Research Article

Seitzhan Orynbayev, Amanzhol Tokmoldayev, Nazym Abdlakhatova*, Aizhan Zhanpeisova and Issakul Tumanov

Improving power plant technology to increase energy efficiency of autonomous consumers using geothermal sources

https://doi.org/10.1515/ehs-2023-0082
Received July 6, 2023; accepted October 8, 2023;
published online November 15, 2023

Abstract: The significance of this study is underscored by the immense potential of binary power plants in the contemporary world. These plants have a pivotal role to play in supplying heat to homes, facilitating greenhouse heating, and supporting air conditioning systems. The purpose of the study is to provide recommendations on eliminating errors in the processes of improving and implementing geothermal plants and analysing their functioning during electricity generation. The analytical method, classification, functional, statistical, synthesis, and others should be noted among the methods used. The features of geothermal plants in Kazakhstan were noted, their differences were analysed, and errors that are made during the operation of power plants to increase the energy efficiency of consumers and the causes of errors were analysed. Uncertainties in the development and their impact on the functioning of geothermal power plants were identified. The practical value lies in the application of the identified results, solving errors in the development and implementation of a binary power plant to improve the energy efficiency of consumers, the reliability of the use of geothermal plants in the region, considering various factors, which will help provide recommendations for the appropriate use of the mechanism.

***Corresponding author: Nazym Abdlakhatova**, Department of Energy Saving and Automation, Kazakh National Agrarian Research University, 050010, 8 Abai Ave., Almaty, Republic of Kazakhstan,
E-mail: nazymabdlakhatova@gmail.com
Seitzhan Orynbayev and Aizhan Zhanpeisova, Department of Electric Power Engineering, M.Kh. Dulaty Taraz Regional University, 080000, 7 Suleymenov Str., Taraz, Republic of Kazakhstan
Amanzhol Tokmoldayev, Department of Energy Saving and Automation, Kazakh National Agrarian Research University, 050010, 8 Abai Ave., Almaty, Republic of Kazakhstan
Issakul Tumanov, Department of Thermal Physics and Technical Physics, Al-Farabi Kazakh National University, 050040, 71 Al-Farabi Ave., Almaty, Republic of Kazakhstan

Keywords: geothermal station; energy resource; thermal waters; heating; construction

1 Introduction

In Kazakhstan, most thermal springs contain water of moderate, medium temperature, ranging from 40 to 800 °C. If the temperature of the water from underground is less than 100 °C at an economically acceptable depth, then it will require the construction of a complex binary geothermal station, the cycle of which was invented in the USSR, based on a patent (as a basic one) for obtaining electricity from hot water with a temperature of more than 80 °C (Babak and Kovtun 2019). In this process, the liquid from the well is not supplied to the turbine in any form at all. Instead, another working fluid with a lower boiling point is heated in the heat exchanger, which, turning into steam, spins the turbine, condenses, and returns to the heat exchange chamber (Fialko et al. 1994). Problems in geothermal plants are some errors at the stage of development and during the operation of this facility, this is conditioned by the issues of determining and optimising indicators at the stages of design, operation, development, and also by the increasing demand of consumers for cheap electricity supplies.

The purpose of this study is to perform an objective analysis to identify problems and errors in the process of improving the technological regime of a binary power plant to increase the energy efficiency of autonomous consumers and in the operation of geothermal plants at the current stage of development of this mechanism. The implementation of this task will provide an opportunity for the progressive development of effective and innovative ways of generating electricity using geothermal sources, and to minimise errors in this process. In order to address some of the issues of providing electricity to off-grid consumers in Kazakhstan in particular, and especially through geothermal sources in southern Kazakhstan, advanced and innovative geothermal plants need to be introduced to ensure the timeliness and quality of electricity supply.

Kazakhstan boasts substantial geothermal resources characterized by medium and low-temperature geothermal water, primarily located within several of its deep sedimentary basins. These resources have been substantiated by the drilling of wells, primarily for petroleum exploration purposes, which have encountered permeable structures yielding hot water. These geothermal assets hold promise for district heating applications. Presently, the Kaplanbek geothermal field, situated near the city of Chimkent, harnesses water with a temperature of 80 °C to provide heat to residential buildings. Similarly, in the vicinity of Almaty, a geothermal source with temperatures ranging from 80 to 120 °C serves the purpose of heating greenhouses during the winter and facilitating air conditioning in the summer. Despite its substantial potential, Kazakhstan has yet to tap into geothermal resources for electricity generation. Nonetheless, the nation possesses ample opportunities for more extensive utilization, which could significantly contribute to achieving established renewable energy targets (Geothermal Power in Kazakhstan 2021).

According to Piralishvili and Veretennikov (2011), to cover the increase of perspective need in power and electrical energy, the development of power plants in Kazakhstan is planned in such areas such as technical re-equipment and modernisation of the equipment of operating power plants, the introduction of innovative capacities at operating power plants, design and implementation of perspective power plants, for example, geothermal power plants, which facilitates the involvement of clean and renewable resources into operation.

As stated by Moldazhanov et al. (2022), in all Central Asian countries there are problems of increased fatigue of production capacities and critical infrastructure, increased energy intensity of production and communal services, and high financial and technical losses. However, by now, most countries are concerned about the increased energy intensity within the country, which is increased in contrast to other developed countries. At the moment, governments have considered the importance of designing and implementing the national policy in the energy saving sector, and plans are being developed to introduce more productive geothermal plants (Çera 2022). Dzhumabaev, Serokhvostov, and Klimenko (2020) report the presence of special reserves of hydrocarbon resources in Kazakhstan is not considered as an obstacle to the progressive use of unconventional energy resources in the country, especially thermal springs.

