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Creation of a complex for the production of heat and electric power based on the geothermal waters of the Zharkent depression

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Abstract. The object of this study is renewable energy sources in the Republic of Kazakhstan, with an emphasis on the geothermal resources of the Zharkent field. Geothermal energy is a promising direction in ensuring energy independence and sustainable development, especially in the context of the need to decarbonize the economy and reduce dependence on fossil fuels. The objective of this work is to develop and scientifically substantiate an integrated complex for the production of heat and electricity based on the geothermal resources of the Zharkent field. The study included an analysis of the hydrogeothermal characteristics of the field, an assessment of the energy potential of existing geothermal wells, and a selection of the most efficient technologies, including binary geothermal units, heat pump systems and direct heat supply systems. A feasibility study of the proposed solutions was carried out considering the climatic, geological and infrastructural features of the region. The research results can be applied in the development of pilot projects in the field of geothermal energy, as well as within the framework of the state strategy for the transition to a «green» economy. The proposed complex is capable of increasing the energy sustainability of the Zhetysu region and becoming an example for the implementation of similar solutions in other regions of Kazakhstan.

Keywords: *Zharkent depression, geothermal waters, geothermal technology park*.

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1. Introduction

Geothermal energy resources, like other types of renewable energy sources, make it possible to satisfy virtually any consumer in terms of energy potential and quality. However, in economic terms, they can only compete with non-renewable energy resources in the area of electricity production and meeting medium and low potential heat needs. In the future, it is expected that geothermal resources will be widely used for the extraction of rare earth metals and gases, the production of biomass for agriculture, thermal processing of oil horizons, and so on [1-4].

The scope of application and efficiency of using geothermal energy resources of a particular field depend on their energy potential, total reserves and well flow rates, chemical composition, mineralization and aggressiveness of water, the presence of a consumer and its remoteness, temperature and hydraulic regimes of wells, the depth of aquifers and their characteristics, as well as a number of other factors [5-8].

Therefore, exploitation of geothermal sources should be based on prior geological investigation in order to avoid significant financial risk in the event of further capital expenditure. In order to determine whether a particular location has the potential to supply geothermal heat for industrial and domestic needs, a preliminary search is necessary. This feature is one of the main differences between geothermal energy and other renewable energy sources [9-12].

Nowadays, geothermal energy is used in two main directions - heat supply and generation of electrical energy. A number of technologies and efficient equipment have been developed for obtaining both thermal and electrical energy separately and for their combined production [13-15]. In the Russian Federation, combined schemes are being developed for using geothermal sources [16-20] as a heat carrier for heating water at thermal power plants, which provides quite noticeable savings in organic fuel and increases the efficiency of converting low-potential energy. Such combined schemes allow the use of heat carriers with initial temperatures of 70-80ºC for the production of electricity, which is significantly lower than those currently accepted (150ºC and higher) [11-12].

At the St. Petersburg Polytechnic Institute, hydro-steam turbines have been created, the use of which at a geothermal power plant (GeoTPP) will allow an increase in the useful capacity of double-circuit systems (second circuit - water vapor) in the temperature range of 20...200ºC by an average of 22% [4-6].

The efficiency of thermal waters is significantly increased when used in combination. At the same time, in various technological processes it is possible to achieve the most complete realization of the thermal potential of water, including the residual one, and also to obtain valuable components of water (iodine, bromine, lithium, cesium, table salt, Glauber's salt, boric acid and many others) for their industrial use.

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Technical and economic analysis shows that with modern technology for extracting subsurface heat, systems with a borehole depth of up to 3 km are economically justified. The thermal potential of 90% of geothermal waters at this depth does not exceed 100ºC. In this case, geothermal heat supply is predominant, as a result of which the replacement of organic fuel is greater than in the production of electricity [1-10].

2. Materials and methods

The Zharkent geothermal basin is located in the southeast of Kazakhstan, in the Almaty region, near the city of Zharkent, not far from the border with China. Geographically, it is located within the Ili depression, at the foot of the Zhungar Alatau ridges. This region is characterized by active tectonics, high geothermal anomalies and the presence of thermal water outlets, which makes it promising for the development of geothermal resources for both heat supply and balneological use and possible electricity generation [1-2].

There are several wells located in the Zharkent geothermal basin that are of interest for use as an energy source [1-2]. At the first stage, two promising geothermal wells were identified – 1PT and 3T (Figure 1), for which research was conducted on obtaining heat and electricity [2].

