the economic efficiency of resource development processes, primarily in the direction of geothermal technologies. In terms of subsidized projects that set research goals, the most relevant are works in the direction of EGS (Enhanced Geothermal Systems). Moreover, there is a tendency towards the creation of international interdisciplinary collaborative research teams. It is noted that the current level of technology development allows producing geothermal energy for use in local heat supply systems practically anywhere in the world. However, given the concentration of power per unit area, the basis of modern geothermal energy is still the direction associated with the rise of deep fluids to the surface in areas characterized by the presence of ascending flows of hot juvenile fluids. It is indicated that Russia is lagging behind the world level of progress in the development of geothermal resources, including in terms of current research and development directions, and measures are proposed to overcome this lag.

Keywords: geothermal energy, geothermal resources, hot rocks, underground fluids, geothermal field, heat energy water field, geothermal technology

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Introduction

Given that there is no established terminology in the field of geothermal resources development, it seems appropriate to define (in the author's definition) the basic concepts that are used in this article. Geothermal energy is the enthalpy of rocks and fluids in the bowels of the Earth. Geothermal resources – geothermal energy that can be extracted (transferred) in the form of heat for efficient use at the current level of technology development. Geothermal technology – the technology of extraction from the bowels and delivery of geothermal energy to the consumer.

The history of the use of geothermal energy dates back thousands of years, while the active development of geothermal resources began in the second half of the last century. Currently, more than 80 countries use geothermal resources as a direct source of energy in heat pumps, balneological pools, heating systems, etc. (Lund, Boyd, 2016). More than 20 countries produce electricity based on geothermal resources (Bertani, 2016). In some countries, such as Costa Rica, El Salvador, Iceland, Kenya, the Philippines, the share of geothermal energy is 15–22% of total electricity production. In the future, using this method is considered possible to produce about 8.3% of the total world electricity, which can satisfy the needs of 17% of the world population (Bertani, 2009).

The path along which the development of geothermal resources took place in the last century can be described as extensive – new sources of geothermal energy were developed and innovative technologies for their development were exploited, while the projects were implemented mainly on a subsidized basis. By the beginning of this century, the scale of development of geothermal resources went beyond the scope of subsidized projects, more and more work began to be carried out on a commercial basis. In the new conditions, questions of the effectiveness of innovative and already traditional technologies are becoming especially acute, which characterizes the transition to an intensive development path.

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Along with new advanced studies, for example, in the field of creating enhanced geothermal systems (Norbeck et al., 2018; Zhang et al., 2019a; Chen et al., 2019) and extracting geothermal energy without lifting deep fluids to the surface (Alimonti et al., 2016; Koohi-Fayegh, Rosen, 2018; Iry, Rafee, 2019), special attention is paid to the efficiency of using existing technologies. For example, two-phase pipeline transportation, which has been actively introduced since the end of the last century трубопроводам (Lee, Jenks, 1989; Wigly, 1989; Delnov, Shulyupin, 1996; Zhao et al., 2000), has received a new impetus for development (Ghaderi, 2010; Rizaldy, 2016; Garcia-Gutierrez et al., 2015; Cheik, Ali, 2015). Also, the issues of measuring the flow parameters of steam-water wells (Banwell, 1955; James, 1970; Shulyupin, 2011; Irsamukhti et al., 2015) and the modeling of two-phase flows in them (Gould, 1974; Tachimori, 1982; Palachio, 1990; Gudmundsdottir, Jonsson; 2015; Shulyupin, Chermoshentseva, 2016) are relevant.

This article contains an analysis of current global trends in the development of geothermal resources. Also, in the context of global trends, the state of the domestic field of research and development in this area is considered.