Turdybekov (2022) notes that according to the features of the progressiveness of energy in Kazakhstan, unconventional energy resources will be leading in the near future, among which thermal springs and geothermal stations can be highlighted. According to Zhumanov et al. (2022), at the moment, at the production facilities in Kazakhstan that have a technical need for electricity all year round, it is necessary and relevant to organise a satisfactory scheme of energy conservation using thermal springs.

The issue of slowing down the design process of geothermal plants is of particular value, at the moment this is conditioned by insufficient financing of this industry, also by the weak development of technologies and insufficient attention to thermal springs in Kazakhstan at many levels, in connection with which it is necessary to investigate ways to overcome this problem and develop a certain range of recommendations. There is also a need to improve the technological mode of the binary power plant to make the operation of the facility more efficient, so that in the future, thermal sources will be used not only for heating, but also for supplying electricity to consumers, in the form of an environmental energy resource.

2 Materials and methods

The problems of improving the technological regime of a binary power plant to increase the energy efficiency of autonomous consumers were investigated using methods that reveal the theoretical and practical content of the object. The analytical method helped identify the problems of the operation of geothermal plants in Kazakhstan, which are involved in the complex process of thermal generation and electricity generation. Using the statistical method, indicators were considered that help to analyse the number and causes of errors in the development of binary power plants to improve the energy efficiency of autonomous consumers, the implementation of improvements in geothermal power plants in the country, the prospects for the use of this energy resource and development in terms of sustainability and productivity in the consumer market.

Using the functional method, the role and essence of geothermal power plants at different levels of development of this mechanism, their advantages and disadvantages, and the impact of their operation on the environment were analysed. Using this method, it was determined that binary geothermal power plants have considerable growth prospects in numerous countries and boast a more extensive history of deployment compared to other types of power plants. The structural and functional approach proved instrumental in scrutinizing trends, factors, and models aimed at enhancing the technological modes of binary power plants. The findings highlight that addressing issues related to development errors, enhancing geothermal power plant maintenance, devising innovative devices for more precise thermal energy conversion, and optimizing performance during the design phase will necessitate increased government funding, a fresh perspective on power plant maintenance, and the creation of high-quality components to elevate technology standards within this industry.

The deduction helped in the disclosure of the concept of "improving the technological regime of a binary power plant to increase the energy efficiency of autonomous consumers" through the prism of highlighting its characteristic features for a full-fledged analysis of the operation and problems of geothermal plants. Applying the synthesis, the obtained theoretical and practical results were summarised to

identify recommendations that contribute to solving problems and increasing the progressive growth of this energy resource, prospects for reducing errors in the development of innovative technological modes of a binary power plant, development in the modelling and design of constituent elements in these stations, namely, in geothermal power plants. The theoretical component of the study was revealed using the methods of logical and functional analysis. With the help of the functional method, the theoretical component was determined. It provided an opportunity to analyse the concept of "thermal springs" in more detail. This allowed characterising the features and principles of geothermal power plants on this energy resource and the complexity of the functioning of this mechanism; in particular, in the complex technological processes of meeting the energy aspirations of different consumers. The essence of thermal sources in the country, how they are used and where, and the feasibility of their use as an energy resource were analysed.

Drawing upon statistical and structural-functional analyses, the practical component of the study was elucidated. This component encompassed an examination of the fundamental principles, challenges in development approaches, and the application of binary power plants. It entailed an exploration of their merits and demerits, an in-depth investigation into the functioning of this mechanism, and an analysis of their role within Kazakhstan's geothermal power plants. The pivotal phase involved scrutinizing the potential for converting thermal energy into electrical power, implementing innovative technologies to enhance these power plants, and devising strategies for reducing errors in the design of technological modes specific to binary power plants. This comprehensive assessment aimed to determine the viability of development and the future prospects of this energy resource. Through deduction and synthesis, recommendations were derived based on the acquired results. These recommendations focus on identifying and addressing challenges in the development of technological regimes for binary power plants and the operation of the mechanism within geothermal plants. Ultimately, these insights are intended to facilitate problem-solving and align with the energy aspirations of consumers. In summary, the application of these methodologies aimed to provide recommendations regarding the feasibility of integrating binary power plants into geothermal power facilities and harnessing the potential of this energy resource effectively.

3 Results

To provide electricity and productive work of enterprises in various industries on the territory of Kazakhstan, it is necessary to develop energy production, namely with the use of thermal sources, especially in the precise design and modelling of technological modes of a binary power plant, which are most often used at geothermal stations. To cover the increase in electric power, actions are needed to expand and technologically re-equip the geothermal power plants used, including the construction of new ones. In the modern world, there are a huge number of geothermal power plants using the energy of low-enthalpy hydrothermal sources, in which the organic Rankine cycle is reproduced (Razmjoo et al. 2022).

An important issue that needs to be addressed today is errors in the development of technological modes of a binary power plant to increase the energy efficiency of autonomous consumers and in their modelling, the reliability of the results of processing and providing energy to consumers by this facility, the efficiency of their mechanisms in remote areas and further development in the use of these energy sources in Kazakhstan, namely thermal springs. The Republic of Kazakhstan has 57 power plants with an installed capacity of approximately 19.1 thousand MW in Kazakhstan and an available capacity of 14.8 thousand MW. The water temperature in hydrothermal vents shows different temperatures, from several tens to 300 °C (Banos et al. 2011).

