Energy efficiency improvement in geothermal district heating in Russia

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**Abstract.** This paper is dedicated to study of the efficiency of geothermal district heating systems of Russian localities exemplified by the present system of Mostovskoy settlement, Krasnodar Krai. It is deemed that the conditions under which the existing Russian space heating systems operate are generally unfavorable for the use of geothermal fluid for district heating needs. This is due to low local price for conventional fuel – natural gas, high value of heat carrier temperature specified for space heating systems, rigid environmental requirements and a lack of government support. An additional constraint imposed by the Mostovskoy geothermal field itself is the technical infeasibility of discharged geothermal carrier reinjection. Nevertheless, direct use of geothermal carrier for district heating was proven rather effective. Therewith, the water of Mostovskoy geothermal field has a health-giving effect, which makes its fluid desirable among the local population.

**1. Introduction**

Geothermal ground fluid is a valuable source of energy. It is traditionally utilized for health purposes. As a sustainable energy source, geothermal energy has been applied widely since the beginning of 20th century, gradually being involved in the energy balance of various regions. According to the Geothermal Energy Association, global geothermal power capacity by the end of 2016 totalled 12.7 GW [1].

Geothermal resources are generally classified into shallow geothermal resources, hydrothermal resources, and hot dry rock [2]. Geothermal fluid may have a temperature above 100°С, which enables its usage for district heating needs, as well as for generating electricity [3, 4].

The traditional geothermal system extracting groundwater from the reservoir is a widely used method to exploit the hydrothermal resource. The system generally consists of at least two vertical wells: one serves as the injection well and the other as the production well. However, this system assumes significant drilling and completion costs, which tends to increase with the number of wells. This hinders the large-scale development and exploitation of hydrothermal resources [2]. Therefore, an open loop geothermal system is preferred to maximize the performance of hydrothermal resources [5, 6].

China, USA and Sweden are the world leaders in installed thermal power capacity of geothermal heat supply systems. Russia also has significant reserves of geothermal resources, but there is a lack of government support to utilize their benefits. At present, geothermal heat supply systems operate mainly in the following regions of Russia: Dagestan, Krasnodar Krai, and Kamchatka [7]. The installed thermal capacity of geothermal systems is 300 MW with the generated thermal energy amounting to 1,700 GW h/year [4].

In the USSR period, geothermal energy was considered as a promising direction of the national economy and substantial efforts were made in this field. This includes more than 60 years of exploitation of geothermal resources and implementation of drilling operations for geothermal carrier production. It was found that numerous regions have hot geothermal carrier fields with the temperature from 50°C up to 200°C at depth from 200 to 3,000 m [8]. Currently, most of these wells are decommissioned, but some continue to operate. One of them serves as a source for the district heating system of Mostovskoy settlement of the Krasnodar Krai.

Mostovskoy settlement has gas and coal boiler plants, as well as geothermal heating sources built in the 1980s. Two wells (named as 4T and 5T) were drilled to conduct Mostovskoy residential space heating. 5T well has a dedicated boiler plant equipped with pumps and a storage tank. Geothermal carrier from 4T well with a flow rate of 1,500 m3/day and a temperature of 74°C is supplied to Boiler Plant-1 in the settlement central area. Estimated thermal capacity of this boiler plant I-st stage is 2 MW, the temperature of carrier is 70°C. The capacity of storage tanks is 600 m3 (2 pcs.).

In 1983, pressure at the 4T wellhead dropped to 30 m H2O with a corresponding decrease in production rate by 30%. In 1984, a cyclic capacity control was implemented to compensate for the shortage of geothermal carrier. At that, the heat supply system was modified to a semi closed-loop type with a periodic discharge of the cooled worked out geothermal carrier into a river and the simultaneous replenishment from the storage tanks.

The existing geothermal heating systems represent the simplest pattern of geothermal carrier utilization: fluid from the wells is fed directly to district heating systems of heated buildings. The heating fluid temperature is controlled manually. The present geothermal heating system has an open-loop design; the splitting of geothermal carrier flow to district heating circuits is provided within each building.

The present heat supply system has several disadvantages listed below.

* Geothermal carrier characteristics (temperature, pressure) in district heating systems of buildings, currently fed from geothermal wells, eventually fail to meet established temperature ratios, as well as Sanitary Regulations and Norms.
* Geothermal carrier fed to district heating systems contains a large amount of oxygen, mineral salts and admixtures, which aggressively effects metal pipelines, fittings, heating and sanitary appliances, leading to a high level of corrosion and clogging.
* Geothermal carrier with a temperature lower than required for district heating systems, but still relatively high, is being discharged onto relief or into a river in a manner that does not comply with the current environmental legislation, so the relevant sanctions may be imposed at any time.