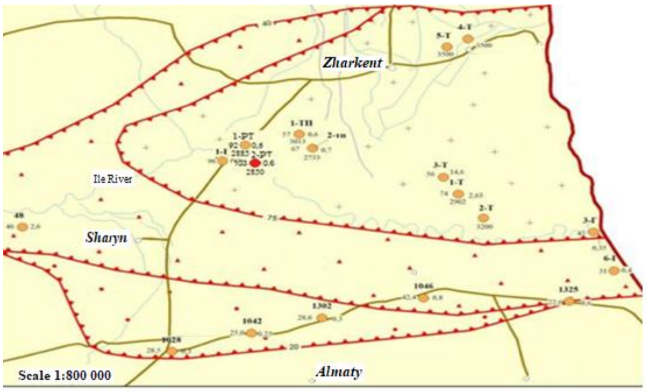

Figure 1. Location of thermal wells in the Zharkent depression

The wells are located 45 km apart and have the same flow rate of 40 kg/s. The water temperature in well 1PT is 92°C, and in well 3T it is 66°C. Both wells penetrate thermal horizons at depths of 1200 to 1800 m within the Zharkent geothermal basin. The reservoirs are represented by fractured sedimentary and volcanogenic-sedimentary rocks. The waters are characterized by medium mineralization (up to 2 g/l) and are of the hydrocarbonate-sodium type. Temperature differences are probably due to the heterogeneity of the geothermal gradient and the depth of the aquifers. The wells are intended for use in heat supply and balneology.

The temperature of geothermal waters in the Zharkent field (from 66°C to 92°C) is considered insufficient for traditional steam turbine plants operating on water vapor. In such conditions, the most effective solution is the use of binary geothermal technology. The essence of binary technology is the use of two working environments (geothermal water and organic working fluid).

Stages of the process flow chart:

1. Supply of geothermal water from the well to the heat exchanger;
2. In the heat exchanger geothermal water heats the secondary liquid which evaporates;
3. Vapors of the organic liquid are fed to the turbine where they rotate the generator and generate electricity;
4. After leaving the turbine the steam cools and turns back into liquid in the condenser closing the cycle;
5. Condensed working fluid returns to the heat exchanger;
6. The spent thermal water is either reused for heating or returned to the reservoir through injection wells (reinjection) which minimizes the environmental impact.

Chemical analyses were carried out according to the scheme of mineral waters. The analysis of the chemical composition of geothermal waters was carried out according to the methods adopted for the classification and assessment of mineral waters, both for drinking and balneological use [2-5].

The purpose of this study is to investigate the possibility of complex (cascade) development of the thermal energy potential of two wells of the Zharkent geothermal field. The main topic of the study is a comparative analysis of the two well options, as well as a brief overview of the chemical composition and possible limitations that may be imposed on the technological process.

Selection and justification of optimal technologies for the production of electricity and heat based on existing geothermal wells of the Zharkent geothermal water field.

For low enthalpy wells such as 3T and 1PT, connecting them by pipeline will not be justified, the pressure and temperature losses over such a distance will outweigh any increase increase in net energy production, in relation to the cost of pumping and the cost of pipelines.

3. Results and discussion

The temperature of the reservoir in the Zharkent field is too low to support the operation of a conventional geothermal power plant. The only practically feasible option for producing electricity from a geothermal flow with a temperature of 70-96°C is binary technology [5, 15].

In recent decades, the production of electricity using binary cycle technology has become increasingly popular. This technology is reliable and has virtually no impact on the environment, and in addition, it allows the use of liquids from less hot thermal sources by heating the working fluid with a lower boiling point (Figure 2).

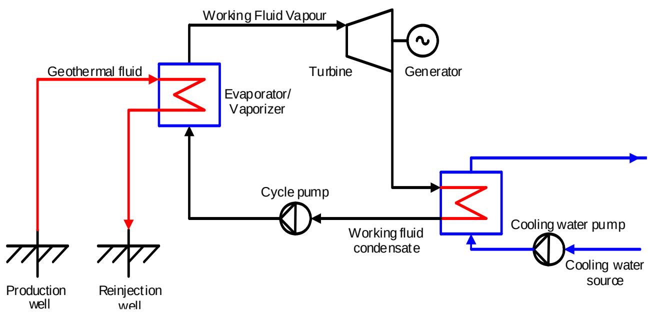

Figure 2. Scheme of electricity production using binary technology

Binary technology is generally divided into two categories: the Organic Rankine Cycle (ORC) and the Kalina Cycle. Since the Kalina cycle is more preferable for geothermal fluid with a temperature of 100-140ºC, it was not considered further. ORC technology is the most common form of power generation from low enthalpy reservoirs [6].

