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Problems and Outlooks of Hydrogeothermal Technologies Development

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ABSTRACT

In order to integrate the energy-efficient and ecologically safe geothermal resources into an energy balanced heat supply in the central European regions of Russia it is necessary to solve a number of technical and technological problems related, particularly, to the moderate temperatures of geothermal fluid (up to 55-60°C at depths of 2.0-2.5 km) and high salinity (more than 200 g/dm^3). Moreover, the factors of high capital investment and existing financial barriers are of great significance.

The Yaroslavl Region feasibility studies for geothermal project have been made: one for a village, another for a block of houses, with a capacity of ~7 and 11 MW respectively. The feasibility studies were made on the basis of economic-mathematical simulation and investigation of heat-mass transfer processes within a geothermal circulating system (GCS) with an aquifer, as well as test drilling and hydrogeological studies of the aquifer accomplished in a well with the help of formation tester.

To substantiate international sponsorship, a financial and economical analysis of a project (for Rybinsk, the Yaroslavl Region) has been carried out using the World Bank / Global Environment Facility (GEF) recommendations. This revealed a rational, in terms of net present value (NPV) and internal rate of return (IRR), financing plan for the project with the utilization of the World Bank’s preferential credits and possible grants from the GEF and other sponsoring organizations.

The experience of submitting an application for a project with GEF sponsorship has shown, that under conditions, when the prices for energy resources, such as natural gas and electric power, are 3-5 and 1.5-2.5 times, respectively, lower in the central European part of Russia than the world level, the original GEF economic concept should be adjusted taking into account real price-increase dynamics for energy resources in these regions, as well as the relation between these prices and the table of rates for heat energy in regions of Russia.

Taking into account the primary expectations from introducing the developed projects in the Yaroslavl Region: the annual saving of fuel up to 7700 tons of equivalent fuel (5400 t o.e.), reduction of thermal energy net cost by 1.5-2.0 time, reduction of CO_2 emissions by more than 13000 tons per year – the introduction of the indicated technology into other regions with proved geothermal resources potential will meet the global purpose of creation of heat-generating systems based on local renewable and ecologically safe energy sources in Russia and other countries of the Commonwealth of Independent States.

1. INTRODUCTION

In the central regions of the European part of Russia, which experiences its own energy resource deficit, the substitution of fossil fuel by renewable and ecologically safe local energy sources is an acute problem. Geothermal energy rates first among such sources (Composite authors, 2002).

SPSMI (TU) and FGUP NPC “Nedra” have made assessment of hydrogeothermal resources in natural reservoirs on the basis of eight central-European regions of Russia, united by a geological structure called the Moscow syneclise. It showed that in these regions geological resources in two main thermal aquifers (Devonian and Cambrian at depths 1200-1800 and 1800-3000 m) are about 44 billion tons of equivalent fuel (30.8 billion t o.e.) (Boguslavsky et al., 1995). It is planned to consume about 55 million tons of equivalent fuel (38.5 million t o.e.) per year for heat supplying in the eight regions up to 2010 (Litvinenko, Boguslavsky, 2003). Thus, hydrogeothermal energy resources in these regions will suffice for 800 years.

As main geothermal energy sources are concentrated in deep aquifers, characterized in Central-European Russia by moderate temperatures of formation waters (40-70°C) at depths economically sound for drilling (up to 2-3 km), it seems to be actual to consider the efficiency and outlooks for practical use of the world experience for such low-potential resources on the basis of geothermal circulating systems (GCS) and heat pumps, to provide heating for various facilities, such as described in paper (Boguslavsky et al., 2000).

2. PROBLEMS AND OUTLOOKS OF THE DEVELOPMENT OF HYDROGEOTHERNAL TECHNOLOGIES IN CENTRAL-EUROPEAN REGIONS OF RUSSIA

Recovered by hydrothermal technology, using a doublet of a production and an injection wells (Fig.1) as a rule, low-potential ground heat can increase the coefficient of the use of primary energy sources up to 2 units or more (for traditional heat supply this value is below 1). This value also exceeds the similar one for present day boiling plants by 2.2-7.0 times (from gas boiler to electric boiling plant respectively) which determines energy-saving potential, ecological effects, as well as technical-economical parameters for hydrothermal-source heat-supply systems (Kalinin et al., 2004).