From the moment of commissioning, the pressure at the wellhead is constantly decreasing, due to the gradual depletion of aquifer. Thus, according to logged data for the first decade of operation, the pressure decreased from 8 to 4 atm. At similar geothermal facilities, reinjection wells are widely used for pumping geothermal carrier back into aquifer. However, the efforts to implement this method at the Mostovskoy settlement have not yielded favorable results, apparently due to characteristics of aquifer earth material. Therefore, it is safe to assume that with the intensive consumption of geothermal carrier within the given scenario, the pressure at the wellheads will continue to drop. At a pressure below 2 atm the use of geothermal carrier for heating may not be feasible. This is due to the presence of suspended solids and gas bubbles inevitable in a given mode of well operation. This circumstance exposes utilities to serious commercial risk. At a certain point in time, they will not be able to continue operating the geothermal heating system and maintaining the obligations of heat supply to connected consumers. The commercial problem for utilities is that the wells are the private property. The owner is a local monopolist of geothermal carrier source wells. The prices set by wells owner make this type of heat supply concept approximately economically equal to the one based on gas boiler plants. Should he increase the price unilaterally, this will surely make the operation of geothermal heating system inappropriate. Furthermore, the present Mostovskoy geothermal heating systems represent an open-loop approach to the domestic hot water supply. In addition, according to the law No. 190-FZ "On Heat Supply" dated July 27, 2010, any open-loop domestic hot water system to be transferred to a closed-loop design.

Given the difficulties experienced by utilities operating geothermal heating system, options for modernization of the existing system using various technologies were considered.

2. Materials and methods

The following alternatives for heating system can be considered.

* Direct utilization of geothermal carrier for district heating needs (present concept to be modernized).
* Direct utilization of geothermal carrier for district heating needs followed by a cooled fluid reinjection back to aquifer through some new-drilled wells.
* Utilization of geothermal carrier in absorption heat pumps.
* Complete shift to gas boiler plants.

The model for calculating the economic efficiency of abovementioned options regarding the given conditions is as follows.

## 2.1. Calculation of a direct use of geothermal carrier in district heating systems

Actual specific consumption of geothermal carrier by heating system of Mostovskoy settlement, *VGC*, equals 49 m3/Gcal. This is due to the fact that the potential of geothermal carrier is not fully utilized for it is cooled down by no more than 20°С (the initial temperature is 95°C), and then the worked out carrier is discharged into a river while having a sufficiently high temperature. Operating on smaller temperature levels may substantially increase the effectiveness of geothermal heating system.

The cost price of heat for space heating needs and for compensation of heat losses in the domestic hot water loops, obtained from geothermal carrier, *PGC*, USD/Gcal, is calculated in equation (1).

|  |  |
| --- | --- |
|  | (1) |

where

*C*GC – price for geothermal heating set by the owner of the well, *C*GC = 0.24 USD/m3.

## 2.2. Calculation of a direct use of geothermal carrier for domestic hot water needs

The cost of hot water supplied for domestic needs would not exceed the cost of geothermal carrier (0.24 USD/m3), since the temperature value of carrier pumped from the well is higher than the one required for the domestic hot water system. The geothermal carrier from Mostovskoy geothermal field is low-mineralized, almost free from hydrogen sulfide component, and has a confirmed therapeutic effect. The locals willingly use it for domestic and hygienic needs. Those are the reasons for feeding of geothermal carrier directly to consumers.

## 2.3. Calculation of a cost price of heat from new drilled wells

In the Mostovskoy settlement, as the cost of geothermal carrier was solely determined by the owner of the wells, it would be rational to calculate the expense for drilling and construction of the new well. The depth of the wells in the area should be about *L*WELL = 2 km, the capital expenditure for deep drilling *CAPEX*WELL = 0.29 thous. USD/m. In case of drilling a new geothermal well, the cost of heat received from it is calculated in equation (2).

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| --- | --- |
| , | (2) |

where

*CAPEX*PUMP – capital expenditure for pumping station, *CAPEX*PUMP = 0.89 thous. USD/m3;

*CRF* – capital return factor, %, to be calculated in equation (3):

|  |  |
| --- | --- |
| , | (3) |

where

*d* – cost of capital, *d* = 12%;

*n* – equipment operational life span, *n* = 25 years.

The further calculations will be based on the price of geothermal carrier obtained from new wells.

## 2.4. Calculation of a cost price of heat from new drilled wells with reinjection of discharged geothermal carrier back into aquifer

The reinjection technology assumes drilling two wells – one for production, and one for reinjection (intended for pumping discharged geothermal carrier back into aquifer). This doubles the capital expenditure for constructing a heat supply system. To overcome aquifer pressure (about 80 m H2O), the value of reinjection over-pressure should be *H* = 100 m H2O given the pump efficiency *η* = 0.7. Consequently, the electricity consumption is calculated in equation (4).

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| --- | --- |
| . | (4) |

*2.5. The aspects of using the heat pumps*

The capital expenditure of absorption heat pump is 210 USD/kW. According to [9], when generating heat, an absorption heat pump can receive up to 33% of power from geothermal carrier, the remaining 67% should be provided by the heat of fuel combustion. Thus, energy consumption per 1 Gcal of supplied heat would be 102 kg of fuel equivalent/Gcal and 5 m3 of geothermal carrier (being cooled from 80°C to 20°C), maintaining the temperature of 70°C in domestic hot water supply system.

