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MODELING OF HEAT PROPAGATION PROCESSES AROUND A GEOTHERMAL WELL USING COMSOL MULTIPHYSICS

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Abstract. Introduction. *Globally, the depletion of conventional fuel and energy resources, along with the increasing environmental impact, has made energy conservation and the efficient utilization of existing energy resources an urgent issue.*

Methods and Materials. *The article investigates natural geothermal energy sources located in the Kashkadarya region and heat propagation processes around geothermal wells using the numerical modeling method. Heat transfer processes were determined based on numerical simulations using the COMSOL Multiphysics software platform.*

Results. *It was established that with an increase in geothermal source temperature within the range of T_G=50-75 °C, the temperature gradient and the intensity of heat propagation in the soil medium increase significantly (Figures 1–3).*

Conclusion. *The obtained results demonstrated the high potential for the efficient use of geothermal energy sources in building heating supply systems.*

Keywords: *geothermal energy source, geothermal well, heat propagation, temperature gradient, numerical modeling.*

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COMSOL MULTIPHYSICS DASTURI ASOSIDA GEOTERMAL QUDUQ ATROFIDA ISSIQLIK TARQALISH JARAYONLARINI MODELLASHTIRISH

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Annotatsiya. Kirish. *Butun dunyoda an'anaviy yoqilg'i-energetika resurslarining kamayib borishi hamda atrof-muhitga ekologik ta'sirning ortishi energiyani tejash va mavjud energiya resurslaridan samarali foydalanish masalalarini dolzarb muammoga aylantirmoqda.*

Usul va materiallar. *Maqolada Qashqadaryo viloyati hududidagi tabiiy geotermal energiya manbalari, geotermal quduq atrofidagi issiqlik tarqalishini sonli modellashtirish usuli yordamida tadqiqot qilindi. Issiqlik tarqalish jarayonlari COMSOL Multiphysics dasturiy platformasi yordamida sonli modellashtirish asosida aniqlandi.*

Natija. *Geotermal manba harorati T_G=50-75 °C oralig'ida ortishi bilan grunt muhitida harorat gradienti va issiqlik tarqalish intensivligi sezilarli ravishda oshishi aniqlandi (1-3 rasmlar).*

Xulosa. *Olingan natijalar geotermal energiya manbalaridan binolarni issiqlik ta'minoti tizimlarida samarali foydalanish imkoniyati yuqori ekanligini ko'rsatdi.*

Kalit so'zlar. *Geotermal energiya manbai, geotermal quduq, issiqlik tarqalishi, harorat gradient, sonli modellashtirish.*

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МОДЕЛИРОВАНИЕ ПРОЦЕССОВ РАСПРОСТРАНЕНИЯ ТЕПЛА ВОКРУГ ГЕОТЕРМАЛЬНОЙ СКВАЖИНЫ НА ОСНОВЕ ПРОГРАММНОГО ПАКЕТА COMSOL MULTIPHYSICS

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Аннотация. Введение. *Во всем мире сокращение запасов традиционных топливно-энергетических ресурсов и усиление экологического воздействия на окружающую среду делают вопросы энергосбережения и эффективного использования существующих энергетических ресурсов особенно актуальными.*

Методы и материалы. *В статье исследованы природные геотермальные источники энергии, расположенные на территории Кашкадарьинской области, а также процессы распространения тепла вокруг геотермальной скважины с использованием метода численного моделирования. Процессы теплопереноса определялись на основе численного моделирования с использованием программной платформы COMSOL Multiphysics.*

Результаты. *Установлено, что при увеличении температуры геотермального источника в диапазоне T_G=50-75 °C значительно возрастают температурный градиент и интенсивность распространения тепла в грунтовой среде (рисунки 1–3).*

Заключение. *Полученные результаты показали высокий потенциал эффективного использования геотермальных источников энергии в системах теплоснабжения зданий.*

Ключевые слова: *геотермальный источник энергии, геотермальная скважина, распространение тепла, температурный градиент, численное моделирование.*

Introduction

Globally, the depletion of conventional fuel and energy sources, coupled with a growing environmental impact, has made energy conservation and efficient use of existing resources a pressing concern. This energy crisis has taken on a global scale, demanding a transformation of our energy infrastructure and the exploration of sustainable alternatives such as renewable energy sources (RES) and heat pump units (HPUs) [1].

In regions experiencing extreme continental climates and significant climate fluctuations, ensuring a consistent energy supply and promoting energy efficiency become crucial challenges for autonomous heating and cooling systems. This is particularly true for facilities situated in rural areas and residential buildings reliant on independent heat and cold supply systems [2].