In the operation of geothermal power plants, it is necessary to find and solve the causes of errors in the energy conversion of thermal sources and the impact of these errors on the quality of consumer supply. Multiple resources of energy sources, for example, thermal sources, allow making not many mistakes in solving optimal devices and areas of the progress of geothermal power plants in Kazakhstan and, based on the experience of neighbouring countries of China and Japan, crating personal innovative mechanisms and large-scale methods of using geothermal power plants. In 1967, the first geothermal power plant on Earth with a binary cycle (freon power plant UEF-90/05) was designed and put into pilot operation – the Paratunskaya geothermal power plant, with a capacity of 670 kW, using freon (R12) as a working object of a steam power plant. Most of the Russian geothermal power plants developed so far were based on the Paratunskaya geothermal power plant. The heating medium for the devices was mainly geothermal liquid of deposits with a temperature of 80 °C (Tomarov and Shipkov 2017).

The compilation of scientific methods for solving problems of eliminating errors in the development and design of geothermal power plants in the southern regions of Kazakhstan currently has tremendous progress and prospects. However, the use of thermal sources is limited by the time of use and the stochasticity of natural factors, therefore, to maintain an uninterrupted power supply, it is necessary to simultaneously use energy storage devices, among which metal-ion batteries, redox batteries, and the hydrogen cycle can be considered the most progressive. At the moment, outdated functional schemes of a geothermal power plant are performed by an organic Rankine cycle, which is carried out by a low-boiling applied body in a closed heat-power circuit, in which a pair of characteristic parameters is created with the help of the heat of the thermal liquid (Bazmi and Zahedi 2011).

If modern electronics and computerised processing of thermal energy flow data are started in the technological regimes of binary power plants, this would help significantly

increase the capacity of power plants and generate the demand for the use of non-conventional energy sources in Kazakhstan. A significant impact on these processes in Kazakhstan on these branches of the energy industry was caused by an increase in the cost of some energy and raw materials sources. During 1967–1974, operational experiments took place in the research rooms of full-scale tests in many countries, which confirmed the stable operation of the power plant when using such a low-temperature energy resource of heat at 80 °C (Hodson et al. 2018).

The tasks of effective management of technological modes of a binary power plant to increase the energy efficiency of autonomous consumers and their problems with the use and development of innovative parts and devices are becoming increasingly relevant and of practical value in Kazakhstan. While maintaining an outdated production base and low rates of its modernisation without the introduction of energy-saving and energy-efficient mechanisms, further progressive growth of Kazakhstan's energy production capacities, laid down in the government's programmes and prospects, will be applied only to meet the consumer requirements of industry without reducing the energy efficiency index. However, the construction of binary geothermal power plants has not received the necessary development due to the underestimated cost of organic fuel in Kazakhstan, but at the moment this type of energy resource is gaining popularity in the country (Ghazi et al. 2022).

In this complex process, the revision of the causes of errors in the generation of thermal energy sources at binary geothermal power plants and their solution is of particular importance, since the development of this mechanism in the current world is one of the urgent problems of modern time in the southern regions of Kazakhstan. In total, the share of thermal power plants in Kazakhstan's energy balance is 88 %, while electric stations on unconventional energy resources are only 12 %, including geothermal power plants. In the modern developed world, binary geothermal power plants in Kazakhstan can be cost-effective at a thermal water temperature of 70–200 °C (Alnatheer 2005).

Very often, the processing of proper energy flows in a binary geothermal power plant system has certain errors, which worsens the efficiency of these stations using thermal waters. The experience of the Czech Republic, which has put into operation geothermal power plants with a capacity of 1952 GW, means that neither the size of the state, nor the climate, nor the lack of technology is an obstacle to the progressive growth of unconventional energy sources. In the modern world, binary geothermal power plants operate in many countries, their total capacity exceeds 500 MW (Tvaronavičienė et al. 2020; Tanchak et al. 2022).

In general, the problem of optimising the elimination of errors in the design of binary power plants to improve the energy efficiency of autonomous consumers has not been completely solved. Considering the self-discharge processes that occur in the batteries of power plants, it is impossible to fully rely on them in terms of a long period of energy storage obtained from renewable energy sources, more precisely from thermal waters, for example, to reduce the imbalance of energy production and its use in summer and winter periods, and in adverse weather conditions. At the moment, many companies abroad (primarily the Israeli firm Ormat) have established the stability of the continuous production of binary power plants on organic functioning bodies (isobutane, iso-pentane) with a single capacity of 1.5–4 MW. The operation of the heat engine, which is shown in Figure 1, occurs according to the organic Rankine cycle, which can cool down due to the water resources of the surrounding conditions with a temperature of 5–28 °C, and the air resources of the surrounding conditions with a temperature up to –55 °C.

Binary geothermal power plants are often used because of their environmental friendliness and the low cost of generating electricity, at the moment there is an increase in interest in this type of energy in Kazakhstan. In this regard, the development and operating modes of technical binary separation power plants at the moment will differ specifically from the design ones. The operation of binary geothermal power plants provides an instant and reliable supply of electricity to villages and even small towns located far from the main areas, especially in the northern edges of the country. There is a need for the practical development and implementation of comprehensive measures and solutions for the decentralisation of electricity supply to different geographical regions that are experiencing a shortage of electricity due to pronounced problems with energy supply. Moreover, it is important to identify the main aspects of the development of comprehensive measures for the decentralisation of energy supply to energy-deficient regions, which can be of significant practical importance in terms of increasing the quality of energy supply to such regions (Kozhageldi et al. 2022). The essence of Kazakhstan's transition to sustainable development for 2007–2024 means that part of the ecological energy sources by 2024 should be 5 % of the total energy balance of the state. The energy of thermal springs is considered not only as environmentally "clean" energy resource – the energy of this resource also supports socio-economic development, energy security, and reduces the dependence of electricity on fuel prices (Kabanbayev, Orynbayev, and Bekmuratov 2020). In the modern world, the development of a mathematical model of a hybrid energy supply system based on a