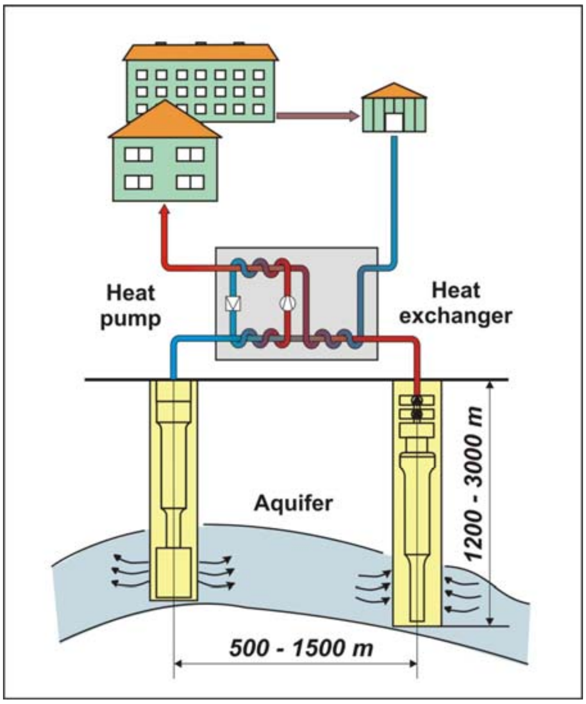

Figure 1: GCS-based heat supply technology.

2.1 Geological and Technological Backgrounds for Creating Heat-Supply Systems Based on Geothermal Circulating Systems in the Central-European Regions Of Russia

Experimental assessment, based on testing a 2250m geothermal well in the Yaroslavl Region (Medyaguino village), made for two aquifers with the estimated potential of about 7.0 billion tons of equivalent fuel (4.9 billion t o.e.) (Pevzner et al., 2001) showed that at depth from 1.2 to 2.2 km, formation water temperatures are 35-60^{o}C, flow rates – from 100 to 250m3/hour, and mineralization exceeds 200g/l. Table 1 shows results from investigations carried out in the Medyaguino well using formation tester (Khakhaev et al., 1994).

Using these basic parameters, FGUP NPC "NEDRA" jointly with SPSMI (TU) have made a feasibility study for the geothermal plants in village Medyagino, where a geothermal well is drilled for a block of houses in the town of Rybinsk, in the Yaroslavl Region. The feasibility studies are based on economic-mathematical simulation technique (Boguslavsky, 1981) and results from the research on heat-mass transfer processes in geothermal circulating systems (GCS). Source information for the feasibility studies were obtained from test drilling into Middle-Upper Cambrian water-bearing reservoir, as well as a hydrogeological investigation of this reservoir while drill stem testing (Khakhaev et al., 1994). In the connection recommendations of Geothermal Engineering GmBH, Neubrandenburg GmBH, having rich experience in building and operation of deep geothermal systems in Germany, were used (Schellschmidt et al., 2000). This allowed us to solve a number of technological problems related to moderate temperatures, high mineralization and corrosion-active properties of formation brines.

The possible borehole flow rate can be up to 120 m^3/hour and the selected distance between boreholes is 800 m, a GCS consisting of two boreholes, taking into account thermo-transformation of the recoverable heat carrier in heat pumps and re-injection of brines with reservoir pressure maintenance, can cover 50% of the heat-supply demand and 100% of the hot-water demand in a block of houses with 8000 of residents (altogether 143000 GJ per year) during long-term operation (at least 25 years). Technical parameters of geothermal plants can provide heat power from 6.9 to 11.0 MW, high-temperature heating (to 85-90^{o}C) and hot water-supply (Table 2).

2.2 Financial-Economical Problems of Hydrogeothermal Technologies Development

For the time present, there are no legislative acts in Russia to provide investment support and promote projects on renewable energy sources on the federal, regional and other levels. Existing conditions of granting credits are inefficient due to the short term of credit repayment and high interest per annum.

Feasibility studies for the geothermal projects in the Yaroslavl Region have shown that original costs on building geothermal plants will amount to USD 3.4-4.0 million. So far such amount of investments to finance the projects under realization from the federal and regional budgets is a problem. This is the main deterrent for hydrogeothermal technologies development in the central European regions of Russia. As shown in Table 3, the share of investments in the cost value of heat, produced using such technologies, is 40-50% and more. Therefore, the existing practice of international sponsorship for such projects by way of grants and other financial tools takes on special significance.

In order to substantiate such support and include the Rybinsk project to a project package to be sponsored by Global Environment Facility (GEF), the completed feasibility study was adapted, taking into account GEF economic concepts and recommendations (Problems of Geothermal Energy Development, 2003), and then submitted to GEF through Russian Geothermal Energy Society (Moscow).

The financial-economic analysis of the project, with an initial cost of USD 3.83 million (Table 3), is based on the World Bank's and GEF recommendations, and revealed is a rational financing plan for the project in terms of net present value (NPV) and internal rate of return (IRR). At the plan chosen (15% - share capital from federal and regional sources of finance; 20% - grants from GEF and other international sponsors; 65% - preferential credits from the World Bank with 6% interest per annum, and credit repayment during 12 years) NPV will come to USD 2.16 million during 25 years, IRR - about 0.1, heat energy cost value – USD 7.8 per 1 GJ with an investment component of 44%.

