METHODS AND RECOMMENDATIONS FOR SUBSTANTIATIONS OF THE INVESTMENTS IN BUILDING SERVERS OF A GEOTHERMAL HEAT SUPPLY

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KEY WORDS

Methodical principles, technical and economic parameters, influence of natural conditions, heat productivity, economy of fuel, charge of the electric power, express methods

ABSTRACT

Using of the low-temperature sources of geothermal energy - one of general directions in the decision of a problem of a heat supply of many regions of Russia in XXI century. It proves to be true: by absence of own traditional power resources, large expenses for their transportation from other regions, certain advantages of geothermal resources, by creation of scientific bases of their development, world industrial experience and specificity of systems of a heat supply in the country. Variety geology and geothermal conditions of productive horizons of regions of Russia characterizes natural conditions for construction of geothermal heat supply station (GHSS). The wide range of heat loads, temperature regime of customers as well as the distances of transportation are defined by the requirements of users. In generally there are around 150 factors that influence on the GHSS constructive and technological parameters. It shows the necessity to optimize these parameters for the estimation of expediency of geothermal resources utilization. The solution of this problem is based on the economical and mathematical modeling (EMM) of GHSS building and exploitation. The first economical and math model for GHSS system optimization had been developed in 1971. Now there is the group of similar models, that imitate functioning this station under different technology of heat mining. The compared estimation, fulfilled on the base of EMM, of main natural factors that have influence on the constructive, technological, electrical as well as economic and work parameters of GHSS allowed to create a new express method of their computing for the conditions of Russia. The created techniques EMM and express analysis can ensure the first stages of designing of a GHSS and, in particular: substantiations of the investments and development of the business - plans. The examples for perspective regions of Russia are given.

1. INTRODUCTION

Keeping Russia as one of the great states, its further development and the prosperity, largely depend on the possibilities to supply own power needs, the export of fuel and electrical energy as well. On this historical phase the power resources are a basic trade source of supplement of the state budget. However, the petroleum resources, under condition of the conservation of their export volumes, are quickly exhausted; natural gas resources are not too boundless. The stores of coal had essentially decreased with a USSR disintegration, and the rest deposits require the high investments. This followed to the rising of current expenses. Deposits are characterized by inferior quality and moreover, the additional expenses on an ecological protection are increased.
Under these conditions, especially for a high rise of fuel prices, the power supply of an European part of the country became worse. The regions of central Russia, characterized by a rather high density of population and concentration of industry, do not have any significant own

conventional power resources. Thus, around 55 million t o.e. per year is predicted to spend on the needs of heat supply of eight regions (tab. 1).

Searching alternative fuel is realized during last years. The use of low-temperature geothermal sources for a heat supply in regions of Russia is one of general directions in the solution of this problem in XXI-st century. It is confirmed by advantages of geothermal utilization, presence of scientific bases of their exploration, worldwide industrial experience and specificity of heat supply systems in our country.

Table 1. Forecasted heating-needs of industry (I), agriculture (II) and dwelling-municipal sector (III) in the central regions of Russia in 2000-2010 years.

Areas	Heating consumption, millions t o.e. /year						
	Total	Towns and settlements			Villages		
		I	III	Sum	II	III	Sum
Vladimirskaya	6,1	3,0	2,2	5,2	0,6	0,3	0,9
Vologodskaya	6,6	3,3	1,5	4,8	1,2	0,6	1,8
Ivanovskaya	5,0	2,6	1,8	4,4	0,4	0,2	0,6
Kostromskaya	3,0	1,3	0,9	2,2	0,5	0,3	0,8
Nizhegorodskaya	18,6	11,5	4,7	16,2	1,2	1,2	2,4
Novgorodskaya	3,7	2,0	0,9	2,9	0,5	0,3	0,8
Tverskaya	6,1	2,8	2,0	4,8	0,8	0,5	1,3
Yaroslavskaya	5,6	2,8	2,0	4,8	0,5	0,3	0,8
Total	54,7	29,3	16,0	45,3	5,7	3,7	9,4

To solve this problems the technology of utilization of geothermal resources of low-temperature natural collectors was created. It includes the following:

- technological schemes of heat mining by geothermal circulating systems (GCS) [1-7];
- theoretical thesis of hydrodynamic, thermal and geomechanical processes [4] of mining earth thermal energy;
- the methods of geological and economic evaluation of geothermal resources and basic principles for an estimation of geothermal deposits reserves [1,3,4,8,9];
- mapping, zoning and estimation of geothermal resources on the territory of Russia [1,3];
- the methods of technical and economic computing of parameters and indexes of geothermal circulating systems (GCS), stations of geothermal heat supply (GHSS) and geothermal power stations (GeoTPS) [1,9-11];
- the economic-mathematical optimization models [12,13] of GCS, GHSS and GeoTPS, for the design of these devices;
- the experimental and industrial work for scientific and industrial checking of reliability of fulfilled researches and functionability of the technological schemes [1,2,4-6];
- industrial utilization of geothermal resources [1, 4-6,10].

The specific peculiarities of central Russia regions stimulate the use of heat power of Earth here. Namely, these peculiarities are:

- the high centralization of heat supply systems in cities, towns and even in the working settlements;
- deficit and difficulties of delivery of organic fuel to customers;
- large term of operation and almost complete deterioration of thermal networks;
- compactness of population residing in cities and even in agricultural districts.