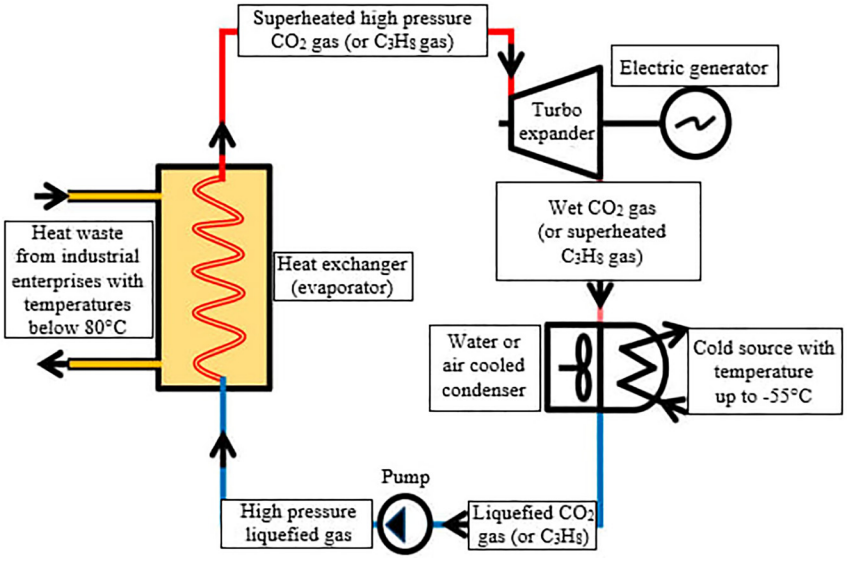

Figure 1: Functional diagram of a heat engine with a closed circulation circuit on carbon dioxide or propane for the disposal of thermal waste. Source: Filote et al. (2020).

photovoltaic-bioenergy installation is relevant, it will help reduce the energy intensity of agricultural production (Keshuov et al. 2017).

Currently, binary geothermal power plants have become the most widespread and developed at various stages, due to the interest of consumers and investors in Kazakhstan and abroad. This will lead to increased competitiveness, improved product quality, and preservation of the status of developed countries of the world. Nowadays, there are huge prospects in the world for the use of binary geothermal power plants of a block type with a capacity from 100 kW to 12 MW for areas where there is hot geothermal water (Hrechko et al. 2023; Zaporozhets et al. 2021). The condition for the reliable functioning of binary geothermal power plants in Kazakhstan is to ensure the stable operation of both the binary power plant and the overall electricity generating industry. Further promising development of the electric power industry in Kazakhstan is impossible without modernisation and improvement of existing and design of new binary geothermal power plants. The mechanism of the binary cycle is based on the application of medium-temperature heat of the discharge separator (hot liquid). As a result, it turns out that the existing binary power plants at binary geothermal power plants do not meet modern requirements and are considered effective in expanding the production of innovative elements. The main conditions are the right legislation, promising management of facilities and mechanisms to stimulate the use of fuel-free energy resources and the creation of personal production of devices for binary geothermal power plants. Previously, the hot liquid coming out with steam from a geothermal well was not used in the process of electricity production.

Binary geothermal power plants in many countries have a huge development potential and a long implementation practice than other power plants, and have made tremendous progress in generating electricity. In comparison with most devices that produce energy, binary power plants are environmentally friendly and highly efficient, the product of their work is only hot water. However, in many closed cycles, the hot liquid is directed to a deliberately designed evaporator, where the process of heating and evaporation of a low-boiling functioning body – halon – takes place. It is also important to pay attention to the quality of the technological process that is carried out in binary geothermal power plants, for the best functioning of binary power plants and the station in general. All these factors increase the requirements for the operation of binary power plants and automated control. Functioning bodies of a binary power plant should apply a low freezing temperature to provide normal winter operation and prevent freezing in emergency situations. The best way to study binary geothermal power plants is precisely mathematical modelling. The best solution for reducing natural resources is the practice of energy conservation and the introduction of energy-efficient mechanisms. Isobutane is presented in the form of a low-boiling coolant of the second circuit – a hydrocarbon of the alkane type, an isomer of normal butane. Its boiling point is –11.75 °C, its melting point is –159.42 °C.

Previously, there was an insufficient number of geothermal power plants in operation in Kazakhstan and almost all of them were dry-steam installations. But even so, there were huge differences between traditional resources that needed special engineering upgrades to cope with the changes. An environmentally friendly scheme of using a

low-boiling coolant (isobutane) with an air condenser helps eliminate indirect contact of a functioning body with the surrounding nature. Increasing energy efficiency is indicated as a very optimal task for the economy of Kazakhstan. Now that a very wide range of energy resources are used to generate electricity, the need to investigate and carefully disassemble each source, and then design a power plant corresponding to the energy resource is even more necessary. During the design, manufacture and application of some combined power units, it is necessary to solve a huge number of scientific and technical issues, such as the type of optimal low-boiling functioning body of the second circuit, the designation of the maximum reduced condensate cooling temperature, the option of a suitable method for removing non-condensing gases from the condenser-evaporator, issues on the introduction of environmental emission measures. Kazakhstan has huge reserves of energy resources and is able to meet its needs to a certain extent. However, at present, the promising opportunities of the fuel and energy complex are not being fulfilled in sufficient form, the operational efficiency of many energy enterprises has decreased, and this sector is experiencing multiple financial and economic problems (Shahini et al. 2023).