Analysis of changes in priorities in the development of geothermal resources on the subject of articles represented to the World Geothermal Congresses

World Geothermal Congresses are held every five years and provide extensive material for the analysis of global trends in the development of the relevant field as they are the main review of achievements in the development of geothermal resources. The next congress was planned to be held in Reykjavik (Iceland) from April 27 to May 1, 2020 (World Geothermal Congress 2020 (WGC 2020), is currently postponed to May 2021). Submission of articles at WGC 2020 was completed on July 30, 2019, according to the official website of the Congress at the end of 2019 there were 1840 articles, which is 40% more than the number of articles at the previous congress (WGC 2015 – 1317, (Horne, 2015)).

At the WGC 2015, a detailed analysis of publication activity in integrated fields of research in the development of geothermal resources from 1997 to 2014 was presented in (Newson, 2015). More detailed and up to date information on individual topics can be provided by an analysis of changes in the numbers of articles submitted in various topics at WGC 2020 relative to similar sections at WGC 2015.

Articles at WGC 2020 are grouped into 38 topics, 29 of which fully coincide with the topics of WGC 2015, another 5 sections are modified versions, and 4 sections are new. Two topics of WGC 2015 at WGC 2020 were not announced. To analyze the change in the number of articles in topics, it is proposed to use the priority development index – the difference between the relative increase in the number of articles in a section and the increase in the total number of articles at WGC 2020 and WGC 2015, expressed as a percentage

$$I_i = (K_{i20}/K_{i15} - K_{s20}/K_{s15})100\%,$$

where I_i is the priority development index of a specific (i-th) topic; K_{i20} and K_{i15} are the number of articles in a particular topic at WGC 2020 and WGC 2015; K_{s20} and K_{s15} are the total number of articles at WGC 2020 and WGC 2015.

The titles of the topics of WGC-2020, the number of reports and the priority development index are presented in Table 1. As can be seen from the table, the topics that are most closely related to the economic efficiency of developing geothermal resources have a positive trend, which is a consequence of the previously noted transition to new conditions development.

Well construction is usually one of the most expensive parts of geothermal projects. Therefore, finding the topic «Drilling and Completion Technology» at the first position in the priority development index is the expected and meets new conditions that put forward increased demands on the effectiveness of the technologies used, which reduces the cost of production. It is also natural to be in the second position of the topic «Advanced Technology (Magma, Geopressure, etc.)», which reflects the search for breakthrough technological solutions. The accumulation of experience in a relatively short history of the active development of geothermal resources leads to the third place in the topic «Case Histories».

The topic «EGS – Enhanced Geothermal Systems» should be considered separately. This section appeared at congresses in 2010 and was considered as the receiver of the HDR (Hot Dry Rock) topic, which was considered in the Advanced Technology section in 2005. That is, the subject of HDR for ten years has moved from the section «Advanced Technology» to the section EGS. Note that the subject of EGS can have a much broader interpretation than is done at the Congresses. For example, often articles on stimulating inflow to a well are related to the topic «Reservoir Engineering» (On, Andrino, 2015; Pasikki et al., 2010; Siratovich et al., 2015). At the same time, at the well-known annual seminar at Stanford University, incentive issues are considered in the context of the EGS EGS (Aguiar, Myers, 2019; Lu, Ghassemi, 2019; Ye et al., 2019). As noted in (Newson, 2015), the total number of articles on EGS topics by 2014 was close to 20%