2. PROSPECTS OF GEOTHERMAL RESOURCES UTILIZATION IN RUSSIA

2.1. Basic principles

Variety of geological and geothermal conditions of productive horizons determines the conditions for GHSS building. The wide range of heat loads, temperature condition of customers and distances of transporting of the heat-carrier are defined by the requirements of users.
In generally, as we mentioned above there are about 150 factors, influenced on design and technological parameters of GHSS. Therefore, the evaluation of expediency of geothermal resources utilization is possible only on optimal parameters of such stations (GHSS). Therefore adequate rating of expediency of development of geothermal resources is possible only on an optimum level of definition of parameters of such stations. The essential value thus, has the analysis of influence of the named conditions and requirements of parameters of a GHSS, electrical and economical characteristics its very important.
The solution of this problem is based on the economical and math modeling GHSS building and exploitation. In 1971 Dr. Emil Boguslavsky had developed the first economic-math model for the GHSS system optimization. Now there is the group of models that imitate functioning geothermal installations under different technologies of mining and for the different purposes of its use [12,13]. On the basis of such HSS model, including GCS with a natural collector and heat-pump station (HPS), optimizing calculations had been completed for various geological-geothermal and thermal energy conditions in central regions of Russia.
The net present value (NPV) was used as a general criterion for GHSS optimization. The estimated criterions were following: the investments, the cost price of a thermal energy in net economies of organic fuel (natural gas) and the factor of an economic feasibility. The project, applyed to an investment, starts at magnitude of NPV > 0. It means that during all economic life GHSS will reimburse the initial expenditures and will provide the profit according to the defined standard discontinuous rate. At NPV < 0 the project is unprofitable, and at NPV = 0 it does not bring the income at all. The investments were differed according to basic building plants and in final evaluations they are reflected as a whole on GHSS and on two complexes - GCS and GHPS.
The economies of fuel characterizes (in oil equivalent – t o.e.) the difference between the production of heat and the consumption of organic fuel for the production of electric power, that is consumed by GHSS on own needs. Moreover, the economies of organic fuel as a difference between production of a heat and calculated development of heat electrical steam-shop is defined with the use of electric power spent by GHSS on own needs.
The factor of an economic feasibility is a ratio of specific expenditures for production of heat by fuel steam-shop to the specific expenditures for heat delivery by GHSS to the same customer, i.e. equal capacity. If this criterion is more than unit, the construction of the geothermal station is possible to consider as the economically expedient one. The use of another criterions of business-scheduling isn’t necessary at the given phase of forecasting researches.
A PC program [11] for calculation and optimization of business-plan had been developed. It is based on the specified EMM of geothermal systems with natural collectors. This program should be used mainly on the stages of substantiations of the investments realization. It allows to calculate and develop the design, technological and economic parameters of GHSS for any customer and for particular natural environments. These parameters are optimum for the particular financial scenario of the project realization, in which the mutual interests of the investors and customers are coordinated.

2.2. Geological-geothermal conditions

Geological-geothermal conditions have the primary meaning for technical and economic evaluations of geothermal resources. In the proposed method 14 factors of this group are used. The long-term experience shows that only five of them have the most significant influence on the

parameters of GHSS. They are the depth of sinking of a productive layer, its temperature, effective capacity, permeability and layer pressure.
The choice of generalized geological-geothermal characteristics for the conditions of is rather difficult, especially for simultaneous utilization of several thermal-aquifers. The analysis of geological-geothermal conditions, of the requirements of potential users on the following and limiting economic parameters values had been accepted:

Occurrence depth of natural collector ....1; 1,5; 2; 2,5 and 3 km.
Thickness of collector ....25, 50, 75, 100 and 150 m
Temperature of collector rocks...................30, 40, 50, 60 and 70 ^{0}C.
Permeability of collector rocks....................0,05; 0,1; 0,2; 0,3 and 0,4 Darcy.
Layer pressure ....hydrostatic.

2.3. Influence of the natural factors on technical and economic GHSS parameters

The influence of the main geological-geothermal conditions on NPV, the investments in GHSS construction and the cost price of a heat was detaily investigated in some publications [1,3,10 etc.]. The criterions for estimation of GHSS especially for evaluation of investments in GHSS construction are changed (fig. 1). This is connected with permeability of rocks productive horizons. However, the main changes occur in a range up to 0,3-0,4 Darcy, and with increasing permeability its influence on the technical and economic indexes (TEI) become insignificant. The same influence happens with the thickness of natural collectors. It has significant effect on TEI up to values of 40-70 m, and then its action sharply drops. Therefore, the temperature of collector rocks and the depth of their occurrence make the greatest constant influence on TEI of mining of geothermal power.

