APPLICATION OF DIFFERENT TECHNOLOGIES TO USE DEEP DRILLHOLES FOR GEOTHERMAL HEAT SUPPLY IN THE RUSSIAN FEDERATION

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KEYWORDS

Heat supply technology, deep drillholes, geothermal circulation systems, deep hole heat exchanger, heat pumps, process and construction variables parameters, feasibility study, recommendations

ABSTRACT

The modern technologies for development of geothermal resources are compared: hydrothermal resources – by using a doublet consisting of production and injection wells the so-called geothermal circulation system (GCS); petrothermal resources – a single-drillhole circulation design by means of creating a deep borehole heat exchanger. Based on example of the Yaroslavl region it is shown that a moderate geothermal rock gradient typical for the central parts of Russia GCS technologies with 2.2 km deep holes using heat pumps and peak heating can provide thermal power totaled from 4-6 to scores of megawatts. FGUP NPTs "Nedra" has worked out feasibility study with participation of German specialists: for a block of houses with 8300 dwellers, for a rural settlement and others. Application of a single-drillhole technology reduces thermals power to 0.3-0.7 MW from one hole (including thermal transformation and peak heating). At low costs for restoration of old hole a deep heat exchanger technology will be effective and economically profitable for some facilities in the central regions of Russia and under favorable geothermal conditions (geothermal gradient 5°C and higher at a depth of 100 m) it becomes profitable to drill two new 2 km deep holes near the heat consumer with a total realizable power up to 3 MW as it is true for the regions of the Northern Caucasus. Application of different technologies facilitates distribution of resource-saving and ecologically safe systems for heat supply in Russia and under involvement of international institutions into a practical realization of projects will contribute to solution of a strategic task on development of geothermal power generation in the Central and East Europe.

1. INTRODUCTION

In the introduced paper the questions of technological and economical feasibility of wide usage in Russia of such renewable ecologically safe and widely spread resources as heat of the Earth are discussed.

Today in a world practice there is an accumulated experience of the Earth's interior exploitation as a source of heat recovered by means of deep drillholes providing heat-and-power usage of reservoir brines with high mineralization level at temperature of 35-60°C through natural aquifer and corresponding equipment for thermal transformation of извлекаемой geothermal energy connected by drillholes, figure 1a. There are several scores of big enough systems with a heat power of 4-20 MW and higher operating in France, Germany, Denmark and other countries that proved the efficiency of geothermal technology that uses geothermal circulation system that provides reliable long-lasting operation (25-30 years) due to reservoir pressure maintenance. This method is widely discussed in the literature, including domestic literature [1, 2].