The quality of research that has been carried out to improve the technological modes of a binary power plant to detect errors and problems in the functioning of this mechanism, and their effectiveness is one of the most pressing issues of modern time, and some problems require immediate solutions. Efficient options for generating electricity were considered due to the utilisation of the low-potential heat of condensation of steam spent in the turbine with a temperature below 50 °C under different external environmental conditions. The huge development of the use of binary geothermal power plants should take place on the original modern mechanisms produced in Kazakhstan.

This study on the operation of binary geothermal power plants enabled a better understanding of the causes of errors during operation, especially during thermal power generation, and assessed whether these problems can be resolved and at what point they can occur. These methods may allow the operation of binary power plants on low-boiling functioning bodies at lower temperatures than current and simulated binary power plants for binary geothermal power plants. In the role of an optimal low-boiling functioning body, it is recommended to use liquefied carbon dioxide or propane. The initial science that guides the processes can be explored, but the application of these forces will require modern solutions to the difficulties that arise throughout the entire period from consideration to drilling and development of the plant, modelling, operation, and technological maintenance.

Many countries and Kazakhstan have made a powerful step forward in the development of the design and modelling of binary geothermal power plants over the past few years. A binary thermodynamic cycle is a mixture of two thermodynamic cycles performed by two functioning bodies so that the heat escaping in one cycle is applied in another cycle. The observed trends indicated an increased interest in this type of energy, which occurs in the programmes of its prospects adopted by a significant number of countries, including Kazakhstan.

When generating and producing electricity in binary geothermal power plants and their elements for a better passage of a complex technological process, process models should adequately describe the essence of the work, be simple and implementable. The urgency of the difficulties of import substitution is closed by creating a model of binary power plants made of simple materials and domestic elements (low temperatures, low circumferential speeds and voltages). For example, Iceland has applied an impressive level of geothermal energy generation since 2007, increasing installed capacity from 422.4 to 715.4 MW, a 69 % increase in four years. And this was done without the withdrawal of any of the older sources from the operation. Iceland has 31 operating stations, as opposed to 24 in 2007.

The state agency responsible for regulating zoning and permitting for new geothermal plants in Kazakhstan is the Ministry of Energy of the Republic of Kazakhstan. It is responsible for overseeing and managing the energy sector, including the development and regulation of renewable energy sources like geothermal power (Ministry of Energy of the Republic of Kazakhstan, n.d.).

The assessment of the potential of expanded geothermal systems in Kazakhstan depends on various factors, including geological conditions, technical feasibility, and economic viability. Kazakhstan possesses significant geothermal potential, particularly in its deep sedimentary basins. These areas have shown promising signs of medium to low-temperature geothermal resources, often encountered during oil and gas drilling. The presence of such resources indicates the geological feasibility of expanded geothermal systems. Geothermal energy is well-suited for district heating applications, and Kazakhstan has already started using geothermal energy for residential heating in some regions, such as the Kaplanbek geothermal field near Chimkent. Expanding district heating systems powered by geothermal energy could be a viable option, especially in colder regions. The use of geothermal energy for greenhouse heating in winter and air conditioning in summer near Almaty demonstrates its versatility. Expanding this application to other agricultural regions could enhance food production and reduce energy costs. Geothermal energy is a clean and

renewable energy source, which can contribute to reducing Kazakhstan's carbon footprint and mitigating the environmental impact of fossil fuel-based energy production.

The first role in ensuring the efficiency of binary geothermal power plants for generating, producing, and providing electric energy to consumers in various almost inaccessible areas is played by the professionalism of the staff and timely diagnostics of equipment, more precisely, the technological modes of a binary power plant. Kazakhstan has significant reserves of geothermal heat. The study and improvement of technological modes of a binary power plant involve the large-scale application of recent achievements in theory and practice in many of the sectors mentioned above.

But there is also the need for health and safety standards to prevent hydrogen sulfide (H2S) emissions is crucial and justified for several reasons. H2S is a toxic gas that poses significant health risks to humans. Exposure to even low concentrations of H2S can result in symptoms such as eye and respiratory tract irritation, nausea, headaches, and in higher concentrations, it can lead to loss of consciousness and death. Establishing safety standards is necessary to protect the health and well-being of workers and the public.

In many industries, such as oil and gas extraction, wastewater treatment, and certain manufacturing processes, workers may come into contact with H2S as part of their job responsibilities. Health and safety standards are essential to ensure that workers are adequately trained, equipped with appropriate personal protective equipment (PPE), and aware of safety protocols to minimize H2S exposure. Uncontrolled H2S emissions can have harmful environmental consequences. When released into the atmosphere, H2S can contribute to air pollution and, in some cases, lead to the formation of sulfuric acid aerosols, which can have adverse effects on ecosystems. Establishing emission standards helps mitigate these environmental impacts.

4 Discussion

The problems of Kazakhstan's oil and gas potential were studied mainly in the western regions of Kazakhstan (the Caspian, Mangyshlak, Ustyurt). The oil and gas potential of these areas was considered in sedimentary complexes of the Paleozoic and Mesozoic-Cenozoic cover. The current energy sector, which is the most important sphere of the economy, is based on traditional energy resources (coal, oil, natural gas), some of which account for more than 80 % of energy generation. Energy based on fossil energy sources cannot guarantee reliable development of macroeconomics for long-term progress due to rising fuel costs and their volatility and is one of the main reasons negatively affecting nature. Greater difficulties of thermal pollution are conditioned by the functioning of industrial production. A large proportion of the energy of the fuel energy resource, which cannot be converted into useful operation, is lost like thermal energy. The simplest way to get rid of this heat is to release it into the surrounding environment. Almost always, the release of thermal effects into reservoirs can lead to changes in the biotic composition of the ecosystem (Havrysh et al. 2020). Because of this, the possibility of the prospective use of thermal secondary energy sources of industrial production is an urgent scientific and technical task.

