ABSTRACT

This dissertation by Abdlakhatova Nazym Shokhadlyaevna, titled "Research and improvement of the technological regime of a binary power plant to improve the energy efficiency of autonomous consumers," is submitted for the degree of Doctor of Philosophy (PhD) in the educational program 8D08702 – *Energy Supply of Agriculture.*

Relevance of the Research. Geothermal energy is becoming increasingly important in heating and energy supply systems worldwide. It is based on the use of the Earth's natural heat and can be applied for both electricity and thermal energy generation. Unlike other renewable energy sources, geothermal energy is characterized by high stability and independence from weather conditions, seasons, and time of day.

Currently, geothermal resources in Kazakhstan are mainly used in agriculture, greenhouse heating, hot water supply, and heating of residential and public buildings. At the same time, electricity generation is still primarily based on thermal power plants, which leads to high CO_2 emissions. Therefore, the use of geothermal resources for electricity generation is particularly relevant, especially given the absence of geothermal power plants in the country. Transitioning to geothermal energy could be an important step toward reducing greenhouse gas emissions and implementing national decarbonization strategies.

Despite their significant energy potential, geothermal resources in Kazakhstan remain underutilized. Their potential for electricity generation has not been sufficiently studied, which indicates a clear scientific gap and highlights the need for comprehensive research.

In addition to the energy sector, Kazakhstan's agro-industrial sector is a strategically important part of the economy. Agricultural processes, including greenhouse farming, crop drying, livestock production, and food processing, require stable year-round energy supply. Currently, these needs are mainly covered by fossil fuels and centralized power systems, which leads to higher operating costs, increased greenhouse gas emissions, and reduced resilience, especially in rural and remote areas.

This dissertation considers the use of low-temperature geothermal resources with an Organic Rankine Cycle (ORC) and their subsequent cascade utilization in greenhouse agriculture. The proposed concept aims at simultaneous production of electricity and heat, which is particularly relevant for Kazakhstan's climatic and socio-economic conditions. This integrated approach improves the efficiency of geothermal systems and ensures reliable energy supply for the agricultural sector.

Aim of the Study. To improve the energy efficiency of autonomous consumers by investigating and optimizing the technological regime of a binary geothermal power plant using an Organic Rankine Cycle (ORC).

Research Objectives.

– Identify geothermal zones with the highest potential;

– Assess the energy potential of geothermal resources in Southern Kazakhstan;

– Develop a thermodynamic model of the Organic Rankine Cycle to calculate the potential for electricity generation and cascade heat supply for greenhouses using geothermal resources;

– Study the properties of low-boiling working fluids and develop an algorithm for their selection;

– Conduct a techno-economic feasibility study of ORC-based systems using geothermal sources in the Almaty region.

Scientific Novelty:

– A thermodynamic model of a binary geothermal power plant based on the Organic Rankine Cycle (ORC) has been developed and adapted to the operating parameters of low-temperature geothermal resources in the Almaty Region, enabling the assessment of their electricity generation potential.

– An approach for the cascade utilization of heat rejected in the ORC condenser has been proposed for greenhouse heating during the winter season and agricultural product drying during the summer season.

– A methodology for selecting a low-boiling working fluid has been developed based on a comprehensive evaluation of thermodynamic performance, environmental characteristics, and fire and explosion safety requirements.

– The techno-economic feasibility of the cascade utilization of geothermal resources using a binary geothermal power plant based on the Organic Rankine Cycle for supplying energy to autonomous consumers has been substantiated.

Object of the Study. The object of the study is geothermal resources of Kazakhstan.

Subject of the Study.

The subject of the study is the process of converting thermal energy from low-temperature sources into electrical energy using the Organic Rankine Cycle (ORC), followed by cascade utilization of residual heat.

Research Methods.

Literature analysis and patent research were conducted to assess the level of development of the topic and identify promising research directions. Both domestic and international studies in the field of geothermal energy were used.