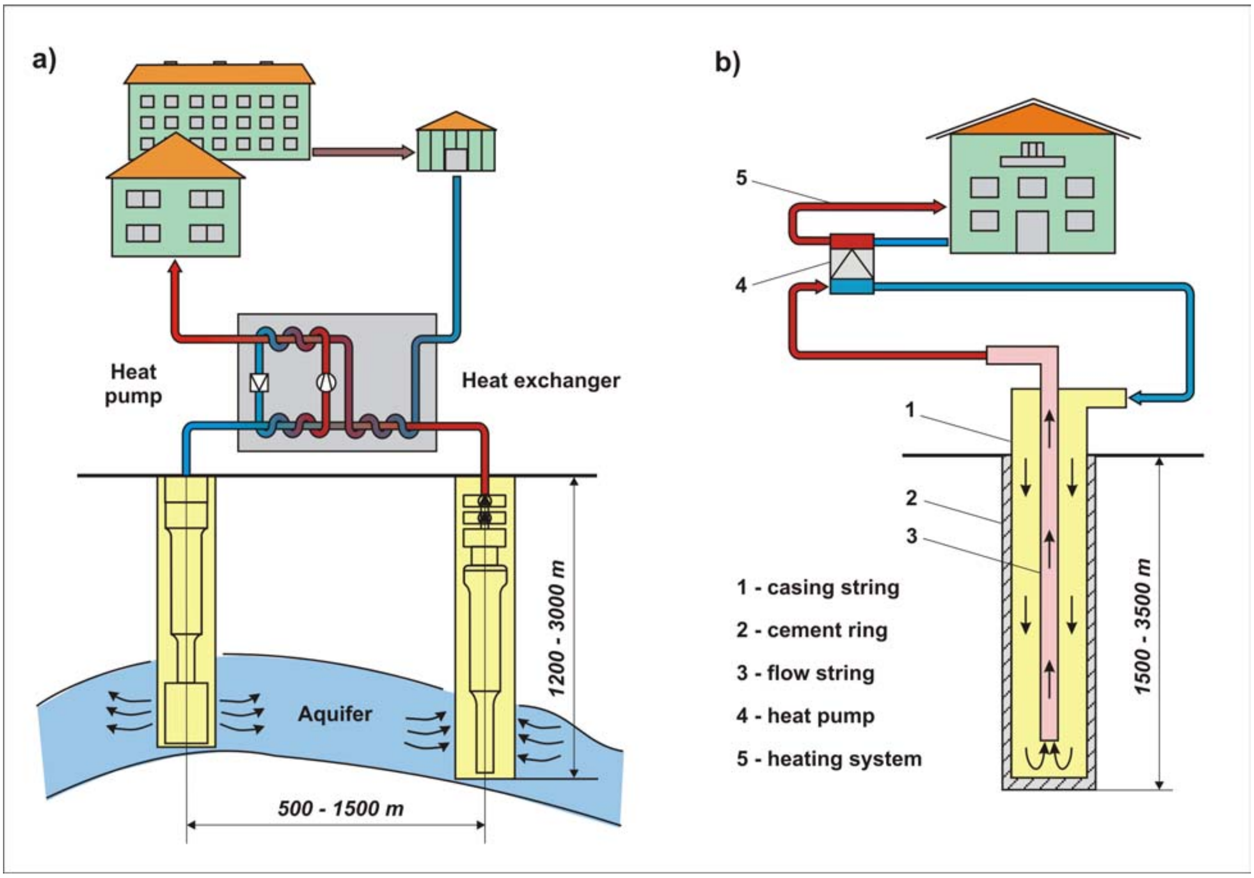

Fig. 1. The technology for deep drillhole utilization for heat supply with geothermal energy production: a) based on GCS; b) based on deep hole heat exchangers.

Recently in number of countries the technology which, by several reasons, in favorable geological and climate conditions can be an alternative to plants with GCS, for example, when there are problems connected with GCS drillholes distribution at a considerable distance of one from another (0.5-1.5 km) with geothermal fluid properties that complicate its utilization (high corrosion activity, mineralization up to 200 g/dm3 and higher), with water bearing horizon properties (permeability, water-intake rate, etc.) has appeared. More over, as it can be seen from the economical calculations, along with decreasing of heat power of systems with GCS from 6.0 to 1.5 MW the capital investments into systems considerably increase (up to 700 USD per 1 kW of installed capacity [3]).

The so-called single drillhole geothermal technology realized by means of closed-loop circulation that comprises a deep hole (up to 2-4 km), flow string installed into drillhole and the pump for heat carrier circulation, where as a carrier the usual process water is used, would (figure 1b) help to overcome the mentioned problems. The heat exchange from the rocks occurs while heat carrier circulation through annular space and the central column.

To the virtues of this technology we can also add the possibility of reutilization, but at this time for heating purposes, of out of use, exploratory, noncommercial oil and gas wells and that result in considerable reduction of capital investments into geothermal systems. It is especially actual problem for Russia that has a great number of deep drillholes closed for drilling in its disposal.

In this paper we gave the comparative evaluation of technologies with GCS and technologies based on deep heat exchangers used in Russian Federation regions with different geological and climate conditions.

2. THE EVALUATION OF TECHNOLOGIES TO USE DEEP DRILLHOLES FOR HEAT SUPPLY IN GEOLOGICAL AND CLIMATE CONDITIONS OF RUSSIA

2.1. The heat capacities of deep holes while application with deep hole heat exchanger technology

As an example of geothermal plant, where the single-drillhole technology of heat supply with the help of deep hole heat exchangers was successfully applied, serves the plant in Prenzlau (Germany) where in the process of building the plant the supplementary drilling of initial hole to the efficient depth was accomplished. The 2.8 km deep drillhole allowed obtaining more than 300 kW of produced heat power to provide 800 apartment in the centre of the town with heat [4]. The similar projects are under realization in Switzerland, Poland and other countries.