2.3.1. Definition of thermal loadings of customers

The definition of the economical heating efficiency of GHSS, under various conditions of temperature and depth of layer, was based on the maximum values for the GCS mod, consisting from one pair of bore-holes. The temperature of the heat-carrier delivered to the customers should be 90/40 ^{0}C. The prices on the electric power is 50 USD/MWh and on the fuel (natural gas) - 124 USD/t o.e. are taken on the base of the state on the world market.
The economic-mathematical HSS modeling and optimization of its parameters were calculated using PC program. Several thousands variants were reviewed. As a result of modeling the optimal value of GHSS heating efficiency for the most cold five-day period of a year is from 4 up to 74 GJ/h (fig. 2).
To draw up business-plans, investment projects or other preplanning documents it is necessary to use the equations for express-calculations. The approximation of outcomes of economic-mathematical modeling gives:

$$Q = -a \cdot H^3 + b \cdot H^2 - c \cdot H + d \text{ [GJ/h]} \qquad (1)$$

$a = 1{,}6 \cdot 10^{-4} \cdot t^{2{,}295}$; $b = 7{,}1 \cdot 10^{-3} \cdot t^2 - 0{,}38 \cdot t + 7{,}269$; $c = 12{,}5 \cdot 10^{-3} \cdot t^2 - 0{,}698 \cdot t + 16{,}232$; $d = 1{,}846 \cdot t - 37{,}8$, where a, b, c and d are numerical coefficients; H is the depth of natural collector [km]; t is the layer temperature [^{0}C].

The verifying calculations had shown the admissible convergence of EMM outcomes with the calculated ones, based equations.

2.3.2. Definition of hydrodynamic parameters of GHSS

For the choice of GHSS equipment it is necessary to estimate the hydrodynamic parameters of the system. The specific debit of producing bore-hole does not depend on the depth of natural collector, but it decreases with the growth of its temperature (fig. 2). The express-analysis can be realized by using the following equation:

$$W_{ud} = 342{,}34 \cdot t^{-1.048}, \ [\mathrm{m^3/GJ}] \quad (2)$$

The specific pressure of charging and pumping (by bottom pump) is reduced with the growth of temperature of layer and its depth. The rise of bore-holes yield for GHSS heating efficiency growth leads to the increasing of losses of pressure in HSS manifold and should be limited by characteristics of charging and pumping equipment. The specific pressure of charging and pumping can be calculated according:

$$P_{sp} = a \cdot t^{b}, \quad [\mathrm{kPa/(m^3/h)}] \quad (3)$$

$$a = 99.15 \cdot e^{0.857 \cdot H}; \quad b = -0.46 \cdot H^{0.5}.$$

2.3.3. Definition of annual combustible economies

Because of the significant consumption of electric power on own GHSS needs, especially on thermal transformation, the electrical power analysis of station had been realized. We compared the annual economies of organic fuel at geothermal heat supply with computed fuel consumption for production of the electric power, consumed by GHSS on own needs, with the potential production of heat electrical steam-shop at the expense of use of the electric power, spent for own GHSS needs (fig. 3). The annual economies of organic fuel from changing steam-shop by the GHSS mod depends from the temperature of a layer and its depth and can be approximately calculated according to following equations (4):

$$T_{ec} = A \cdot t^{b} \quad [\text{t o.e./year}]; \quad (4)$$

$$a = 5{,}13 \cdot 10^{-5} \cdot \exp(0{,}254 \cdot H); \quad b = -0{,}119 \cdot H + 4{,}4.$$

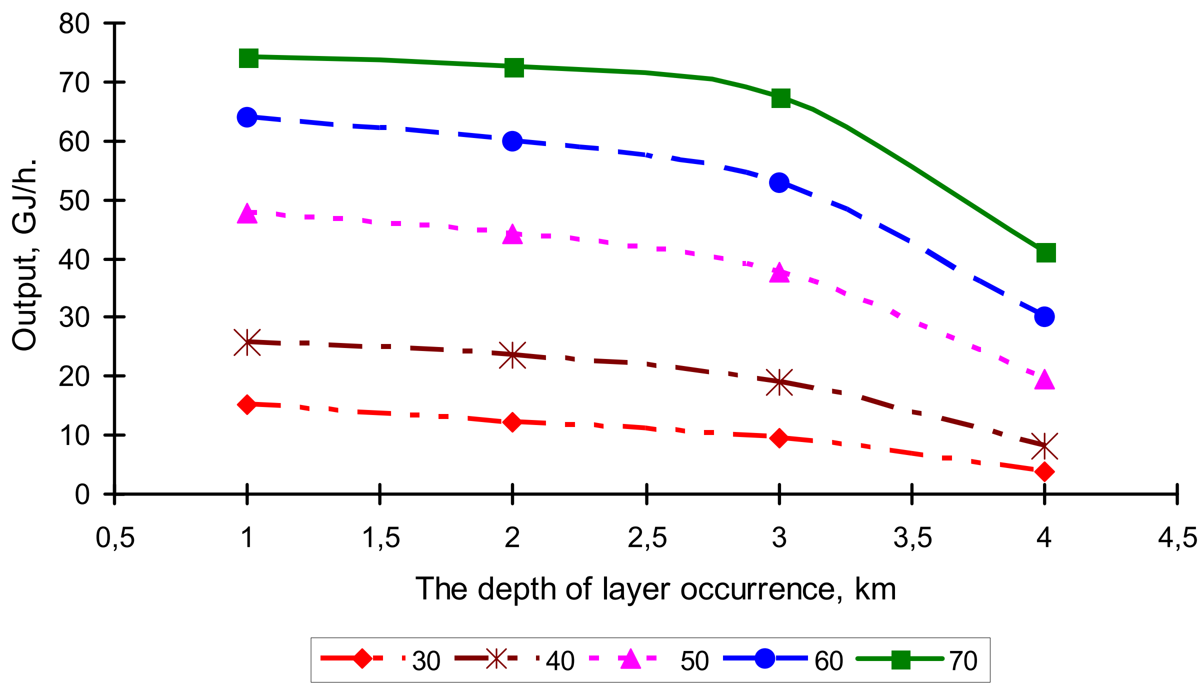

Figure 2. Thermal efficiency of GHSS mod versus the depth of layer and its temperature.