No.	Topics	K_{i15}	K_{i20}	I, %
1	Drilling and Completion Technology	35	85	103
2	Advanced Technology (Magma, Geopressure, etc.)	11	24	78
3	Case Histories	29	52	39
4	Geology	85	149	35
5	Corrosion and Scaling	42	72	31
6	Business Strategies	18	30	27
7	EGS - Enhanced Geothermal Systems	59	94	19
8	Exploration	92	145	18
9	Production Engineering, Steam Gathering Systems	25	39	16
10	Geothermal Education	18	28	16
11	Economics and Financing	16	25	16
12	Software for Geothermal Applications	27	39	4
13	Geophysics	109	151	-1
14	Geochemistry	99	128	-11
15	Direct Use	40	50	-15
16	Country Updates	77	90	-23
17	Field Management	20	23	-25
18	Geothermal Heat Pumps	56	63	-28
19	Reservoir Engineering	108	109	-39
20	Integrated Energy Systems, Cascaded Uses	12	12	-40
21	Health, Tourism and Balneology	7	7	-40
22	Geomicrobiology	1	1	-40
23	Keynote	1	1	-40
24	Power Generation	74	69	-47
25	Hydrogeology	34	31	-49
26	Resource Assessment	80	71	-51
27	Minerals Extraction and Processing	8	7	-53
28	Injection Technology	17	14	-58
29	Other	2	1	-90
30	Environmental Aspects	48	56	50
31	Societal and Cultural Aspects		35	
32	District Heating	17	27	42
33	Agriculture		4	
34	Policy, Legal and Regulatory Aspects	27	44	23
35	Sustainability and Climate Change		34	-
36	Heat/Gas/Oil/Coal Fields		12	-
37	Big Data and Data Analytics		12	-
38	International Collaborations		6	-
	Total	1317*	1840	0

*Table 1. Topics of WGC 2020 and priority development index of topics. *The value is based on topics that are not presented at WGC 2020*

of the total number of articles on the development of geothermal resources.

The topic «Production Engineering, Steam Gathering Systems», which first appeared at congresses in 2010, also has a high position, which is directly related to improving the efficiency of resource development processes. Note that in domestic practice regarding issues of this topic, the definition of the direction: «Arrangement of geothermal fields» was previously actively used.

According to the table, among the topics with decreasing interest was the previously highly demanded direction «Power Generation». This fact should not be regarded as a tendency to a loss of interest in this topic at all. This trend is a consequence of the fact that the technologies in this area have already been well studied, and over time it is becoming increasingly difficult to find research interest in it.

There was also a decrease in interest in the topic «Resource Assessment». This can be explained by a shift in attention in the area of the resource base in favor of practice. This is reflected in the increase in the number of articles on the topic «Exploration», which expresses the general tendency to focus on researches that are directly related to the efficiency of resource development.

It can't be ignored the last position, not counting the statistically insignificant theme of «Other», the theme of «Injection Technology». In the 80s of the last century, injection was considered to be the most important aspect of the development of geothermal fields, both in terms of ensuring environmental demands, and, by analogy with the development of liquid and gaseous mineral deposits, in terms of the most complete use of resources. The experience of injection in various fields of the world did not always live up to expectations. For example, unjustified hopes for replenishment of resources through injection became one of the reasons for the decrease in the installed capacity of power plants since 1990 to 2004 by 346 MW at (Lund et al., 2010) at the Geysers field (Geysers, USA). Note that in this case, the volume of equipment actually dismantled is four times more than the installed capacity of all geothermal power plants in Russia. In addition to an unjustified positive effect, injection can have a negative effect. It was shown in the work (Vasyanovich et al., 2019) that a decrease in the enthalpy of fluid in a geothermal reservoir as a result of injection can lead to an early failure of a production well in a steam-lift operating.

Topics indicated in the table at numbers 30 and 31 at WGC 2015 were combined under the theme «Environmental and Societal Aspects». The table shows the comparison data of the two indicated sections of WGC 2020 with the corresponding section of WGC 2015. The increased interest in these topics, as well as the expansion of the scope of issues due to consideration of cultural aspects, determined the high value of the index.

The topics indicated in the table at numbers 32 and 33 at WGC 2015 were also combined under the same theme «District Heating and Agriculture». The topic indicated in the table under number 34 was previously presented by two sections «Legal and regulatory aspects» and «Energy pricing and rules». Index values are also indicating increased interest in these topics.

The table below numbers 35–38 shows the new topics that appeared in 2020. Moreover, the section «Sustainability and Climate Change» to some extent can be considered as an expanded version of the topic «Sustainability», presented at WGC 2015 with nine papers. Note that interest in using oil and gas wells to extract geothermal energy revived in 1999 after nearly twenty years of oblivion (Newson, 2015).