*2.6. Calculation of an alternative cost price of heat produced by the gas boiler plants*

The cost price of heat produced via gas boiler plants is calculated in equation (5).

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| --- | --- |
| , | (5) |

where

*C*GAS – natural gas price, *C*GAS = 0.08 USD/norm. m3;

*CONS*GAS – specific gas consumption for heat generation via boiler plant, *CONS*GAS = 154 kg of fuel equivalent/Gcal;

*CAL* – heating value of natural gas, CAL = 8,100 kcal/norm. m3;

*CAPEX*BOIL – capital expenditure for construction of a gas boiler plant, *CAPEX*BOIL = 89.33 thous. USD/Gcal/h.

The cost price of hot water for hygienic needs is calculated in equation (6).

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| --- | --- |
| , | (6) |

where

*t*1 – hot water temperature, *t*1 = 60°С;

*t*2 – cold water temperature, *t*2 = 5°С;

*C*CW – cold water price, *C*CW = 0.40 USD/m3.

3. Results

The costs of various options considered for space heating needs are shown in table 1.

**Table 1.** Estimated costs of various options for district heating needs in Mostovskoy settlement.

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| --- | --- | --- | --- |
| Pos. | Type of system | Costs | |
| District heating, USD/Gcal | Domestic hot water, USD/m3 |
| 1 | Direct supply of geothermal carrier – present geothermal heating system | 11.56 | 0.24 |
| 2 | Direct supply of geothermal carrier – new geothermal heating system | 17.07 | 0.35 |
| 3 | Direct supply of geothermal carrier – new geothermal heating system with reinjection | 32.96 | 0.67 |
| 4 | Gas boiler plants system | 16.31 | 1.30 |
| 4.1 | Gas boiler plants system in terms of Europe\* | 47.18 | 2.99 |
| 5 | Geothermal heating system with absorption heat pump | 16.51 | 1.31 |

\* Regarding 0.2 USD/m3 fuel cost and 50 USD/tonne carbon tax.

4. Discussion

In compliance with Russian environmental standards, the temperature of fluid discharged into basins shall not significantly exceed the temperature of their own water. The discharged geothermal carrier should therefore have a temperature of about 20°C, which is not practically achievable in Russian high-temperature space heating systems.

The concept with heat pumps for cooling discharged fluid down to the temperature stipulated was once developed and successfully implemented for the Mostovskoy geothermal heating system back at the original project phase. However, subsequently, the heat pumps were dismantled, as they went out of service, and the geothermal heating system continued operation in its currently existing design.

When reviewing options for the new heat supply system concept, it was taken into account that the Mostovskoy settlement has sufficient gas boiler plants coverage, so the natural gas could be supplied at any point.

The calculation given in previous section made it possible to detect and compare the most technically and economically realistic options.

Comparing the cost of heat supplied for district heating needs from equation (2) – 17.07 USD/Gcal, and for domestic hot water needs – 0.35 USD/m3 with the owner-set cost (11.56 and 0.24, respectively), it can be concluded that the current price of geothermal carrier is not overstated.

The cost of heat supplied for district heating needs from equation (2) for the case of drilling a new geothermal well and reinjection of discharged geothermal carrier back into aquifer, regarding electricity consumption from equation (4) (*E* = 0.39 kWh/m3), will be 32.96 USD/Gcal – twice as high as preferable value. Additionally, as mentioned above, studies conducted back in 1980s showed that reinjection into the aquifer of Mostovskoy settlement is practically infeasible due to geological reasons, though it is common in other geothermal fields.

The cost of heat generated via absorption heat pumps for district heating would be 16.51 USD/Gcal, for domestic hot water needs – 1.31 USD/m3, which makes this concept competitive in terms of Russia and highly preferable when implemented in terms of Europe, when compared to natural gas system. The best solution for the efficient use of geothermal carrier would be a lithium bromide absorption heat pump [10]. This is also essential for providing a deeper cooling of discharged fluid down to a temperature specified by the norm (20°C).

The cost of 16.31 USD/Gcal can be taken as retail price for heat supply in studied system configuration.

5. Conclusion

The set of conclusions upon the study is as follows.

* For environmental reasons, the use of geothermal carrier for heating needs is viable either with heat pumps integrated to the system, or with the reinjection technology implemented (which is not applicable for Mostovskoy settlement).
* The economic dimension of operation of geothermal heating system with integrated heat pumps for space heating needs in Russia is about the same as gas heating. Thereupon, the latter option is more preferable for practical implementation given the complexity of construction of geothermal system with heat pumps compared to further development of a gas boiler plants system.
* The integration of reinjection technology to the present geothermal system would have increased the costs.
* Direct use of geothermal carrier for domestic hot water needs shows high economic efficiency, environmental friendliness and probable customer satisfaction.
* The studied status of Mostovskoy settlement geothermal heat supply system reflect the typical situation in this industry in Russia nowadays, so the conclusions above may be scaled up at the country level.
* With the European cost of fuel and carbon tax, geothermal heat supply under studied conditions can be highly efficient.

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