For the whole range of temperatures and depths of thermal aquifers the producing of GHSS energy (15-45 %) is higher than the consumption on own needs.

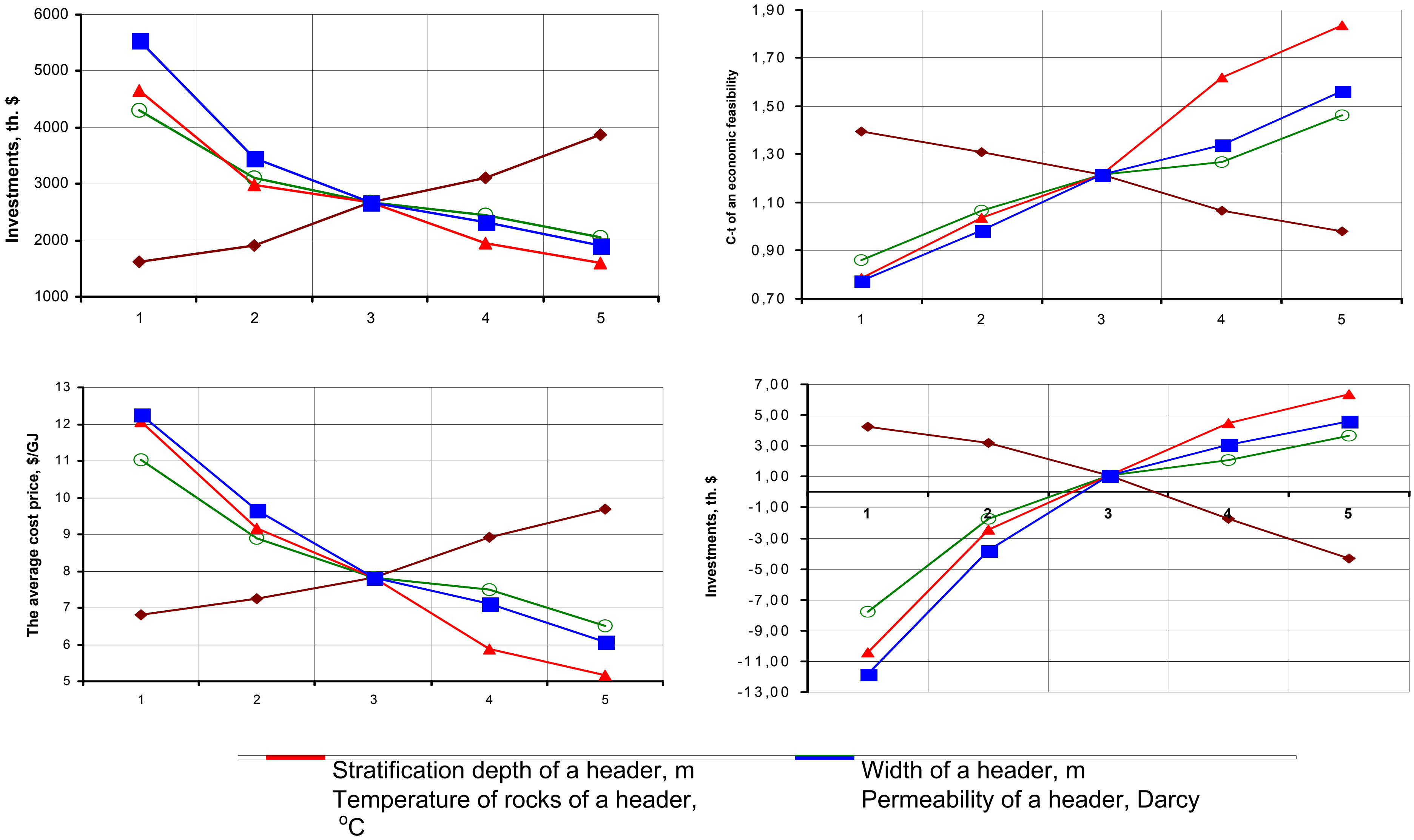

Figure 1. Influencing of geological - geothermal conditions on the main economic characteristics of a GHSS.