In order to accomplish the comparative feasibility study of the single drillhole geothermal technology with respect to the technology based on GCS it is, first of all, required to evaluate the heat capacities of deep holes while exploration of another kind of geothermal resource where, in contrast to GCS, mainly the heat of rocks (petrothermal resources) serves as a source of heat energy.

To do the efficient evaluation of multi-season processes of deep heat exchanger exploitation (more that 30 years) the new analytical computation technique based on physical-mathematical model of unsteady heat transfer within multilayer geological formation taking into account the parameters that vary with depth, geothermal rock gradient, drillhole and flow string design was developed in FGUP NPTs "Nedra". The above-mentioned calculation technique has shown satisfactory precision with results of numerical computing widely used in other countries for design calculations, was discussed in details in periodic literature [5].

The developed calculation technique was tested while evaluation of possibilities of deep drillhole effective application in Russia using single-hole technology of heat supply. As an example the two drillholes from one of the central regions of Russia (Yaroslavl region) were taken. For this region the moderate rock gradient is typical. The drillholes chosen for evaluation (Medianskaja and Danilovskaja №11) are located in different municipal districts and differ in depth and have some distinctions in geothermal rock gradients (Medianskaja hole: 2250 m deep, average geothermal gradient – 0.025 degree/m, Danilovskaja hole: depth – approximately 3000 m, gradient – 0.030 dergree/m). The variant with drilling new holes in the region where geological and climate conditions are more favorable (as it has been shown after 4 km deep hole test drilling in Kabardino-Balkarija which is close to Tyrnyauza where the average geothermal gradient is 0.052 degree/m) was considered as well.

Optimization calculations, described in paper [5], have shown that heat carrier temperature values at the inlet and outlet of deep hole heat exchanger (deep SHE), at optimized water consumption (20-33 m^3/h) in different modes of flow circuit operation will be from 9 to 30ºC for the 1900-3000 m deep holes under investigation (table 1). The average specific heat exchange for deep heat exchanger (per 1 running meter of the hole), according to data presented in table 1 will vary from 70 to 200 W/m, the upper limit is for the drillhole located in the region with high geothermal rock gradient. For the holes under investigation it corresponds to the total produced thermal power from 125 to 450 kW and to the amount of produced geothermal energy from 685 to 2580 MW/h and, as a result 85-320 tones of equivalent fuel per year can be saved from a single drillhole with installed deep hole heat exchanger.

Table 1. Heat capacities of drillholes with deep hole heat exchangers

The indices	The unit	Parameter value for the drillhole		
		Mediaginskaja	Danilovskaja №11	Tyrnyauzskaja (project)
Hole depth	m	2250	2986	1900
Average geothermal gradient	ºC/m	0.025	0.030	0.052
Rock temperature at the drillhole bottom	ºC	56	87	100
Operating heat exchanger length	m	2200	2950	1890
Flow circuit run time	h/year	5208-8760	5208-8760	4780-8760
Heat carrier (water) consumption	m^3/h	20-23	20-23	25-33
The minimal temperature of water at the outlet of the heat exchanger within 30 year period of exploitation	ºC	9.5-16.1	12.4-19.6	19.7-30.2
Temperature difference of water at the inlet and outlet (the temperature limit at the inlet for 30 years: 4ºC)	ºC	5.5-12.1	8.4-15.6	15.7-26.2
Possible transformation coefficient in the heat pump	-	4.0-4.6	4.4-5.2	5.2-6.0
The produced thermal power	MW	125-190	190-287	310-450
The amount of produces geothermal energy per year	MWh	685-1100	1027-1670	1850-2580

2.2. Selection of geothermal heat supply scheme and required equipment

The evaluation accomplished according to the variants of old drillholes utilization and drilling new holes allowed to select the schemes of geothermal heat supply and the basic equipment for geothermal systems with deep hole heat exchanges for specific regions of application (picture 2) taking into account the advantages and disadvantages of every system design. For instance, selection of variant with deep hole heat exchanger installed into existing drillhole would, first of all, mean that there is potential consumer not far from the hole because that kind of system is profitable when the expenses for drillhole restoration and for building a heating main to the consumer are moderate (as it can be seen from the results of calculations the distance to the consumer should not exceed 1.0-1.5 km). In case when the cost components appear to be commensurable with the other elements of capital investments (the price for purchasing the materials and for installation of flow circuit, heat pumps and other equipment) and the geological conditions are favorable the variant with drilling a new drillhole can be considered.