From the calculations using the GEF concept and other economic models (Litvinenko, Boguslavsky, 2003) based on average world prices for heat energy (USD 12-14 per 1GJ) it follows that pay-back period for the geothermal plants is about 10 years (Table 3). However, on comparison with the table of rates for heat in the central-European regions of Russia, which are 2.5-5.0 times lower than the average world values, pay-back period of projects becomes a problem. Obviously, this is the main reason why the Rybinsk project did not meet with support from GEF, although estimated cost of heat energy proved to be 1.5 times less compared to the average world price for heat energy.

2.3 Outlooks and Ways of Problem Solving

As experience of submitting applications for joint realization (with international sponsorship) has shown, taking into account GEF economic concept for the central European regions of Russia, there is a contradiction between average world prices for energy sources and the table of rates for heat energy applicable in the regions, which appreciably differ from the world level so far. Since a rather long period of price adjustment (at least 5-10 years) is required, it is necessary for Russia to have a possibility to adjust the original GEF economic model taking into account real price increase dynamics for energy sources in these regions.

Therefore attention should be paid to attempts of using various economic estimation models which include reported predictions for real price increase dynamics for energy sources in Russia (Yulkin, Balashova, 2001). For instance, one of such models (Bloomquist, 2001) was used to plot current cost per unit (for 1kW of installed heat power capacity) for a geothermal system and an alternative boiler plant (Khakhaev, Kalinin, 2003). In this case a value of specific seed money for comparable heat supply systems is laid off on the axis of ordinates, and this value is the starting-point for plotting to show cost accumulation during service life of a system at the expense of variable specific running costs. In addition, the pay-back period of a geothermal system can be conditionally defined by the projection of intersection of curves on the abscissa axis, which shows time of system operation (Fig.2). To the right from this point, expenses on an alternative boiler plant will exceed expenses on a geothermal system.

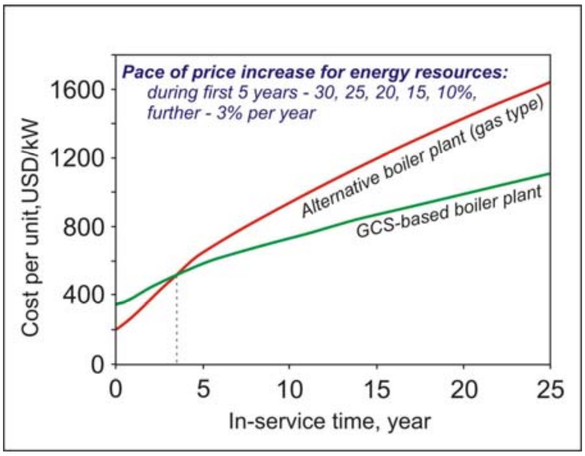

Figure 2: Cost per unit curves for the geothermal project and the alternative boiling plant, the town of Rybinsk (primary annual operating costs USD 33.4 and USD 63.0 per 1 kW of heat rate, respectively, and discount rate – 6%)

The application of this model for calculation accomplished on the example of the two geothermal projects indicated above – for the village and for the block of houses in Rybinsk – suggests that if this approach is applied, then the pay-back periods keep within 3.5-4.5 year period (see Table 3).

It should be also noted that since the arising international market of quotas for CO_2 emissions (The Kyoto Protocol, 2003) is closed for Russia, which has not signed the Kyoto agreement yet, it is necessary to find other measures for stimulation of environmental premium of geothermal resources. For example, to influence the operational part of the projects, in order to reduce the pay-back period, it is recommended to use finance mechanisms meant to reduce the price ratio for such energy sources as natural gas and electric power. At present time the central European part of Russia ratio is 1: 8-14 (Kalnin, 1996; Petin, 2001) (abroad it equals 1: 1.3-2.5) and it can be reduced, for example, at the expense of introduction of reduced rates for electric power required for heat pumps which serve as the special equipment necessary for effective generation of resource-saving and clean thermal energy.

In Table 3 it is demonstrated on the example of the project developed for Rybinsk, that the pay-back period for the geothermal systems is almost 2 years less.

3. CONCLUSIONS

In the conditions, when the prices in the central European part of Russia for energy resources, such as natural gas and electric power, are 3-5 and 1.5-2.5 times, respectively, lower than the world level, and the price relations do not stimulate the maximum use of economic benefits of electric heat pumps, it becomes problematic to count on current mechanism of international support of the projects dealing with capital-intensive heat supply technologies, using GCS, within the next 5-10 year period. For example, the economic conceptions for the substantiation of such support, proposed by the World Bank and International Geological Fund (GEF), are oriented on world average price levels and relations for energy sources and require adjustment for real permanent price increase dynamics in Russia to the world values. Only then the final estimated indices will be ratable and comparable with the tariffs for output thermal energy in the regions of Russia.