2.3.4. Definition of the specific charge of electrical power on GHSS own needs

The specific consumption of electric power on the heat production is indicative. It insignificantly depends on the depth of layer and linearly depends from its temperature (5-7). GHPS spends up to 80 % of expenditures of the electric power for own GHSS needs.

$$Y_{HSS} = -0{,}775 \cdot t + 138{,}4 \text{, [kWh/GJ]} \quad (5)$$

$$Y_{TPI} = -0{,}573 \cdot t + 113{,}7 \text{, [kWh/GJ]} \quad (6)$$

$$Y_{GCS} = -0{,}199 \cdot t + 24{,}7 \text{, [kWh/GJ]} \quad (7)$$

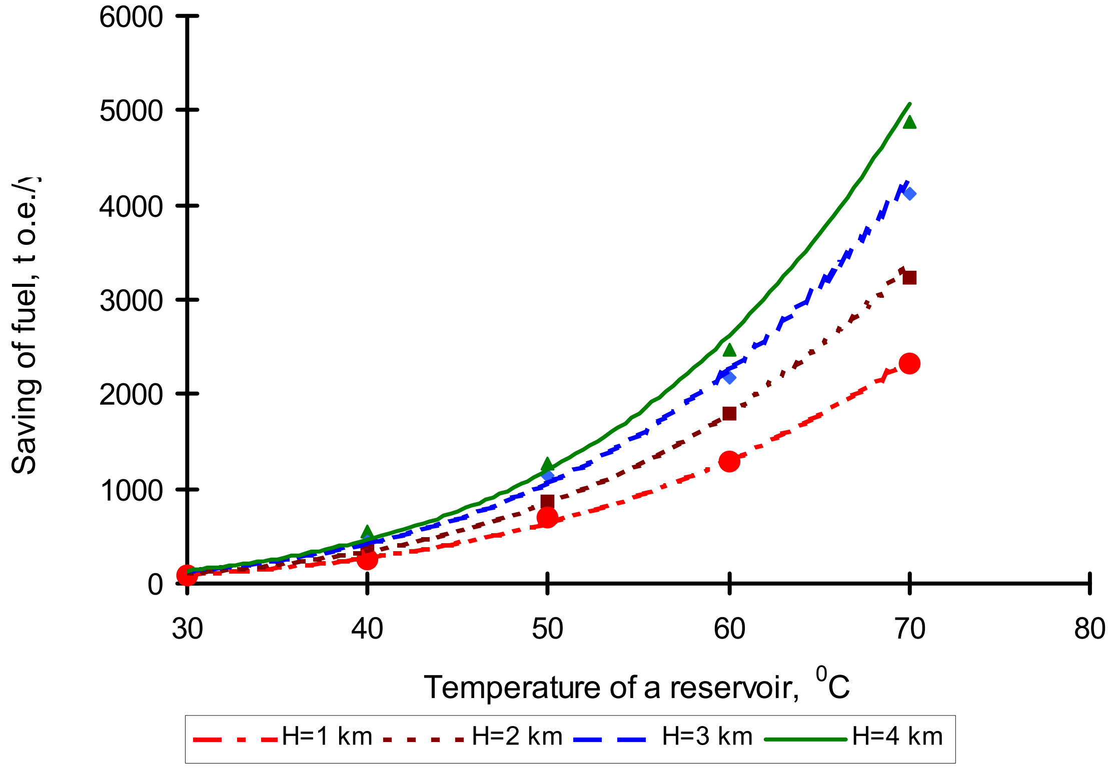

Figure 3. The annual economies of organic fuel at a replacement of steam-shop by GHSS mod versus the temperature of a layer - t and its depth - H.

2.4. Influence of the natural factors on economic parameters of GHSS

Because of unguided and unpredictable dynamics of prices and tariffs changes in Russia, the attempt to transform the economic calculations into dollar equivalent for forecasted estimations is made. Seeing the actual and calculated data of thermal utilization in USA as well as the specific character of transitional phase in the countries of former USSR (cheap manpower, the state monopoly on production tools etc.), the correcting coefficients are admitted. These coefficients allow to use the rating value of dollar closed to exchange rate of ruble and correspond to the technical and economic calculations on "Baltic project", fulfilled by the experts of Denmark, and estimations of German specialists [1,23]. The approximates and the conventionality of these factors is partly compensated by the compared character of verifying evaluation criterion.

2.4.1. Definition of capital investments on building of the optimum GHSS module.

The investments on building of optimum GHSS mod depend significantly on the depth, and at small depths weakly depend on the temperature of layer (fig. 4). The significance of the express-analysis of investments are difficult to overestimate. The equations (8) allow to calculate needs of investments with admissible approximation to EMM results.

$$K_{sp.HSS} = a \cdot t^2 - b \cdot t + c \text{, ths.US doll./(GJ/h)} \quad (8)$$

$$a = -0{,}00317 \cdot H^3 + 0{,}016 \cdot H^2 + 0{,}0127 \cdot H - 0{,}0052; \quad b = 4{,}13 \cdot H - 1{,}634;$$

$$c = 27{,}29 \cdot H^3 - 164{,}04 \cdot H^2 + 431{,}96 \cdot H - 175{,}94.$$

2.4.2. Definition of NPV

The general criterion of economic feasibility is NPV. It defines the limits of the possibilities of GHSS building for heat supply of settlements. At depths of layers more than 3-4 km, and their temperatures are lower 50-60 0C, the economic activity of a GHSS - has negative result. At depths of layer from 2 up to 3 km and temperatures 30-40 ^{0}C we see the same results (fig. 5). The definition NPV can be made on the equations (9), providing results adequate a EMM:

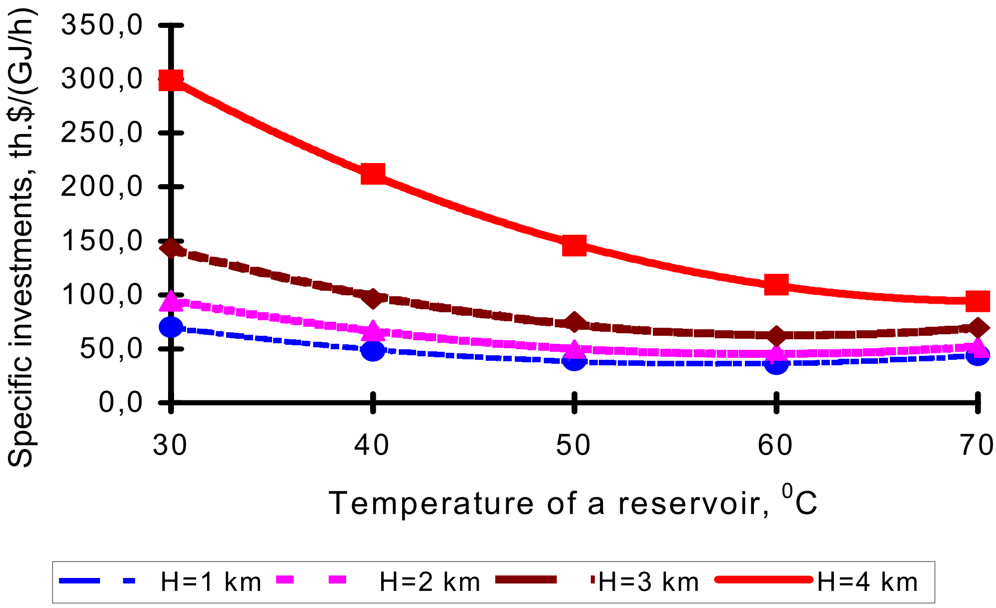

Figure 4. Specific investments on GHSS building versus temperature and depths of a layer.

$$NPV_{sp} = a \cdot \ln(t) - b \text{, ths.US doll./(GJ/h);}$$

(9)

$$a = 6{,}027 \cdot H^3 - 33{,}5 \cdot H^2 + 60{,}81 \cdot H - 7{,}21;$$

$$b = 24{,}6 \cdot H^3 - 135{,}1 \cdot H^2 + 249{,}3 \cdot H - 60{,}9.$$

3. PARAMETERS AND INDICES OF A HSS FOR SUBSTANTIATIONS OF THE INVESTMENTS

For development of the first design documents: the investment projects, business of the plans etc. the information on integrated, but authentic enough parameters both indices of building and operation of a GHSS is necessary. By the orders or requests of administrations of areas, chiefs of the industrial, agricultural and municipal enterprises on base a EMM the technological, technical, power and economic parameters and indices of a GHSS were determined. The calculations were carried out for several tens objects, the information on some of them, located in various regions of Russia, is given in the tables 2-5.

4. CONCLUSIONS

1. The utilization of low temperature thermal aquifers on the main territories of the regions of Russia is technically possible and economically expedient.

2. The dimensions of mining and the using of ecologically clear geothermal energy in XXI century should provide its important role in fuel and energy balance of Russia.

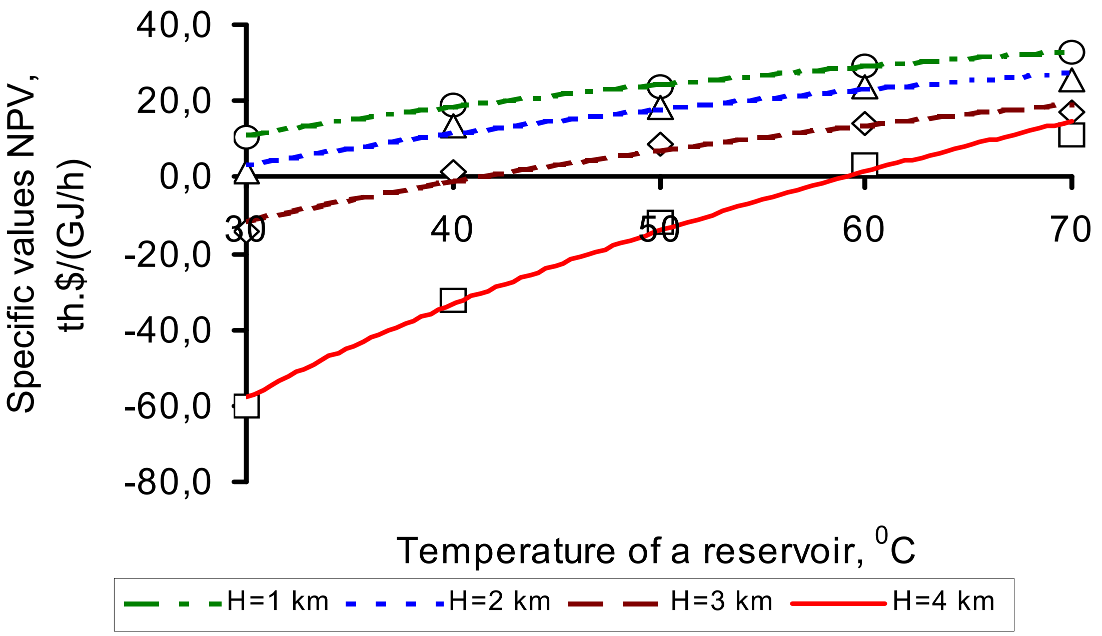

Figure 5. Specific NPV values versus temperature - t and depth - H layer.