The table 1 shows the temperature range at the deep hole heat exchanger outlet which perfectly suits for water-to-water heat pumps, including the ones of home manufacture [6], because the possible transformation coefficient which depends on these temperature values, will be from 4 to 6 units and the average (within the whole period of exploitation) operation coefficient of the geothermal system that takes into account the expenses for energy required for heat and circulation pumps operation in 30 years will not be lower than 3.5-4.5 units. According to this, the energy carrier consumption will decrease as compared to the traditional heat supply.

Figure 2a shows the scheme of geothermal heat supply – the variant of utilization of drillhole existing in one of the regions of Russia where the moderate values of geothermal gradient are typical, based on example of heating and water supply of rural settlement located 1 km distance from the drillhole. The peculiar feature of this scheme is application of gas boiler available in the settlement for peak heating.

For the regions with more favorable geological and climate conditions (for example for the Northern Caucasus regions) in order to increase thermal power the scheme that requires drilling of 2 new drillholes close to the consumer at a 100 m distance one from another was suggested (Figure 2b). The 1.9 km depth of the holes was chosen in order to achieve 100ºC rock temperature at the hole bottom (table 1). In this connection, along with heat pumps and peak heating the total thermal power of heat supply system (up to 2-3 MW) can be provided which is enough for a single settlement or block of houses that has an average temperature mode (up to 70ºC in the pipeline). The heat supply system is oriented so that in the winter mode of operation the heat carrier circulates through both drillholes with total consumption at the outlet up to 60 m^3 per hour, in the summer mode only one drillhole is in operation with 10 m^3 per hour feeding into heat pump of hot water supply system.