To temper the problems specified and to accelerate hydrothermal technologies promotion in central regions of the European part of Russia, where geological conditions are characterized by moderate geothermal gradients, but there is confirmed outlook for resource base, geological, and technical and technological background and for current demands for thermal energy, specific approaches could be recommended. Possibilities of the adjustment mentioned would result in more objective GEF appraisal of effectiveness of the projects submitted from Russia and other countries with similar price and rates relations in power engineering. Otherwise the international support of such projects will be limited by the regions with the most favorable geological and climate conditions (the Krasnodar Territory, Northern Caucasia) or by the areas with geological anomalies (for example, it is planned to restudy the similar anomaly in the Kostroma Region).

As one of the measures for stimulation of geothermal technologies development, taking into account the improvement of technical and economic indices, we can recommend a support, which is standard in a number of countries, in the form of reduced tariffs for electric power for heat pumps which have proved their consistency while effective generation of clean electric power.

By the example of hydrogeothermal sources in the central European part of Russia, the primary energy-resources use factor, with respect to the conventional heat supply, can be increased by approximately 2.2-7.0 times. Taking into account the primary expectations from introducing the developed projects in the Yaroslavl Region, such as the annual saving of fuel up to 7700 tons of equivalent fuel (5400 t o.e.), reduction of thermal energy net cost – by 1.5-2.0 times, reduction of CO_2 emissions – by more than 13000 tons per year, introduction of the indicated technology into other regions with proved geothermal resources will meet the global purpose of creation of heat-generating systems based on local renewable energy sources in Russia and other countries of the Commonwealth of Independent States.

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Table 1. The results of geothermal well test in Medyagino village, the Yaroslavl Region (Khakhaev et al., 1994)

Testing interval, m	Testing method	Properties of aquifers				
		Formation pressure, MPa	Water permeability, $m^3/Pa \cdot s \cdot 10^8$	Permeability, $m^2 \cdot 10^{12}$	Productivity, $m^3/MPa \cdot$ days	Temperature, °C
Old Oskol horizon	Formation tester in					
1224-1234	open hole	13.3	3.93	5.90	2037	35
1544-1579	The same	17.5	6.44	2.76	3338	36
Middle-Upper Cambrian horizon	Formation tester					
2086-2095	In open hole	23.4	1.17	1.17	608	53
	In cased hole		0.82	0.82	425	
2120-2148	The same	23.5	1.30	0.42	673	54
			1.26	0.41	653	
2158-2190	In cased hole	24.0	1.26	0.39	653	56
2086-2190 (the whole horizon)	The same	23.4	3.34	0.46	1730	56

Table 2. Technical parameters and process variables for geothermal heat supply projects

The index	Unit	Index value for	
		Medygino village, the Yaroslavl Rerion	Block of houses in Rybinsk
Estimated heat output	GJ/hour	25	40
Annual heat generation	ths GJ	87.3	143.0
Depth of GCS well doublet	m	2200	2000
Distance between wells	m	500	800
Temperature of geothermal fluid at the well outlet	^{o}C	52	52
Water temperature within the heating network (direct pipeline) - incl. the one from heat pumps (further – peak heating)	^{o}C	85 75	90 80
Hot water supply temperature	^{o}C	55-60	55-60
Geothermal system service durability, nor less	year	25	25

Table 3. Financing proposals and economic indexes for geothermal heat supply projects

Index	Unit	Index value for			
		Medyagino village, the Yaroslavl Rerion		Block of houses in Rybinsk	
		Direct investments + growth of rates around Russia	Including payment of credits + world average rates	Direct investments + growth of rates around Russia	Including credit repayment + world average rates [4)]
Capital investments for the whole system[1)] - incl. the investments for the wells	ths. USD[2)]	3210 2200	3444 2360	3567 2000	3828 2146
Operating costs[3)] - incl. the costs for energy resources and maintenance service	ths. USD	244 118	676 373	368 184	1118 (998) 573 (453)
Average net cost for 1 GJ	USD	2.80	7.74	2.58	7.82 (6.98)
Pay-back period taking into account discounting of expenses	year	4.4	11.2	3.5	9.8 (8.1)
Annual fuel saving with respect to the gas-based boiling plant	t o.e.	2080		3360	
Reduction of CO_2 emissions with respect to the boiling plant	ths. t/year	5.05		8.16	

Notes:

1) with costs for immersible, delivery, circulation, and heat pumps etc.;
2) at exchange rate 1 USD=29.00 rub.;
3) at cost of natural gas equal to 900 rub./1000m^3, average daily electricity rate equal 1100 rub./MW·h, cost of 1GJ – 120-140 rub.;
4) in brackets - values for reduced electricity rate (50%) for heat pumps.