The first observation was to model the 1PT well in a system for maximum power production. In addition, a heating plant was added as a waste heat recovery unit, using waste heat from electricity production. Initially, it was obvious that these two wells could not simultaneously provide both maximum electricity production and sufficient heat supply, however, the waste heat could be used as a base load for district heating or for other purposes with the addition of an oil/gas/coal fired water heater, or for hot water supply for a swimming pool, spa, or other low temperature applications.

The available maximum geothermal energy under different conditions is shown in Table 1.

Table 1. Maximum heat extraction from geothermal water

Name	Well 1 PT with max. electric energy production	Well 1PT without power generation	Well 3T
T at the entrance, °C	62	92	70
T at outlet, °C	40	40	40
Flow rate, dm^3/s	40	40	40
Thermal power, kW	3.681	8.714	5.02

Each well has its own technological scheme for providing heat to the district heating network.

Well 1PT is capable of providing heating water at a temperature of 75ºC without using a post-heating boiler. Figure 3 shows a diagram for maximum heat supply to the district heating network from well 1PT, where the calculated supply temperature is 75ºC.

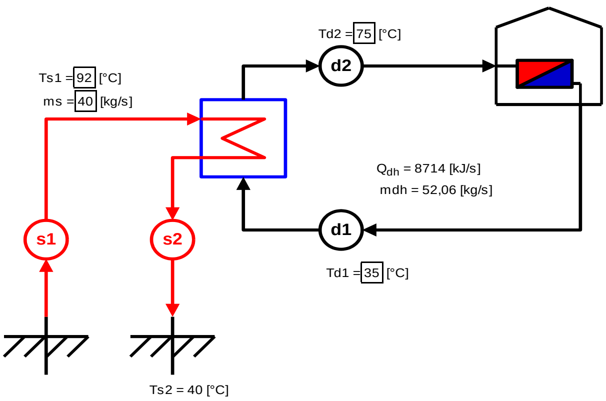

Figure 3. Technological scheme of thermal energy production from well 1PT

However, due to the extremely high demand on cold days, it will certainly be more economical to install a secondary heating boiler. There are two ways to use a secondary heating boiler in a heating system:

– to increase the temperature above 75ºC when necessary.

– when the flow in the network is increased, use the boiler to maintain the supply temperature at 75ºC.

Figure 4 shows a diagram for maximum heat supply to the district heating network from well 3T. A secondary heating boiler must be added to the system as the geothermal water temperature is 70ºC.

The power that can be extracted from a geothermal source depends largely on the heating system used. For example, if a room has 90/70ºC type systems installed, the geothermal energy utilization will be much less. On the other hand, using a geothermal resource for other uses (non-heating) will result in increased energy extraction.

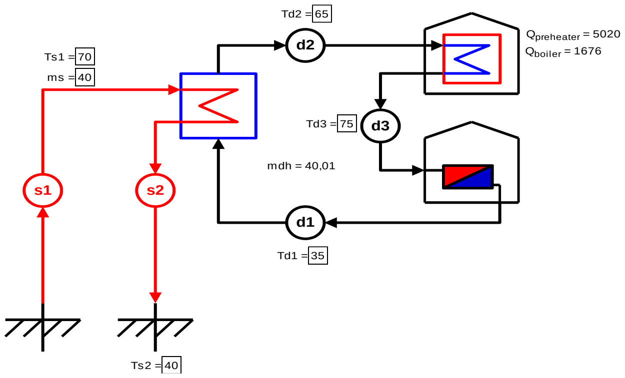

Figure 4. Technological scheme of thermal energy production from well 3T

If domestic hot water is supplied by a system, it is estimated that 10% of the total mass flow will be required.

Vegetables, fruits, spices and flowers are the most common species grown in greenhouses heated using geothermal energy. The optimal growing temperature depends on the plant species, for example, tomatoes are grown at a temperature of 20-21ºC, roses at a temperature of 20-25ºC. The design load of greenhouses is calculated based on a set of requirements for air temperature, natural cooling, lighting and air conditioning. This needs to be further investigated considering detailed information regarding weather conditions, the number of daylight hours, and the plant species grown [6].

The use of geothermal energy in hydrotherapy and other bathing establishments is very effective. The water in swimming pools often has a temperature of 26-29ºC, and in baths 38-42ºC. The heat load for geothermal energy use therefore depends on many factors such as conductive and convective heat exchange and heat transfer between the pool and the environment. Outdoor air temperature, evaporation rate, precipitation, system type (closed or other) also play an important role in this design.