In studies of binary geothermal stations in Kazakhstan, it is necessary to consider, based on generalised analyses of extensive geological and geophysical material, the progressiveness and prospects of oil and gas potential, such as sedimentary basins of Southern Kazakhstan. The basis of the current energy geopolitics has become solutions aimed at increasing the efficiency of energy use, energy efficiency, and reducing the impact of energy enterprises on the environment (Cui 2022). This strategy is used for renewable energy resources. One of the progressive types of unconventional energy turns out to be geothermal energy, and already at the moment, an impressive experience of its practical use has been accumulated. Today, utilisation of low and moderate potential heat at the 80–160 °C stage is generated mainly in geothermal energy, where the organic Rankine cycle is implemented in energy mechanisms using low-boiling functioning bodies, which involves various hydrocarbons (Dinzhos et al. 2020). The option of using freon in the form of a working fluid of a steam-powered device for generating electricity was initially implemented in 1967 at a pilot geothermal power plant. However, the possible scope of application of such power plants with a low-boiling working fluid is much larger.

According to the results of recent studies by Juntunen and Martiskainen (2021), the possibility of applying various temperature regimes and geothermal environmental conditions helps efficiently generate electricity using carbon dioxide and propane binary power plants. Notably, the temperature period of the use of liquefied carbon dioxide gas in the role of a low-boiling functioning body in the thermal circuit of the binary cycle is inhibited by indicators of a dangerous temperature of 31 °C and a temperature at the triple point −56.56 °C. Therefore, the use of liquefied carbon dioxide gas in the temperature range from 60 °C to −55 °C will help ensure optimal pressure of the circulation circuit of the heat engine and the cost of its compression. At the moment, it is necessary to improve the quality of various methods and devices for converting the energy of thermal sources to binary geothermal power plants for efficient

operation. The entire mechanism of operation of the technological modes of a binary carbon dioxide power plant was analysed, as a result, it was decided that in order to apply different constructions, especially theoretical ones, it is necessary to have acquired basic knowledge to designate physical devices and their number, which will help understand the process of developing thermal energy conversion devices under appropriate conditions.

Referring to the definition by Dahiru et al. (2021), so-called "greenhouse gases", such as carbon dioxide, were presented as the main points of global warming. From the very beginning of the industrial age about two hundred years ago, the population extracted and used carbon in the form of hydrocarbons, which have been lying under the crust of the earth for millions of years. The burning of non-renewable fuel to a certain extent implies a response for the quality of existence to which many are accustomed. This indicates that in the modern world, when designing and modelling binary geothermal power plants, it is necessary to consider all factors that affect the quality of the presented type of energy for the population. Also overlooked is the fact that, given the diversity of economies and cultures in the world's energy supply, the use of traditional energy sources and the failure to consider renewable sources, such as thermal energy, can have an impact on an effective broad energy policy.

Kakran and Chanana (2018) determined that according to experimental data, fuel consumption for electricity generation is 10–15 %, for heat supply – 15–20 %. The costs of implementing energy saving are almost 5 times less than for new energy generation. Disregarding the northern latitude of the geographical location of Kazakhstan, the resources of thermal springs in the state are permanent and acceptable, in particular, due to favourable weather conditions. For a more correct operation of the energy conversion of thermal sources, it is necessary to check binary power plants on an ongoing basis, so that the potential of thermal energy in the southern regions will soon reach high levels. Therefore, it is very important to consider the specifics of using this type of power plants, timely study of data and possible causes of malfunctions, for further promising development of the use of binary geothermal power plants to provide energy to consumers in remote areas.

Nasruddin et al. (2016) determined that the electric power system of Kazakhstan is definitely an independent enterprise and works simultaneously with the power system of Central Asia. The development of the national energy supply continues to be significantly influenced by the environment, which weakly subordinates the efforts of producers and the state. The energy of thermal sources is designated one of the progressive industries of the country, since it has significant resources of water and energy sources, such as binary geothermal power plants and which are involved in less than one-third. The results of this characterisation study have been analysed and considered more precisely, it can be concluded that the country needs to develop green energy, especially the use of thermal sources for power generation in the southern regions of Kazakhstan to ensure energy independence in the future.

Guzović, Lončar, and Ferdelji (2010) argued that for developed countries there is an inherent shortage of huge capital investments, which allows the construction of large-scale traditional power plants. At the time, binary power plants are mainly modular and allow for a certain amount of capacity to be included and increased as required. The creation of autonomous low-power structures based on binary power plants supplying autonomous consumers has a huge advantage. However, it was not indicated that these devices are based on carbon dioxide, have a huge potential for further use and are cost-effective and environmentally friendly. It can also be noted that some areas are not connected to the central power supply network, for them the provision of electricity, and sometimes heat supply based on binary geothermal power plants is predetermined by the solution of significant social difficulties and a condition for reliable development. As noted by Fridleifsson (2001), the attempt at large-scale implementation of binary geothermal stations at this time has a huge potential.

It is also necessary to mention the energy efficiency of these thermal springs in the country and their prospects in the future. It is necessary to increase funding and improve the skills of employees, to begin the introduction of new technologies to improve the design and modelling of binary geothermal power plants and to reduce errors during the complex technological process in these power plants and in their binary power plants.