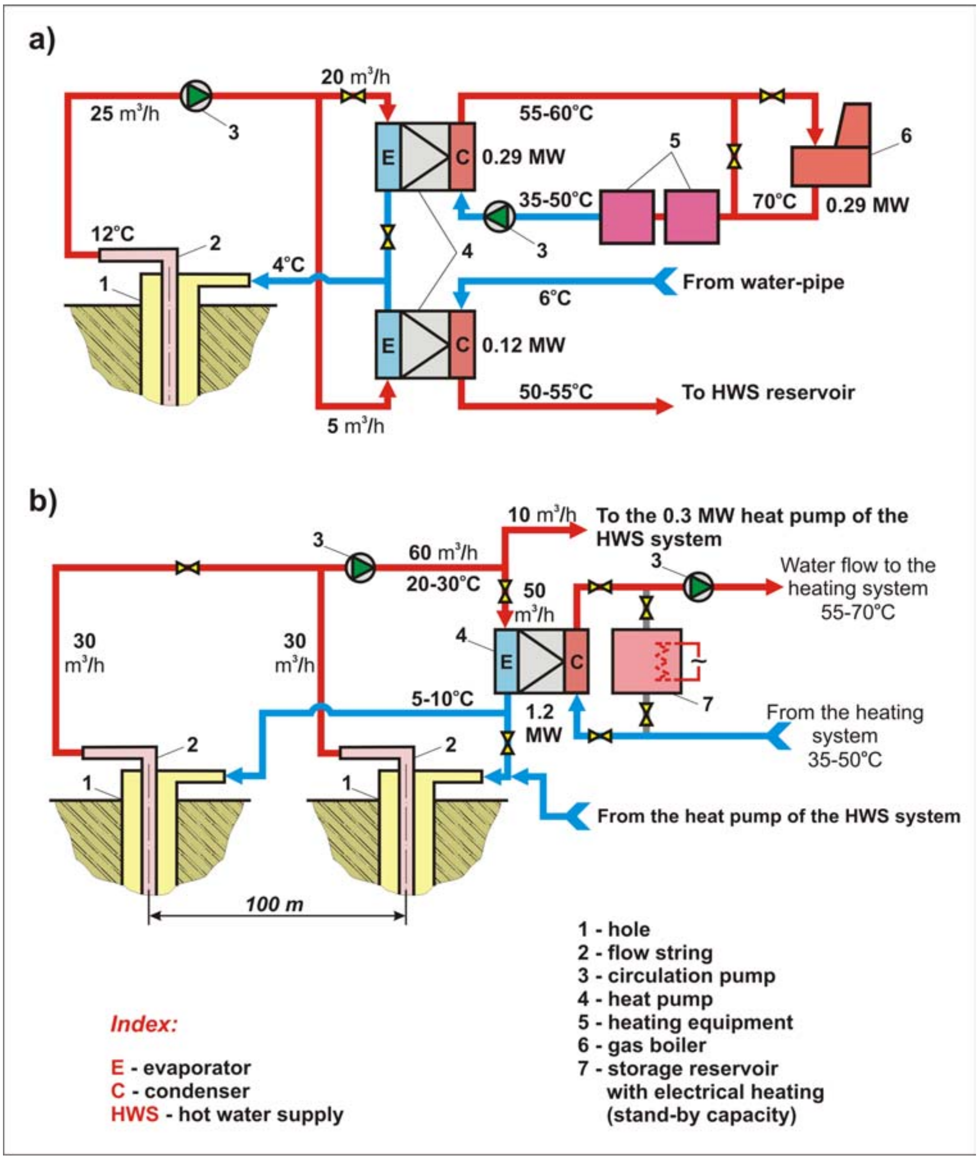

Fig. 2. The schemes of heat supply variants with application of deep drillhole heat exchanger technology presented in variants:
a) the scheme of existing hole (Danilovskaja №11, for rural settlement Gorushka, Yaroslavl Region); b) the scheme of drilling two 1.9 km drillholes (the project suitable for conditions of Kabardino-Balkarija).

2.3. Comparison of technical and economic indices of the geothermal projects based on deep holes

For feasibility study of the systems with different geothermal technologies that includes evaluation of capital investments and other indices, three variants have been chosen: two variants with deep hole heat exchangers which correspond to schemes on picture 2, and a variant with GCS technology that requires reservoir water utilization (picture 1a). As the last variant, out of two projects for which feasibility study was accomplished by FGUP NPTs "Nedra" (for a microdistrict with 8300 dwellers and a rural settlement) the project for Mediagino settlement which is in Yaroslavl Region that has been approved in cooperation with German specialists (Geothermie Engineering GmBH, Neubrandenburg) was chosen. This project requires exploitation of two 2.2 km deep holes using waters with high level of mineralization of Cambrian aquifer with temperature more than 60ºC. The choice of this variant is also grounded by the horizon testing accomplished earlier at this location with the help of 2250 m deep Medianskaja drillhole that proved the expected parameters of geothermal source and the effectiveness of building a geothermal plant with 4-6 MW thermal power close to the settlement [1].

The results of technical and economic indices evaluation that allow us to compare geothermal projects with different guaranteed level of heat productive rate while deep holes utilization according to one or another geothermal technologies by the example of various regions of the Russian Federation are tabulated in table 2.

From the table it follows that according to selected type of geothermal project the specific capital investments into realization (per 1 kW of installed thermal power) range within 440-780 USD. In this connection the lowest cost per unit correspond to the variant that requires installation of deep heat exchanger into already existing hole (Danilovskaja № 11), the highest – correspond to the variant with drilling new holes for deep heat exchanger installation. However, if we compare three projects which are under discussion according to the annual expenses for exploitation and net cost of produced thermal energy the variant with drilling new holes for deep hole heat exchangers is slightly more expensive than other variants. Therefore, every project under discussion can be considered as perspective because they allow reducing the net cost of produced thermal energy almost by a factor of two as compared with traditional heat supply.

For calculation of pay-back period of geothermal projects we used one of economic models (for example, the model used in Washington State University [7]) according to which the projects are being compared according to accumulated within 20 year period of service cost per unit (per 1 m^3 of heated space or per 1 kW of total heat power of heat supply system). In this connection, the specific capital investments are successfully supplemented by expenses for exploitation (for consumable energy sources) and servicing annually changing according to the discounting rate and energy source price growth.

In our case, the expenses were brought into accord with 1 kW power of the system and for more pictorial presentation of economic indicator dynamics the graphs of expanses depending on system period of exploitation were drawn. On Figure 3 we can see this on the example of indices of the project realized with the help of technology based on GCS (one of the projects presented in the table 2). To draw the graphs the computing origin was placed on the vertical axis in accord with the difference in specific capital investments for systems under comparison.