Mathematical modeling of energy conversion processes was performed, including the development of a thermodynamic model of a geothermal power plant.

Calculations were carried out using software tools such as Microsoft Excel and ThermoState.

Practical Significance of the Results.

The practical significance of the dissertation lies in the development of a methodology for selecting organic working fluids for geothermal power plants based

on the Organic Rankine Cycle (ORC).The following tools were used in the calculations:

– CoolProp library – software for calculating thermophysical properties of refrigerants and organic fluids, enabling the determination of enthalpy, entropy, density, and other parameters required for thermodynamic modeling of the Organic Rankine Cycle;

– ThermoState software – used to verify the properties of working fluids.

The use of multiple software packages allowed for cross-validation of thermodynamic property calculations, thereby improving the accuracy and reliability of the obtained results.

Practical Value and Implementation of Results.

The practical value of the research is confirmed by acts of implementation in the educational process of M. Kh. Dulaty Taraz University. The results of the study are used in laboratory and practical classes for the course *"Alternative and Renewable Energy Sources"* within the Department of Automation and Telecommunications, for the educational program 6B07107 – "Digital Energy."

In addition, implementation acts were obtained from: Kazakh National Research Technical University named after K. I. Satpayev and L. N. Gumilyov Eurasian National University.

The research materials are used in lectures and practical classes for the course *"Alternative Sources of Electrical Energy,"* delivered for the following educational programs: 6B07128 – "Digital Energy", 7M07113 – "Electrical Engineering and Energy", 7M07144 – "Innovative Technologies and Equipment in Renewable Energy", 6B07117 – "Heat Power Engineering".

Key Provisions Submitted for Defense

1. Based on the developed thermodynamic model of the Organic Rankine Cycle (ORC), it was established that the total electricity generation potential of geothermal wells No. 5539, 1-RT, and 2-TP at the Zharkent geothermal field is 11,440.2 MWh/year, of which 5,905.5 MWh/year is generated by well No. 5539.

2. The cascade utilization of heat rejected in the ORC condenser, with an annual thermal potential of 92.4 GWh, can provide heat supply for greenhouse facilities with a total area of up to 17 ha during the winter season or support the drying of 29,840–44,760 t/year of agricultural products during the summer season.

3. Of the 14 low-boiling working fluids evaluated, 11 satisfy the requirements for thermodynamic performance, environmental safety, and fire and explosion safety. Among them, R-152a provides the highest annual electricity generation while maintaining an ozone depletion potential (ODP) of 0 and a global warming potential (GWP) of 124.

4. The cascade utilization of heat rejected in the ORC condenser reduces the payback period of the binary geothermal power plant from 7.2 years for electricity-only generation to 5.1 years when supplying heat to greenhouse facilities and to 5.3 years when the recovered heat is used for agricultural product drying.

Research Dissemination. The main results of the dissertation research were presented at the International Scientific and Practical Conference "Innovative and Practical Solutions for Accelerated Restoration of Productivity of Degraded

Irrigated Lands" (Taraz, Kazakhstan, 2021), the International Scientific and Practical Online Conference "Integration of Science, Education, and Industry as the Basis for the Implementation of the National Plan" (Saginov Readings) (Karaganda, Kazakhstan, 2021), as well as at scientific seminars of the Department of Energy of the Kazakh National University of Water Management and Irrigation.

Publications. The research results have been published in 10 papers in international and national scientific journals and conference proceedings. In addition, one utility model patent of the Republic of Kazakhstan has been granted. These publications reflect the main content of the dissertation.