5 Conclusions

The main problems of geothermal power plants and their binary power plants are mediocre training, problems of proper modelling and design of these stations, and multiple errors in the technological process of energy conversion and production, these problems are and will be relevant and need further study. The results obtained show that it is possible to use liquefied propane gas as a low-boiling functioning body in the thermal circuit of a binary cycle with limited temperature values of 96.7 °C and saturation temperature at a pressure of at least 0.1 MPa, therefore, the use of liquefied propane gas will eliminate the difficulties of

creating a vacuum and providing tightness of pipelines if continuous optimisation of operation processes is performed this mechanism. In this paper, recommendations were considered and presented regarding the elimination of errors in the design and implementation of power plants in binary geothermal power plants and the analysis of their functioning, complex technological processes in these power plants were thoroughly analysed, including errors and problems during the operation of these stations, introducing effective tools to address these issues and preventing the occurrence of errors. To improve the use of modern geothermal energy, characterised by an increased demand for binary energy technologies, enabling methods were considered that significantly expand this resource base by introducing low-temperature energy resources into power generation.

It was considered that the heat transfers a geothermal coolant to another low-boiling liquid is predetermined in a binary power plant, and it was revealed that the other coolant is a functioning body of the second closed circuit. It was possible to fulfil all the tasks assigned to the study, namely: to highlight the problems of the processes of operation of binary geothermal power plants in Kazakhstan and analyse them more accurately; to provide recommendations for the popularisation of this energy source; to find and propose methods for solving errors in improving the technological modes of binary power plants, conversion and energy production for more efficient operation of the presented mechanism and improve the energy efficiency of autonomous consumers. The condition is considered and analysed, the fulfilment of which, when designing and modelling binary geothermal power plants, allows to perform at the expense of utilisation of heat of low-temperature geothermal coolant, and also discharge separator of exploited these plants at the basis of application of binary power plants. The analysed modern approaches to the problems of improving the technological modes of a binary power plant will try to respond to modern needs for further promising use of this energy resource. Further study will be focused on the development and implementation of innovative binary geothermal power plants and on the promotion of this energy resource.

Research ethics: Not applicable.
Author contributions: The authors have accepted responsibility for the entire content of this manuscript and approved its submission.
Competing interests: The authors confirm, that they have no conflicts of interest to disclose.
Research funding: Not applicable.
Data availability: The authors confirm that the data supporting the findings of this study are available in the article.

References

Alnatheer, O. 2005. "The Potential Contribution of Renewable Energy to Electricity Supply in Saudi Arabia." *Energy Policy* 33 (18): 2298–312.

Babak, V. P., and S. I. Kovtun, 2019. "Calibration Thermoelectric Heat Flux Sensor in the Diagnostic System of Thermal State of Electric Machines". *Technical Electrodynamics* 2019 (1): 89–92, https://doi.org/10.15407/techned2019.01.089.

Banos, R., F. Manzano-Agugliaro, F. G. Montoya, C. Gil, A. Alcayde, and J. Gómez. 2011. "Optimization Methods Applied to Renewable and Sustainable Energy: A Review." *Renewable and Sustainable Energy Reviews* 15 (4): 1753–66.

Bazmi, A. A., and G. Zahedi. 2011. "Sustainable Energy Systems: Role of Optimization Modeling Techniques in Power Generation and Supply – A Review." *Renewable and Sustainable Energy Reviews* 15 (8): 3480–500.

Çera, G. 2022. "Europe's Economic Pandemic Shock: How EU Economies Endured the Effects of COVID-19 Restrictions." *European Chronicle* 7 (4): 35–43.

Cui, L. 2022. "The European Energy Crisis of 2022 in the Context of Increasing Sanctions Pressure on the Russian Federation: Analysis of Economic Losses and Scenarios." *European Chronicle* 7 (3): 19–29.

Dahiru, A. T., C. W. Tan, A. L. Bukar, and K. Y. Lau. 2021. "Energy Cost Reduction in Residential Nanogrid under Constraints of Renewable Energy, Customer Demand Fitness and Binary Battery Operations." *Journal of Energy Storage* 39: 102520.

Dinzhos, R., N. Fialko, V. Prokopov, Yu. Sherenkovskiy, N. Meranova, N. Koseva, V. Korzhik, O. Parkhomenko, and N. Zhuravskaya. 2020. "Identifying the Influence of the Polymer Matrix Type on the Structure Formation of Microcomposites when They Are Filled with Copper Particles." *Eastern-European Journal of Enterprise Technologies* 5 (6-107): 49–57.

Dzhumabaev, T. R., V. D. Serokhvostov, and S. A. Klimenko. 2020. "Structural-Parametric Study of the Combined Spatial Cam-Lever Mechanism." *Modern Science: Current Issues, Achievements* 1: 44–6.

Fialko, N. M., V. G. Prokopov, N. O. Meranova, Yu. S. Borisov, V. N. Korzhik, and G. P. Sherenkovskaya. 1994. "Heat Transport Processes in Coating-Substrate Systems under Gas-Thermal Deposition." *Fizika i Khimiya Obrabotki Materialov* 2: 68–75.

Filote, C., R. A. Felseghi, M. S. Raboaca, and I. Aşchilean. 2020. "Environmental Impact Assessment of Green Energy Systems for Power Supply of Electric Vehicle Charging Station." *International Journal of Energy Research* 44 (13): 10471–94.

Fridleifsson, I. B. 2001. "Geothermal Energy for the Benefit of the People." *Renewable and Sustainable Energy Reviews* 5 (3): 299–312.

Geothermal Power in Kazakhstan. 2021. https://conventuslaw.com/report/geothermal-power-in-kazakhstan/#:~:text=This%20is%20why%20renewable%20energy,its%20fifteen%20deep%20sedimentary%20basins.

Ghazi, Z. M., S. W. F. Rizvi, W. M. Shahid, A. M. Abdulhameed, H. Saleem, and S. J. Zaidi. 2022. "An Overview of Water Desalination Systems Integrated with Renewable Energy Sources." *Desalination* 542: 116063.