Two topics: «Hot sedimentary aquifers» (HSA) and «Clean Development Mechanism», which took place at WGC 2015 with the number of articles 11 and 3, respectively, were not announced in 2020. Articles on issues related to these topics at WGC 2020 will be addressed in other topics.

In general, the dynamics of the number of articles presented at WGC 2020 in various topics shows an increase in the relevance of issues related to reducing costs and risks in the development of resources. It should be noted that in the top ten in the priority development index in the table, half of the topics are directly related to geothermal technologies. In this regard, geothermal technologies can be considered the most relevant area for research in the development of geothermal resources.

Global trends in the development of geothermal resources

An analysis of the articles presented at the World Geothermal Congresses on the topic provides useful, but not exhaustive information on current global trends in the development of geothermal resources. Additional information is provided by the analysis of publications in leading specialized publications and publications on adjacent fields of study, of which there are many due to the presence of many issues requiring an interdisciplinary approach to their solution.

Several years ago, research on the processes and technologies for using heat recovery system of wells was significantly intensified. This has been reflected in a number of publications in leading specialized publications in the field of geothermal resources (Alimonti et al., 2016; Holmberg et al., 2016; Michalski,

Klitzsch, 2019). Interest in this topic continues to this day (Koohi-Fayegh, Rosen, 2018; Iry, Rafee, 2019; Michalski, Klitzsch, 2019), and it can be associated with the development of local heat supply systems using heat pumps.

A heat pump operating in the reverse thermodynamic cycle (the principle of the well-known refrigerator) allows the transfer of energy in the form of heat from a relatively cold body to a warm one. At the same time, the amount of energy received in the form of heat in a heated place exceeds the work spent on the transfer of energy. Relatively constant, not subject to seasonal changes and a sufficiently high temperature of bowels of the earth, even at shallow depths, is acceptable for an object used as a heat source. The use of heat recovery system of wells allows to produce geothermal energy without lifting deep fluids to the surface, moreover, it allows the possibility of efficient operation even in the absence of deep fluids. The current level of technology of heat recovery system of wells and heat pump technology allows to produce geothermal energy almost anywhere in the world for use in local heat supply systems.

Analyzing the current state of the world research and development, it is difficult to ignore the growing role of Chinese scientists. Not having such easily accessible high potential geothermal fields as Italy, the USA, New Zealand, Iceland, Russia, etc., China has already become a leader in the direction of direct use of geothermal energy (Lund, Boyd, 2016). At the same time, the issues of using the energy of hot dry rocks are actively investigated (Xu et al., 2019; Zhang et al., 2019b). There is no doubt that the efforts of Chinese colleagues in this area, with the use of heat recovery system of wells and heat pumps, will continue to develop.

Previously, when considering the development of topics at the World Geothermal Congresses, it was noted that the direction for the use of hot dry rock energy (HDR) from independent advanced technologies was transformed into a section for creating and developing enhanced geothermal systems (EGS). This is explained by the presence of many common questions regarding the energy extraction of both dry rocks and irrigated, poorly permeable reservoirs that require improving their characteristics for effective exploitation, for example, increasing permeability in a geothermal reservoir by temperature stimulation (Siratovich et al., 2015a).

Consideration of the issues of creating and developing enhanced geothermal systems is currently the subject of many publications both in specialized publications and in leading publications on related sciences (Zhang et al., 2019a). This indicates that this area is currently in a state of active development. At the same time, given the presence of interdisciplinary issues, there is a tendency to create collaboration teams (Chen et al., 2019).

As noted, the current level of development of geothermal technologies allows producing geothermal energy even in areas that do not have temperature anomalies, that is, almost everywhere. At the same time, the basis of modern geothermal energy is still the direction associated with the rise of deep fluids to the surface (in Russia this direction is associated with the development of thermal-energy water fields). Note that the high efficiency of convective heat transfer provides significant, attractive for practical use, thermal power in areas characterized by the presence of ascending flows of hot juvenile fluids. Therefore, when it comes to creating powerful geothermal energy facilities, for example, geothermal power plants, the immediate prospects should be associated with geothermal fields formed by ascending flows of hot juvenile fluids. They are usually associated with areas of increased volcanic activity.