The main peculiarity of pay-back period evaluation was the fact that while drawing the graphs the real price growth rate for energy sources in Russia will in the nearest future conform to the world average level, was taken into account. To explain this thesis the graphs reflecting moderate annual price growth rate for energy sources at a similar discounting rate (5%) typical for USA and Western Europe countries (3%. figure 3a) and graphs drawn in accord with price growth for natural gas up to the year 2005 by a factor of 2.0-2.5 [8] are shown on picture 3.

Table 2. The indices of geothermal heat supply projects using deep drillholes and heat pumps (investment suggestions)

The indices	Unit	The values of indices for every technology		
		Based on GCS (Medjagino, Yaroslavl Region)	Based on deep hole heat exchanger	
			With existing drillhole (for Gorushka settlement)	With new holes (Kabardino-Balkaria)
The output rate incl. – from heat pumps	MW	6.4 1.5	0.7 0.4	3.0 1.5
Annual heat output incl. – geothermal energy	Gkal	25175 17890	2040 1310	9800 5400
Hole depth	m	2200	2986	1900
The amount of holes	units	2	1	2
Distance between the holes	m	800	-	100
Distance top the consumer	m	700	1100	200
The temperature of water required for heating, incl. – from heat pumps	ºC	80 60	70 55	70 60
The temperature of hot water supply (HWS)	ºC	60	55	55
Investments for the whole system[1)], incl. - heat source (incl. – hole restoration or drilling) - heat pumps - heat mains to the consumer - etc.	thous. dollars[2)]	3520 2800 (2200) 150 200 370	310 175 (40) 40 55 40	2370 2060 (1900) 150 20 130
Annual expenses for exploitation[3)], incl. - for energy sources and servicing	thous. dollars	236.0 118.0	15.6 10.8	100.0 45.0
Net cost of 1 Gkal of heat	dollars (rubles)	9.4 (285)	8.0 (243)	10.2 (310)
Fuel saving per year	tons of equivalent fuel	2570	187	770
CO2 emission decreasing (as compared to gas boiler, COP = 0.85)	tons/year	4700	450	1860
Pay-back period (taking into account the expenses discounting and the growth of prices for energy sources)	year	4.1	3.0	5.2
Period of service	year	25	30	30

Notes: 1) with expenses for flow circuit (bottomhole, forcing, circulation pumps, water circulation pipelines, etc.); 2) exchange rate: 1 USD = 30.3 rubles; 3) at gas price 900 rubles/1000 m^3, daily rate for electricity 1100 rubles/MWh and cost for 1 Gkal of heat – 500-700 rubles.