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2. Tulenbayev Zh., Zhanpeisova A., Omarova A., Tleshova A., Abdlakhatova N. Prospects of using organic Rankine cycle for geothermal power generation // International Journal of Power Electronics and Drive Systems. 2025. Vol. 16, No. 1. pp. 575–583.
3. Zhanpeisova A., Tleshova A., Abildaeva A., Uzbekova D., Abdlakhatova N. Analysing efficiency and economic aspects in organic Rankine cycle systems // Polityka Energetyczna – Energy Policy Journal. 2024. Vol. 27, Issue 3. pp. 87–108.
4. Orynbayev S., Tokmoldayev A., Abdlakhatova N., Zhanpeisova A., Tumanov I. Improving power plant technology to increase energy efficiency of autonomous consumers using geothermal sources // Energy Harvesting and Systems. 2024. pp. 1–10.
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6. Orynbayev S.A., Tokmoldayev A.B., Abdlakhatova N.Sh., Ribeiro L.F., Zhusup T.S. The potential of geothermal sources in southern Kazakhstan for heat supply to rural consumers: The case of the Zhambyl region // *Toraighyrov University Bulletin. Energy Series*. 2023. No. 2. Pavlodar. pp. 261–270.
7. Orynbayev S.A., Abdlakhatova N.Sh., Zhusip T.S., Zhanpeisova A.O., Tleshova A.S. Application of the Organic Rankine Cycle for the Geothermal Resources of Southern Kazakhstan // *Toraighyrov University Bulletin. Energy Series*. 2024. No. 4. Pavlodar. pp. 297–309.
8. Abdlakhatova N., Orynbayev S.A., Zhusip T.S. Prospects for the Utilization of Groundwater // Proceedings of the Scientific and Practical Conference of the Kazakh Scientific Research Institute of Water Management, Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan. Taraz, 2022. pp. 97–101.
9. Abdlakhatova N., Zhanpeisova A.O. Steam Turbine Unit in a Binary Geothermal Power Plant // *Mechanics and Technologies*. 2022. No. 2. pp. 73–78.

10. Abdlakhatova N., Tokmoldayev A.B. Development Prospects of Hydrogeothermal and Hydrogeomineral Resources in Kazakhstan // *Mechanics and Technologies*. 2022. No. 1(75). pp. 45–54.

11. Orynbayev S.A., Ribeiro L.F., Tokmoldayev A.B., Abdlakhatova N. Method for Utilizing the Energy of Geothermal Waters Using the Organic Rankine Cycle. Utility Model Patent of the Republic of Kazakhstan No. 10678, Bulletin No. 23, June 5, 2025.

Relationship of the Research to National and International Research Programs.

This research was conducted in accordance with the research plan of the Department of Energy and Electrical Engineering at the Kazakh National Agrarian Research University, where the author pursued doctoral studies. The work was also carried out within the framework of the state-funded research project "Development of Resource-Saving Technologies for the Advancement and Management of Water Resources and the Processing Industry of Kazakhstan, and Establishment of an Innovative Engineering Center" (State Registration No. BR24992867) at M.H. Dulaty Taraz University.

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Author's Contribution.

Using a thermodynamic model based on the Organic Rankine Cycle (ORC), the author performed calculations to evaluate the electricity generation potential of geothermal resources in the Almaty Region. The obtained results were processed, analyzed, and interpreted by the author in collaboration with the scientific supervisors: Professor-Coordinator Luis Frölén Ribeiro, D.Sc., Associate Professor S.A. Orynbayev, Ph.D., and Associate Professor A.B. Tokmoldayev.

The author substantiated the criteria for selecting ORC working fluids and determined quantitative indicators of geothermal energy utilization efficiency. A cascade utilization approach was proposed, involving the use of residual geothermal heat for supplying thermal energy to agricultural facilities, including greenhouse complexes. In addition, a methodology was developed for assessing the environmental and economic feasibility of the integrated utilization of geothermal energy under the conditions of Kazakhstan.

Structure and Scope of the Dissertation.

The dissertation consists of a list of normative references, definitions, symbols and abbreviations, an introduction, five chapters, a conclusion, a list of references, and appendices.

The dissertation contains 30 tables, 25 figures, and 5 appendices. The main body comprises 111 pages, while the total length, including the appendices, is 138 pages. A total of 100 references were reviewed and cited in the preparation of the dissertation.