At the present stage, the development of high-potential geothermal fields is increasingly carried out on a commercial basis. This forces geothermal energy to compete on an equal footing without any preferences in the energy market. There have been cases when geothermal energy had to successfully compete with traditional energy that have subsidized support (Kolesnikov et al., 2015). Issues of production costs are becoming crucial for such conditions.

The possibilities of reducing the cost of production due to the development of technologies for the use of geothermal energy are not so great. Geothermal fluids are supplied products for direct use. In the direction of the electric power industry, geothermal power plants, by the principle of operation, are well-studied thermal stations. There is some specificity in the operation of binary geothermal power plants using agents with a low boiling point (freon, isopentane, etc.) as working fluids. Nevertheless, the main reserve in reducing the cost of production lies in improving the technology of production and transportation of geothermal energy to the consumer, that is, in improving geothermal technologies.

Geothermal technologies combine the most important specific issues of the practical development of geothermal resources, for example, such as stimulating reservoirs (Siratovich et al., 2015), stimulating steam-lift wells (Mubarok, Zarrouk, 2017), improving the heat transfer system (Rizaldy, Zarrouk, 2016), ensuring a stable operating mode of production wells (Shulyupin,

Chernev, 2015). As previously noted, the dynamics of the number of articles on topics at the World Geothermal Congresses also indicate increased attention to issues related to geothermal technologies.

Thus, an important characteristic of the current stage of development of geothermal resources is the tendency to move from subsidized to commercial projects. This trend in the practical sphere increases the relevance of research in the field of geothermal technologies, which most clearly reflects the specifics of the processes of development of these resources and has a significant impact on their economic efficiency.

In terms of subsidized projects that set not only commercial, but also research objectives, the most relevant are the works within the EGS – enhanced geothermal systems. In the research part, this area includes many issues of geothermal technologies.

The state of the domestic sphere of research and engineering in the field of geothermal resources development

According to a data compilation presented at WGC 2015 by countries, Russia, which is among the leading countries in terms of available geothermal resources, is 23rd in terms of their development in direct use (Lund, Boyd, 2016), and 14th in terms of installed power of Geothermal power plants (Bertani, 2016). Comparing the dynamics of the development of these areas in Russia and in the world in recent years, it can be assumed that the position of Russia is even lower at present.

By the beginning of Perestroika, Russia had one of the most developed research and engineering in the world in the field of geothermal resources development, corresponding to the scale of plans for their development. For example, by the end of the last century it was planned to transfer all Kamchatka's energy to geothermal resources. Geothermal field exploration was actively studied in the Institute of Volcanology (Petropavlovsk-Kamchatsky) V.V. Aver'ev, V.M. Sugrobov and others, the development of geothermal fields were studied with at the Leningrad Mining Institute (St. Petersburg) Ju.D. Djad'kin, Ju.M. Parijskij and others, geothermal power plants were studied in ENIN (Moscow) D.A. Labuntsov, F.G. Solomozoda and others, a complex of issue was studied at VNIPIgeoterm (Makhachkala) G.M. Gaidarov, F.G. Sharafutdinov and in his Kamchatka's multifaceted department (Petropavlovsk-Kamchatsky) G.N. Zabarny, R.I. Pashkevich, A.N. Shulyupin and others. Some developments were carried out at the Institute of Thermophysics (Novosibirsk), Kazan University (Kazan), Central Boiler and Turbine Institute (St. Petersburg), and other universities and scientific institutions in Russia also studied geothermal resources. Active scientific work was also carried out in the production organizations of Kamchatka: the Kamchatskenergo, the Kamchatka Directorate for the Use of the Earth's Deep Heat, the Hydrogeological Expedition of the «Kamchatgeology», the Hydrogeological Expedition of the «Sakhalingeology» and others.