Rural facilities, encompassing residential homes, schools, preschools, agricultural operations like greenhouse farms and livestock complexes, milk and meat processing plants, and textile industries, are linked by networks that deliver essential services such as fuel, heating, cooling, hot water, and electricity. These systems must operate reliably and continuously even under emergency conditions, fuel shortages, and interruptions in energy supply. At the same time, there are problems associated with daily and seasonal irregularities in thermal, cooling, and electrical loads of consumers, low exergetic efficiency of traditional heating systems, as well as the need to ensure efficient and high-quality energy supply under conditions of abnormally cold and hot climates [2].

To solve these problems, the implementation of integrated autonomous heating and cooling supply systems formed on the basis of an optimal combination of renewable energy sources and heat pump units, taking into account the potential of geothermal energy sources in each region, is considered highly effective. Such systems can serve as an alternative to traditional heating and cooling systems for buildings and structures.

Over the coming 15 years, a significant focus will be placed on advancing energy-efficient devices and technologies. This will include exploring alternative renewable energy sources like geothermal heat pumps and thermal storage systems that leverage phase change materials. The goal is to establish a competitive and sustainable energy landscape by developing innovative and eco-conscious energy solutions.

The Republic of Uzbekistan is actively focusing on energy conservation and optimizing the use of traditional energy sources for heating, cooling, and hot water in a wide range of buildings, including municipal, residential, and public facilities. A key priority is adopting energy-efficient technologies throughout different economic sectors and rapidly expanding the use of renewable energy [3].

Materials and methods

The Kashkadarya region boasts a substantial capacity for renewable and alternative energy, encompassing solar, wind, biomass, and geothermal power derived from hot underground waters. Among these, geothermal energy, following solar and biomass, demonstrates considerable technical potential, positioning it as a promising contributor to the region's energy needs. Effectively harnessing geothermal energy for building heating and cooling systems can significantly decrease reliance on conventional fuels and energy. Studies show that utilizing geothermal energy can lead to a 60-80% reduction in traditional fuel consumption and a 1.5 to 2.0-fold decrease in harmful gas emissions released into the air [4].

Furthermore, geothermal energy sources offer an environmentally sustainable, reliable, and consistent supply of energy. They are recognized as a crucial element in enhancing the energy efficiency of regional heating systems.

Researchers conducted field measurements and experiments to analyze the temperature patterns of existing geothermal hot water sources in Kashkadarya region's Mubarak, Kasan, Nishan, and Kamashi areas. These studies focused on identifying key thermotechnical and operational features of these geothermal wells, such as the volume of geothermal water produced, its temperature, and the local climate conditions. Throughout the experimental studies, researchers continuously monitored geothermal water temperature, flow rate, and discharge levels, meticulously recording these changes over time. The collected data was then analyzed comparatively. Additionally, the assessment of the thermal and energy performance of the geothermal wells considered the influence of natural climatic and hydrogeological conditions.

Through experimental research, measurements, and observations at geothermal sites located in the Mubarak, Kasan, Nishan, and Kamashi areas of Kashkadarya, a comprehensive assessment of the region's geothermal energy potential was achieved [4]. Furthermore, both experimental and computational analyses were performed to determine the thermophysical and physicochemical characteristics of the geothermal water. Heat transfer processes were modeled numerically employing the COMSOL Multiphysics computational platform.

Results and discussions.

Based on the results of experimental investigations, measurements, and observations conducted at geothermal sources in the Mubarak, Kasan, Nishan, and Kamashi districts of Kashkadarya region, a numerical analysis of the heat propagation process in the soil medium surrounding a geothermal well was performed using the COMSOL Multiphysics software package. During the numerical simulation, a two-dimensional steady-state heat conduction model was applied.

The computational domain represented a 20 × 20 m soil layer, in the central part of which a geothermal well with a radius of 0.4 m was located. At the boundary of the geothermal well, a constant temperature in the range of $T_G = 50 - 75$°Cwas specified, whereas at the outer boundaries of the computational domain, the average soil temperature was assumed to be $T_\infty = 10$℃.

The heat propagation in the soil medium was calculated based on the heat conduction equation:

$$\nabla \cdot (\lambda \cdot \nabla T) + Q = 0 \tag{1}$$

where: T is the temperature, K; λ is the thermal conductivity coefficient of the soil, W/(m·K); and Qis the internal heat source, kW.