3. The comparative evaluation of the influence of the main natural factors on the design, technological, electrical and economic parameters of GHSS allowed to create and to recommend the new express methodology of their calculation for the conditions of regions of Russia.

4. The wide range of expedient heat efficiency of the mod, competitive parameters and the indexes of HSS, allow to use the low temperature geothermal energy for customers almost on whole territory of regions of Russia.

5. The considered examples of parameters and indices of a GHSS in various regions of Russia and for the different requirements of the customers allow to estimate the concrete characteristics of geothermal stations.

Table 2. The initial data for designing a HSS.

Parameters and indices	Units measurem.	Kaliningrad region		Yakutia		Kamchatka		Vologda region	Pskov region	Kost-roma region	Yaroslavl region	
		Devo-nian	Cam-brian	Vilyusk	Vuktil	Site 1	Site 2	Devo-nian	s. Palkino	city Buy	d. Me-dyagino	city Ribinsk
Heating capacity of a HSS *	GJ/h	40,0	40,0	25,0	25,0	25,0	25,0	100,0	35,8	56,8	25.0	5,0
Temperature of network water **	^{0}C	90,0	90,0	90,0	90,0	90,0	90,0	90,0	90,0	110,0	90,0	90,0
Temperature of network water ***	^{0}C	40,0	40,0	40,0	40,0	40,0	40,0	55,0	55,0	70,0	55,0	55,0
Temperature of rocks collector	^{0}C	40,0	70,0	110,0	55,0	115	140,0	50,0	50,0	53,0	56,0	25,0
Permeability of rocks collector	Darcy	3,0	1,7	0,7	0,67	1,0	0,7	2,0	0,7	2,7	0,46	2,5
Thickness of a collector	м	75,0	45,0	500,0	800,0	300,0	300,0	137,0	40,0	174	104	125,0
Depth of a collector	м	1000	2000	3350	2100	1600	2200	1644	900	1970	2190	1030
Price for water (for $м^3$)	doll.	0,01	0,01	0,1	0,1	0,09	0,09	-	0,011	0,8	0,01	0,1
Price for 1 kWh of the electric power	doll.	0,0468	0,0468	0,05	0,05	0,05	0,05	-	0,02	0,056	0,05	0,05
The price for fuel (for т о.е.)	doll.	86,9	86,9	124,0	124,0	124,0	124,0	-	57,1	110,0	129,0	124,0
Factor of a discount		0,09	0,09	0,09	0,09	0,09	0,09	-	-	0,09	0,9	0,09

* The maximal (settlement) heating capacity of a HSS per the most cold five days. ** Maximal temperature of network water in the direct pipeline.
*** Same in the return pipeline of a network.

Table 3. Constructive and technological parameters of a HSS.

Parameters and indices	Units measurem.	Kaliningrad region		Yakutia		Kamchatka		Vologda region	Pskov region	Kost-roma region	Yaroslavl region	
		Devo-nian	Cam-brian	Vilyusk	Vuktil	Site 1	Site 2	Devo-nian	s. Palkino	city Buy	d. Me-dyagino	city Ribinsk
Diameter of bore-hole	м	0,2	0,2	0,1	0,15	0,1	0,1	0,2	0,15	0,2	0,2	0,15
Distance between bore-holes	м	1000	1000	300	250	250	200	750	500	600	400	350
Maximal pressure of a forcing	MPa	1,09	2,56	0,39	0,61	4,25	1,77	1,29	5,98	2,15	3,49	1,06
Maximal output of bore-hole	m^3/h	275,3	158,8	46,1	113,5	64,2	51,3	227,4	123,7	260,2	156,4	81,8
Temper. of the geothermal heat-carrier	^{0}C	39,0	67,2	100,9	52,8	104,5	131,0	47,8	47,5	51,4	52,6	24,0
Service life of the module of GCS	year	22,6	27,1	29,5	28,8	32,9	39,7	22,8	17,3	21,7	28,8	31,3

Table 4. Energy indexes of a GHSS.

Parameters and indices	Units measurem.	Kaliningrad region		Yakutia		Kamchatka		Vologda region	Pskov region	Kost-roma region	Yaroslavl region	
		Devo-nian	Cam-brian	Vilyusk	Vuktil	Site 1	Site 2	Devo-nian	s. Palkino	city Buy	d. Me-dyagino	city Ribinsk
Annual development of a heat	TJ/y	146,0	172,0	130,0	102,0	105,0	115,0	370,0	116,0	201,2	87,3	17,6
Annual saving of organic fuel	ths. t o.e.	6,26	7,39	5,58	4,4	4,5	4,94	15,9	4,97	8,65	3,75	0,76
Annual expenditure of the electric power	GWh/y	14,9	12,6	4,35	8,95	3,68	1,61	31,0	11,0	18,1	7,93	1,71
Conditional expenditure of fuel*	ths. t o.e.	5,07	4,3	1,48	3,04	1,25	0,547	10,5	3,73	6,17	2,69	0,58
Spec.Consum.of the elect.power on a GJ	kWh	102,4	73,5	33,5	87,4	35,2	14,0	83,9	94,8	90,2	90,6	97,4
Annual development of a heat of EB**	ths. t o.e.	1,83	1,55	0,535	1,1	0,45	0,198	3,8	1,35	2,23	0,97	0,21

* Conditional expenditure of fuel on a development of the electric power of a consumed GHSS on own needs.