The determination of the thermal energy and hydrogeodynamic potential of thermal waters was based on the study of hydrogeological and geothermal data. Based on the available factual materials on geology, hydrogeology and geothermy, an assessment of regional and operational reserves of thermal waters is given below [9, 11].

Natural heat reserves should be understood as heat contained in groundwater, and operational reserves should be understood as the amount of heat that can be obtained by a technically and economically rational reservoir structure under a given mode during the entire estimated service life [7].

Natural heat reserves of thermal waters are determined based on natural reserves and average temperature (Table 2).

Table 2. Calculated parameters and natural heat reserves of thermal waters of the Zharkent basin

Age of water-bearing rocks	Natural reserves of thermal waters, billion m^3	Estimated temperature, °C	Natural heat reserves, 10^{12} calories
Neogene	86.9	15	1303.5
Paleogene	26.7	35	934.5
Cretaceous	54.1	50	2705
Jurassic	37.7	60	2262
Triassic	42	75	3150
Total			10355

Regional exploitable heat reserves of thermal waters are determined based on Regional exploitable reserves and average temperature as shown in Table 3.

Table 3. Regional exploitable heat reserves of the Zharkent basin

Age of water-bearing rocks	Regional operational reserves, m^3/day	Estimated temperature, °C	Operating heat reserves, 10^3 kcal/day
Neogene	368452.3	15	5526784.5
Paleogene	210836.6	35	7379281
Cretaceous	108164.5	50	5408225
Jurassic	63344.6	60	3800676
Triassic	68049.1	75	5103682.5
Total			27218649

The carrier of geothermal energy is underground water, which compares favorably with all types of energy raw materials due to its widespread occurrence, constant renewability, large reserves, accessibility of obtaining it using modern technical means and the possibility of their comprehensive use.

To generate electricity, a steam-water mixture with a temperature of over 100ºC is used.

Using heat pumps with low energy consumption, water with a temperature of 30-40ºC can be heated to a high temperature suitable for heating, and vice versa, water with a temperature of 70-90ºC can be used to obtain artificial cold in absorption refrigeration machines [8].

The thermal energy productivity of geothermal wells 1-PT and 3-T is determined by the formula:

$$G = 365 \cdot Q \cdot c \cdot \gamma_g \cdot \left(T_m - T_f\right) \cdot 10^{-6}, \qquad (1)$$

where G heat energy productivity, Gcal/year; Q is water flow rate, t/day; c is specific heat capacity of water, 1000 kcal/tºC; γ_g is water density during well operation, t/m^3; T_m is water temperature at the wellhead, ºC; T_f is final temperature after use, ºC.

For well 1-PT G is equal to 74.17×10^3 Gcal/year. For well 3-T G is equal to 35.64×10^3 Gcal/year.

The total thermal capacity of the two wells is therefore $G_{total} = 109.81\times10^3$ Gcal/year.

This value is equivalent to the combustion of more than 16 thousand tons of standard fuel per year.

Thus, the calculations show that the total thermal energy productivity of wells 1-RT and 3T is 109.81 thousand Gcal/year, which is equivalent to burning more than 16 thousand tons of standard fuel per year. This confirms the high energy potential of the Zharkent geothermal field, sufficient for local heat supply and partial electrification of facilities, as well as for organizing balneological and agro-industrial complexes. Given the high degree of resource sustainability, low greenhouse gas emissions and low operating costs, the use of geothermal energy in this region is a popular area of sustainable energy development. The introduction of binary power plants and heat pumps further expands the possibilities of efficient utilization of low-potential heat. All this makes the Zharkent field a promising object for the implementation of projects within the framework of green energy in Kazakhstan.

4. Conclusions

This article presents the results of a preliminary justification of the possibility of complex (cascade) development of the thermal energy potential of two wells of the Zharkent geothermal field in the Almaty region of the Republic of Kazakhstan.

The wells are ready for operation and require limited restoration work. The cost of drilling a well usually accounts for 50-60% of the cost of a power plant, but in this case, it is not considered. The distance between wells makes it difficult to use them together for economic reasons.

In this paper, two options for using these wells were studied:

1. The maximum power generation for well 1PT, W_{clean} = 265 kWe. Well 3T does not meet the requirements for generating electricity from a geothermal power plant, the water temperature is very low. But thanks to the high pressure, it is possible to obtain electricity from micro hydroelectric power plants. By adding a waste heat recovery unit to the power plant at well 1PT, it is possible to produce 3.7 MW of thermal energy from waste heat after electricity generation.
2. The maximum production of thermal energy without electricity for district heating needs or other applications is 8.6 MW (thermal energy) and 5 MW (thermal energy) for wells 1PT and 3T, respectively.