The heat flux density was determined according to Fourier's law:

$$\mathrm{q} = -\lambda \cdot \nabla T \tag{2}$$

Numerical calculations were performed in the COMSOL Multiphysics software package based on the Finite Element Method (FEM). The simulation results demonstrate the radial propagation of heat from the geothermal well into the surrounding soil massif. The obtained results are presented in Figures 1-3.

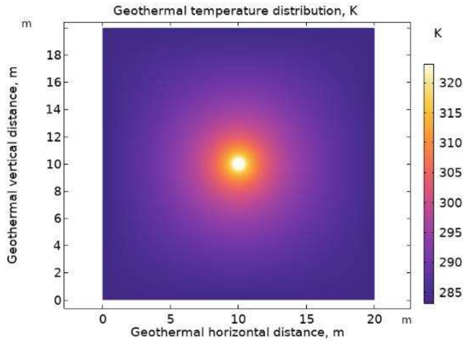

Figure 1. Temperature field distribution around the geothermal well for the "Mubarak" geothermal source located in the Mubarak district of Kashkadarya region at $T_G = 50$ ℃.

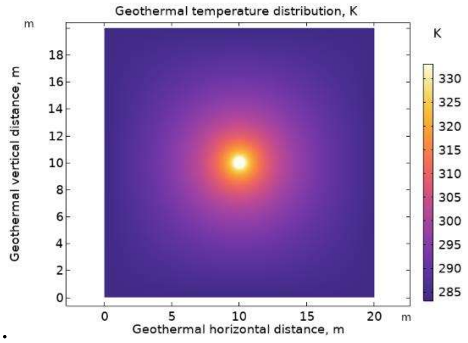

Figure 2. Temperature field distribution around the geothermal wells of the "Otkuduk" and "Chirokchi" geothermal sources at $T_G = 60$ ℃.

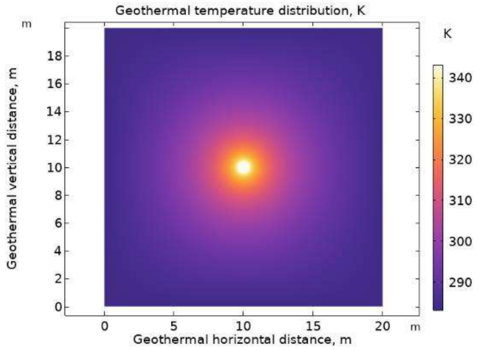

Figure 3. Temperature field distribution around the geothermal well for the "Karlyk" geothermal source located in the Mubarak district of Kashkadarya region at $T_G = 70$ ℃.

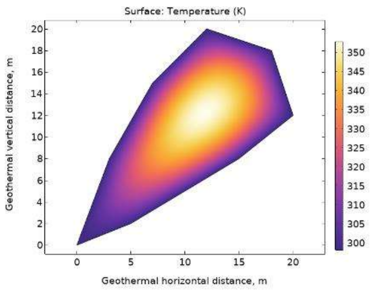

Figure 4. Temperature field distribution in the soil medium around the geothermal well.

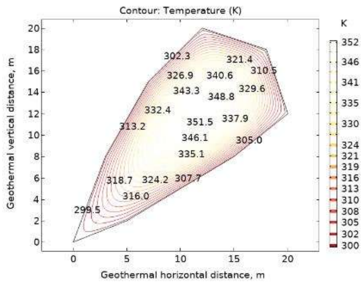

Figure 5. Distribution of temperature contours around the geothermal well.

The results presented in Figures 4 and 5 illustrate the temperature field distribution in the soil medium surrounding the geothermal well, as well as the radial heat propagation processes. The obtained results demonstrate that an increase in geothermal source temperature leads to a higher temperature gradient and greater heat propagation intensity in the soil medium.

Conclusions

The presented results illustrate the numerical simulation of the temperature field around a geothermal well obtained using the COMSOL Multiphysics software package. The numerical simulation results demonstrate the radial propagation of heat from the geothermal well into the surrounding soil medium. According to the calculation results, the maximum temperature is observed at the boundary of the geothermal well, while the temperature gradually decreases with increasing distance from the well.

It was established that with an increase in geothermal source temperature within the range of $T_G = 50 - 75$ °C, the temperature gradient and the intensity of heat propagation in the soil medium increase significantly. In particular, high-temperature geothermal sources are characterized by an increase in the heat propagation radius, resulting in a considerable portion of the soil massif being affected by elevated temperatures.

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