The problems of the end of the last century related to the period of «Perestroika» negatively affected the field of research and development, primarily in the field of technical sciences, including the development of geothermal resources. Nevertheless, the created groundwork was enough for the successful implementation of the Mutnovsky project, the result of which was the building and commissioning in 1999 and 2003 of two power plants in Kamchatka, with a total installed capacity of 62 MW, which was greatly contributed to by O.A. Povarov's entrepreneurial talent. These stations are still the flagships of domestic geothermal energy, generating more than 80% of domestic electricity from geothermal resources.

Recently, after about a twenty-year period of decline, there has been a tendency to increase, declarative for the most part, interest in domestic geothermal resources and a slight revival in the relevant field of research and development. This trend is due to the declaration of a strategic course for the development of Russian regions with available reserves of geothermal energy (Kamchatka, Kuril Islands, the Caucasus). However, often geothermal resources fall outside the scope of specific programs and projects.

Currently, systematic work on geothermal topics is being carried out in a number of domestic universities and scientific organizations. Studies are being conducted at the Institute of Problems of Geothermy and Renewable Energy of the Russian Academy of Sciences (Makhachkala) on a range of topics related to the use of low-grade thermal waters (Alkhasov, Alkhasova, 2019), including the allocation of the component composition of geothermal brines (Ramazanov et al., 2019), as well as the technology of the circulating system for geothermal energy production (Alishaev, 2019). A study of the circulation systems of geothermal energy production is also carried out at the Grozny State Oil Technical University (Grozny) (Iliukhin et al., 2015). Systematic work on modeling geothermal reservoirs is carried out at the Institute of Volcanology and Seismology of the Russian Academy of Sciences (Petropavlovsk-Kamchatsky) (Basmanov et al., 2016; Kiryukhin et al., 2018). At the Geotechnological Research Center of the Russian Academy of Sciences

(Petropavlovsk-Kamchatsky) they are engaged in modeling of geothermal systems (Pashkevich et al., 2015; Pashkevich, Mamaev, 2019), development of EGS technology, including the creation of permeable zones in supercritical geothermal reservoirs, questions of the use of waste heat carriers (Gorbach, 2014, 2019), extraction of valuable components from geothermal solutions (Belova, 2019; Popov, Pashkevich, 2018; Potapov et al., 2020), environmental issues in the development of geothermal fields (Veselko 2018) and the development of technological schemes of industrial geothermal complexes. Steam-lift technology for geothermal fluid production is being studied at the Institute of Mining of the Russian Academy of Sciences (Khabarovsk) (Shulyupin, 2019).

The presented list of organizations allows us to conclude that there is a centrifugal trend in the geography of the sphere of research and development – the central regions of Russia are not represented in the list. This is a worrying trend. Note that it is usually the central regions that determine the scientific and technical policy, and the lack of their protection affects the domestic authority of the scientific field.

A significant part of domestic research is based on numerical modeling of heat and mass transfer processes in geothermal systems. In international practice, such studies are usually attributed to the topic of «Reservoir Engineering» which, as the data in Table 1 show, is losing its position. The same, but to a slightly lesser extent, can be said in relation to studies on the allocation of the component composition of geothermal fluids. Despite the presence of a large number of valuable components in geothermal fluids (Shulyupin, Chernev, 2012), a low concentration is a significant obstacle to creating an effective technology for their extraction. At the same time, some of the most relevant topics, including those related to the development of geothermal technologies, are not included in the circle of attention of the domestic sphere of research and development. This indicates its incomplete compliance with modern world trends.