** Annual development of a heat electrical boiler at the expense of the electric power of a spent GHSS on own needs.

Table 5. Economies indexes of a GHSS.

Parameters and indices	Units measurem.	Kaliningrad region		Yakutia		Kamchatka		Vologda region	Pskov region	Kost-roma region	Yaroslavl region	
		Devo-nian	Cam-brian	Vilyusk	Vuktil	Site 1	Site 2	Devo-nian	s. Palkino	city Buy	d. Me-dyagino	city Ribinsk
Investments on a GHSS	mill.doll.	2,40	2,81	3,66	2,77	2,15	1,39	9,9	1,12	2,49	1,25	0,89
The annual working costs	mill. doll.	1,02	0,89	0,747	0,842	0,468	0,315	3,39	0,41	1,25	0,373	0,29
Annual disbursement of the credit and %	ths. doll.	228	257	335	254	166	127	-	-	240	88	-
of the rate												16,48
The average cost price 1 GJ	doll.	6,99	5,17	7,28	8,25	6,36	4,97	9,16	3,53	6,22	7,74	0,92
Investments on alternate boiler-house	mill. doll.	3,0	3,0	5,93	3,95	3,95	3,95	12,1	1,62	4,09	2,18	18,26
The cost price 1 GJ from alternate B-H	doll.	7,46	7,46	11,51	10,73	10,64	10,64	10,73	4,18	7,77	9,45	1,11
C-t of an economic feasibility	-	1,21	1,63	1,58	1,30	1,67	2,14	1,17	1,18	1,25	1,22	0,09
NPV	mill. doll.	2,98	11,32	10,07	3,54	9,08	14,90	4,60	0,75	5,30	2,48	

REFERENCES

1. Богуславский Э.И. Технико-экономическая оценка освоения тепловых ресурсов недр. Высшая школа, Л., изд. ЛГУ, 1984,- 168 с.

2. Геотермальная технология низкопотенциальных высокоминерализованных пластовых вод. Разведка и охрана недр N 1, 1994. / Хахаев Б.Н., Певзнер Л.А. Самхан И.И., Богуславский Э.И., Шурчков А.В.

3. Development of geothermal resources of Moskow artesian basin. “Proceedings of the World Geothermal Congress”, 1995. Florence, Italy, 18-31 May 1995, Volume 1.- p.601-605. / Emil I. Boguslavsky, Anna B. Vaineblat, Lev A. Pevzner, Anatoly A. Smyslov, Bilat N. Khakhaev.

4. Дядькин Ю.Д. Разработка геотермальных месторождений. М., Недра, 1989.

5. Lund John W. Direct Utilization of Geothermal Energy. Проблемы использования геотермальной энергии. Международный симпозиум “Проблемы геотермальной энергии”, т. 3, 1995, с.3-23.

6. Mahler Allan. Geothermal Plant in Thisted, Denmark With Absorption Heat Pump. Проблемы использования геотермальной энергии. Международный симпозиум “Проблемы геотермальной энергии”, т. 3, 1995, с.34-40.

7. Sistems of geothermal supply on the base of low temperature aquifers of Moscow syneclise. “Geothermische Energie. Nutzung, Erfahrung, Perspektive.” Schwerin. 1994. / Emil I. Boguslavsky, Lev A. Pevzner, Igor I. Samkhan.

8. Богуславский Э.И. Методические принципы геолого-экономической оценки тепловых ресурсов недр. Экономический механизм рационального использования и охраны недр. АНХ СССР, М., изд. МГУ, 1980, стр. 91-94.

9. Boguslavsky E. I. The economy of utilization and potential of lov-temperature geothermal resources in the regions of the central Russia. "Groundwater and Geothermal Energy". Proceedings of Latvian-Danish seminar, Volume 3. Riga-Copenhagen, 1994 - 353 p.

10. Богуславский Э.И. Оценка технико-экономических параметров и показателей систем геотермального теплоснабжения в различных условиях России. Проблемы использования геотермальной энергии. Международный симпозиум “Проблемы геотермальной энергии”, т. 3, 1995, с.75-88.

11. Богуславский Э.И., Табаченко Г.С. Принципы бизнес-планирования на стадии технико-экономических обоснований геотермальных систем теплоснабжения. Сборник трудов аспирантов и студентов СПГГИ. Изд. СПГГИ, 1995.

12. Богуславский Э.И. Экономико-математическое моделирование систем извлечения и использования тепла Земли. Учебное пособие. Л., изд. ЛГИ, 1981.- 105 с.

13. Boguslavsky Emil. Economic-Mathematical Modelling ot Geothermal Circulation systems and Optimization of Their Parameters. “Proceedings of the World Geothermal Congress”, 1995. Florence,Italy, 18-31 May 1995, Volume 4.- p.2847-2851.