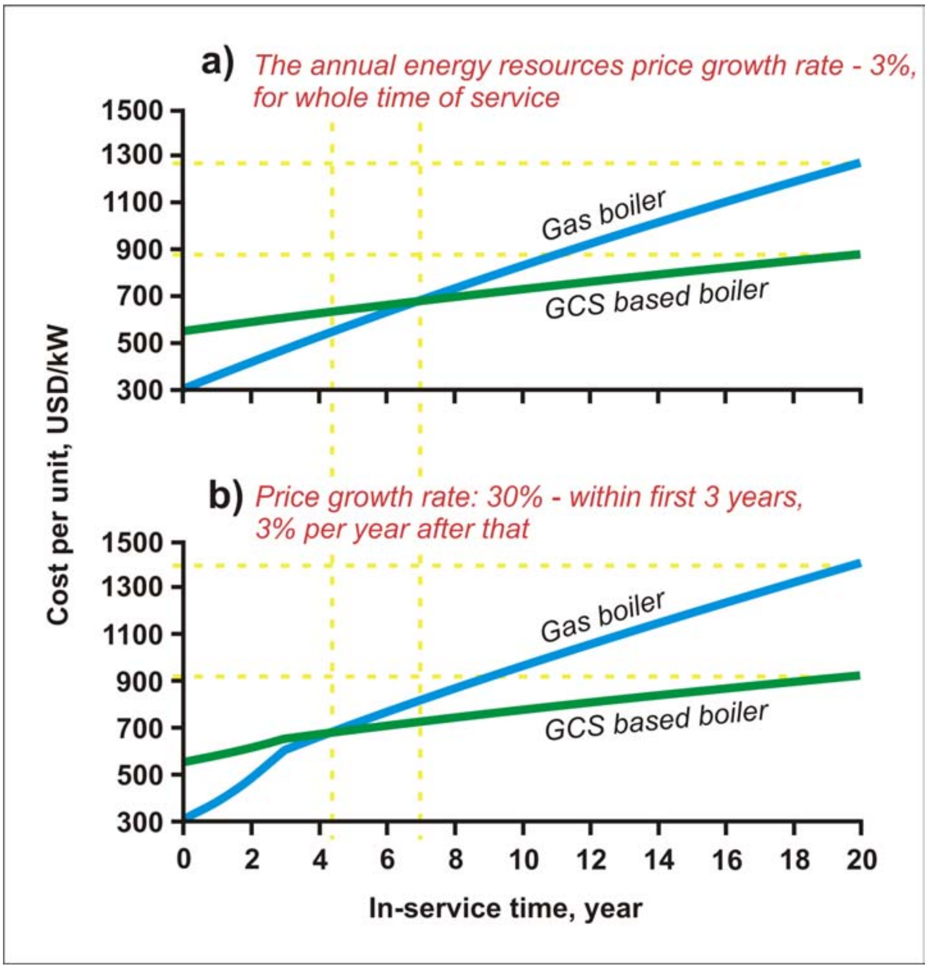

Figure 3. The costs per net graphs for geothermal project and for gas boiler (at initial annual cost per unit for energy sources and servicing – 18.5 and 55.0 USD/kW respectively and discounting rate – 5 %)

As a pay-back period we assumed the projection of intersection point of graphs drawn for geothermal plant and gas boiler onto horizontal axis. This projection reflects the period of time when total specific expenses for gas boiler tend to exceed the geothermal variant. As it can be seen from the graphs, in the first case (Figure 3a) the pay-back period will be approximately 7 years. But this parameter significantly varies when the real price growth for energy sources is taken into account and it will be 4.1 years (Figure 3b).

Similarly, the values of pay-back period for other variants of geothermal system under comparison were obtained and they vary from 3.0 to 5.2 years (table 2) in case the pay-back period of the systems is no less than 25-30 years.

Therefore, the excess of capital investments for geothermal systems will be repaid within satisfactory period of time due to significant economy on expenses for exploitation and servicing of geothermal system. From the graphs on Figure 3b it follows that: if within two year period the cost per unit including investment and exploitation variables are approximately twice as much as the expenses for project based on GCS than within 20 year period of exploitation the situation will change and the expenses will be 1.5 times greater for traditional heat supply system. The similar conclusions can be made from the calculations accomplished for other projects that use deep holes and heat pumps (table 2).

3. CONCLUSION

The evaluation of heat capacities of drillholes where the deep hole heat exchanger technology is applied, of technical and economical indices of various heat supply schemes where this technology is applied, denote that in technically and economically sound cases this technology can be considered together with the technology based on GCS when the it is required to make a decision about which technology should be chosen. All that broadens the possible cases of introducing the energy-saving and ecologically safe projects of heat supply based on renewable (geothermal) energy in Regions of Russia with different geological and climate conditions.
The accomplished feasibility study indicates that every geothermal system under discussion that use deep holes and heat pumps can compete with traditional heat supply in net price of produced thermal energy. The results of the study allow us to recommend the calculated indices of capital investments as investment proposals for building experimental-industrial plans in one of the regions of the Northern Caucasus with further distribution of geothermal technologies in these and other regions.
When the pilot (demonstration) plants were introduced the replications of such projects, GCS projects for instance, only in 8 central regions of Russia provided with geothermal resources [1], can amount to 100 units and more. Taking into account the reduction of CO_2 emissions from one geothermal station with average power (10MW) by 10 thousand tons per year, it will generate mutual interest both in Russia and abroad for developing market of pollution quotas that can be sold to foreign partners interested in meeting the commitments within the framework of U.N.O. Convention on climate changing (Kyoto Protocol). This fact makes geothermal projects presented in this paper more attractive for Russian and foreign investors and opens possibilities for Russian Federation economy.

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