Historically, specialists in the field of hydrogeology have been very active in the development of domestic geothermal resources. Under their influence, the domestic sphere of research and development was largely formed, regulatory documents were prepared. For example, the main document regulating the development of geothermal fields are the Rules for the development of thermal energy water fields (Rules for the development of thermal energy..., 2003). This document draws a direct analogy of a geothermal field with a groundwater field. This approach limits the geothermal energy resources under consideration only to the enthalpy of underground fluids, excluding from consideration the enthalpy of the host rocks. Foreign experience, as Yu.D. Dyadkin wrote about 30 years ago (Dyadkin, 1989), involves considering both fluids and dry rocks as an energy source. Accordingly, the assessment of the resources of a field developed by producing fluids should be based on the energy of the host rocks. Identification of geothermal fields with groundwater fields does not give a complete picture of available resources and may negatively affect the choice of technologies for their development.

The indicated limited view on the development of geothermal fields hinders the development of the domestic sphere of research and development. It is known that the possibility of publishing works is a significant incentive for research. Some domestic mountain publications refuse to accept articles on geothermal topics, citing a commitment to solid minerals. Some publications on water resources also do not recognize their geothermal theme. Once again, we note that with some assumptions in the development of geothermal resources, minerals, that means the mineral formation of the earth's crust, which has the necessary physical properties (high enthalpy), is represented by both fluids and dry rocks, and the presence of rocks, unlike fluids, is mandatory.

The development of domestic research in the field of geothermal resources development is also not facilitated by the lack of formalization of certain areas of relevance for scientific workers in the current Nomenclature, which does not allow the use of such an effective mechanism for stimulating scientists, such as defending dissertations in the specialty appropriate to their work. For example, the actively developing direction of geothermal technology in the world should be a section of the specialty 25.00.22 – «Geotechnology (underground, open and construction)». Note that the example of using circulation systems for geothermal energy production is an analogue of the classic example of geotechnology – borehole leaching. However, in the passport of the specialty there is an indication of solid minerals, and as already noted, in the domestic scientific field a one-sided understanding of geothermal resources dominates. As a result, there are no formal grounds for performing a dissertation in this specialty.

Despite the difficulties, the domestic sphere of research and development in the field of geothermal resources development is still alive and developing. The researches carried out in the previously mentioned domestic scientific organizations are carried out at the modern world level, the results are published in leading world publications (Pashkevich, Muratov, 2015; Shulyupin, Chernev, 2015; Kiryukhin et al., 2017).

To increase the efficiency of the development of domestic geothermal resources, it is necessary to adapt the scope of research and development to modern global trends in this area. It is necessary to overcome the one-sided perception of geothermal fields as groundwater fields and to make a new regulatory and methodological base for their development. It is advisable to form a wider understanding of the scientific specialty «Geotechnology», covering geothermal technology.

Conclusions

1. An important characteristic of the current stage of development of geothermal resources is the tendency to move from subsidized to commercial projects. This global trend increases the relevance of research in areas that most clearly reflect the specifics of the processes for developing these resources and have a significant impact on their economic efficiency, primarily in the field of geothermal technologies.

2. In terms of subsidized projects that set themselves not only commercial, but also research goals, the most relevant are the work within the EGS – enhanced geothermal systems. One of the sections of this direction is represented by the once considered separately HDR projects (hot dry rocks).

3. The current level of development of heat recovery system of wells technologies and heat pump technology allows producing geothermal energy almost anywhere in the world for use in local heat supply systems. At the same time, the basis for modern geothermal energy is still the direction associated with the rise of deep fluids to the surface, which provide thermal power attractive for practical use in large energy facilities in areas characterized by the presence of ascending flows of hot juvenile fluids.

4. Currently, Russia lags behind in the development of geothermal resources from the corresponding world development, including in terms of relevant areas of research and development.

5. To increase the efficiency of the development of domestic geothermal resources, it is necessary to adapt the scope of research and development to current global trends in this area. It is necessary to overcome the one-sided perception of geothermal fields as groundwater fields and to make a new regulatory and methodological base for their development.

6. To stimulate domestic research in the most actively developing global area of research in the field of geothermal resources development, it is advisable to introduce geothermal technology in the field of research of specialty 25.00.22 – «Geotechnology (underground, open and construction)».

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