The first option can be practically implemented with an internal rate of return on investment in 10 years. Also, when adding a waste heat recovery unit to feed the district heating network, the internal rate of return on investment will be 270% for such a unit separately, since it can be used to preheat water for the district heating system (the costs of the afterheating boiler, heating main and district heating system are not taken into account).

The practical implementation of the second option is possible with an internal rate of return on investment in the range of 270-333% after 10 years of operation. Both alternatives are practically feasible. Electricity production has a slower payback period but is feasible from an environmental perspective.

Thermal energy production is a very profitable option when used as a base load preheating element for a district heating system. In the Zharkent depression, several promising areas have been identified that meet the parameters for their practical use: Usekskaya, Priiliyskaya, Neftebaza.

Author contributions

Conceptualization: MKA, VDV, DKA; Data curation: MKA, VDV; Formal analysis: DKA, VDV; Funding acquisition: MKA; Investigation: AMB; Methodology: VDV; Project administration: MKA; Resources: VDV; Software: AMB; Supervision: MKA; Validation: AMB; Visualization: VDV, AMB; Writing – original draft: VDV; Writing – review & editing: DKA. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Жаркент бойының геотермалдық суларының негізінде жылу және электр энергиясын өндіру кешенін құру

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Аңдатпа. Бұл зерттеу объектісі Жаркент кен орнының геотермалдық ресурстарына баса назар аудара отырып, Қазақстан Республикасындағы жаңартылатын энергия көздері болып табылады. Геотермалдық энергетика – энергетикалық тәуелсіздік пен тұрақты дамуды қамтамасыз етудің перспективалық бағыты, әсіресе экономиканы декарбонизациялау және қазба отындарына тәуелділікті азайту қажеттілігі жағдайында. Бұл жұмыстың мақсаты Жаркент кен орнының геотермалдық ресурстары негізінде жылу және электр энергиясын өндірудің кешенді кешенін әзірлеу және ғылыми негіздеу болып табылады. Зерттеу кен орнының гидрогеотермиялық сипаттамаларын талдауды, қолданыстағы геотермиялық ұңғымалардың энергетикалық әлеуетін бағалауды және бинарлы геотермиялық қондырғыларды, жылу сорғы жүйелерін және тікелей жылумен жабдықтау жүйелерін қоса алғанда, ең тиімді технологияларды таңдауды қамтиды. Аймақтың климаттық, геологиялық және инфрақұрылымдық ерекшеліктерін ескере отырып, ұсынылған шешімдердің техникалық-экономикалық негіздемесі жасалды. Зерттеу нәтижелері геотермалдық энергетика саласындағы пилоттық жобаларды әзірлеуде, сондай-ақ «жасыл» экономикаға көшудің мемлекеттік стратегиясы аясында қолданылуы мүмкін. Ұсынылып отырған кешен Жетісу өңірінің энергетикалық тұрақтылығын арттыруға және Қазақстанның басқа аймақтарына ұқсас шешімдерді енгізуге үлгі болуға қабілетті.

Негізгі сөздер: *Жаркент ойпаты, геотермалдық сулар, геотермалдық технопарк.*

Создание комплекса производства тепловой и электрической энергии на основе геотермальных вод Жаркентской впадины

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Аннотация. Объектом настоящего исследования выступают возобновляемые источники энергии в Республике Казахстан, с акцентом на геотермальные ресурсы Жаркентского месторождения. Геотермальная энергия представляет собой перспективное направление в обеспечении энергетической независимости и устойчивого развития, особенно в условиях необходимости декарбонизации экономики и снижения зависимости от ископаемых видов топлива. Целью данной работы является разработка и научное обоснование интегрированного комплекса по производству тепловой и электрической энергии на основе геотермальных ресурсов Жаркентского месторождения. В процессе исследования проведен анализ гидрогеотермальных характеристик месторождения, оценен энергетический потенциал существующих геотермальных скважин, а также осуществлён выбор наиболее эффективных технологий, включая бинарные геотермальные установки, теплонасосные системы и системы прямого теплоснабжения. Проведено технико-экономическое обоснование предложенных решений с учётом климатических, геологических и инфраструктурных особенностей региона. Результаты исследования могут быть применены при разработке пилотных проектов в сфере геотермальной энергетики, а также в рамках государственной стратегии перехода к «зелёной» экономике. Предлагаемый комплекс способен повысить энергетическую устойчивость Жетысуской области и стать примером для внедрения аналогичных решений в других регионах Казахстана.

Ключевые слова: *Жаркентская впадина, геотермальные воды, геотермальный технопарк.*

Publisher’s note