Guzović, Z., D. Lončar, and N. Ferdelji. 2010. "Possibilities of Electricity Generation in the Republic of Croatia by Means of Geothermal Energy." *Energy* 35 (8): 3429–40.

Havrysh, V., A. Kalinichenko, G. Mentel, and T. Olejarz. 2020. "Commercial Biogas Plants: Lessons for Ukraine." *Energies* 13 (10): 2668.

Hodson, E. L., M. Brown, S. Cohen, S. Showalter, M. Wise, F. Wood, J. Caron, F. Feijoo, G. Iyer, and K. Cleary. 2018. "US Energy Sector Impacts of Technology Innovation, Fuel Price, and Electric Sector CO_2 Policy: Results from the EMF 32 Model Intercomparison Study." *Energy Economics* 73: 352–70.

Hrechko, Y., I. Sereda, I. Babenko, and M. Azarenkov. 2023. "Thermionic Coating Method with Preliminary Bombardment of the Substrate Surface with a Stream of Low Energy Ions." *Scientific Herald of Uzhhorod University. Series Physics* 53: 9–18.

Juntunen, J. K., and M. Martiskainen. 2021. "Improving Understanding of Energy Autonomy: A Systematic Review." *Renewable and Sustainable Energy Reviews* 141: 110797.

Kabanbayev, A. B., S. A. Orynbayev, and M. Bekmuratov. 2020. "Investigation of Aerodynamic Characteristics of a Wind-Driven Power Plant." *ARPN Journal of Engineering and Applied Sciences* 15 (22): 2728–35.

Kakran, S., and S. Chanana. 2018. "Smart Operations of Smart Grids Integrated with Distributed Generation: A Review." *Renewable and Sustainable Energy Reviews* 81: 524–35.

Keshuov, S., R. Omarov, A. Tokmoldayev, D. Omar, S. Amirseit, and Kunelbayev. 2017. "Hybrid System for Using Renewable Sources of Energy for Local Consumers in Agriculture." *Journal of Engineering and Applied Sciences* 12 (5): 1296–306.

Kozhageldi, B. Z., Z. S. Tulenbayev, S. Orynbayev, G. Kuttybaev, N. Abdlakhatova, and S. Minazhova. 2022. "Development of Integrated Solutions for the Decentralisation of Electricity Supply to Power-Hungry Regions." *The Electricity Journal* 35 (4): 107108.

Ministry of Energy of the Republic of Kazakhstan. n.d. https://www.gov.kz/memleket/entities/energo?lang=en.

Moldazhanov, R. E., O. A. Stepanova, A. R. Khazhidinova, and M. V. Ermolenko. 2022. "Improving the Efficiency of Heat Supply Enterprises on the Example of the Use of the Binary Cycle Water-Freon-410." *Bulletin of Shakarim University. Engineering Science Series* 3, 32–5.

Nasruddin, Alhamid, M. I. Y. Daud, A. Surachman, A. Sugiyono, H. B. Aditya, and T. M. I. Mahlia. 2016. "Potential of Geothermal Energy for Electricity Generation in Indonesia: A Review." *Renewable and Sustainable Energy Reviews* 53: 733–40.

Piralishvili, G. Sh., and S. V. Veretennikov. 2011. "Thermodynamic Analysis of Schemes of Power Plants." *Bulletin of the Rybinsk State Aviation Technological Academy* 2: 154–60.

Razmjoo, A., S. Mirjalili, M. Aliehyaei, P. A. Østergaard, A. Ahmadi, and M. M. Nezhad. 2022. "Development of Smart Energy Systems for Communities: Technologies, Policies and Applications." *Energy* 248: 123540.

Shahini, E., D. Shehu, O. Kovalenko, and N. Nikonchuk. 2023. "Comparative Analysis of the Main Economic and Biological Parameters of Maize Hybrids that Determine Their Productivity." *Scientific Horizons* 26 (4): 86–96.

Tanchak, A., K. Katovsky, I. Haysak, J. Adam, and R. Holomb. 2022. "Research of Spallation Reaction on Plutonium Target Irradiated by Protons with Energy of 660 MeV." *Scientific Herald of Uzhhorod University. Series Physics* 52: 36–45.

Tomarov, G. V., and A. A. Shipkov. 2017. "Modern Geothermal Power: Binary Cycle Geothermal Power Plants." *Thermal Engineering* 64 (4): 243–50.

Turdybekov, R. W. 2022. *Modernization of Multi-Apartment Housing Stock in the City of Nur-Sultan on the Principles of a Green Economy*. https://repository.apa.kz/bitstream/handle/123456789/986/%D0%A2%D1%83%D1%80%D0%B4%D1%8B%D0%B1%D0%B5%D0%BA%D0%BE%D0%B2%20%D0%A0.%D0%A3.pdf?sequence=1&isAllowed=y.

Tvaronavičienė, M., J. Baublys, J. Raudeliūnienė, and D. Jatautaitė. 2020. "Global Energy Consumption Peculiarities and Energy Sources: Role of Renewables." In *Energy Transformation towards Sustainability*, 1–49. Amsterdam: Elsevier.

Zaporozhets, A., V. Babak, A. Sverdlova, V. Isaienko, and K. Babikova. 2021. "Development of a System for Diagnosing Heat Power Equipment Based on IEEE 802.11s." *Studies in Systems, Decision and Control* 346: 141–51.

Zhumanov, E. E., S. K. Kumyzbaeva, M. J. Konyrova, and E. Kadylbekkyzy. 2022. "Analysis of the Effectiveness of Applying the Theory of Teletraffic for Direct Load Control in Intelligent Networks." *Vestnik AUES* 4 (59): 127–36.