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EVALUATION OF WASTEWATER HEAT RECOVERY AND TECHNICAL WATER PRODUCTION USING A PARABOLIC TROUGH SOLAR CONCENTRATOR

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Abstract. Introduction. *This study evaluates the potential for recovering secondary heat from industrial wastewater using a parabolic trough solar concentrator (PTSC).*

Methods and Materials. *The research analyzes the stepwise heating of wastewater through efficient utilization of solar energy, the generation of high-temperature steam, and the subsequent production of technical water.*

Results. *Heat transfer processes were solved using the finite element method (FEM), while radiative heat transfer was modeled based on the Monte Carlo method.*

Conclusion. *The obtained results are significant for determining optimal design parameters of high-temperature solar energy systems and for implementing energy-efficient technologies through effective utilization of industrial wastewater heat.*

Keywords: *parabolic trough solar concentrator, wastewater, Shurtan GCC wastewater, secondary heat.*

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PARABOLASILINDRIK QUYOSH KONSENTRATORI ASOSIDA SANOAT OQOVA SUVLARINING ISSIQLIGINI UTILIZATSIYA QILISH VA TEXNIK SUV OLISH IMKONIYATLARINI BAHOLASH

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Annotatsiya. Kirish. *Mazkur tadqiqot ishida sanoat korxonalaridan chiqayotgan oqova suvlarning ikkilamchi issiqligini qayta foydalanish imkoniyatlari parabolasilindrik quyosh konsentratori (PSQK) asosida baholangan.*

Usul va materiallar. *Tadqiqotda quyosh energiyasidan samarali foydalanish orqali oqova suvlarning haroratini bosqichma-bosqich oshirish, yuqori haroratli bug‘ hosil qilish va undan texnik suv olish imkoniyatlari tahlil qilindi.*

Natijalar. *Tadqiqot ishida issiqlik uzatish jarayonlari chekli elementlar usuli yordamida yechildi, radiatsion issiqlik almashinuvi esa Monte-Karlo usuli asosida modellashtirildi.*

Xulosa. *Olingan natijalar yuqori haroratli quyosh energetik qurilmalarini loyihalashda optimal konstruktiv parametrlarni aniqlash hamda sanoat oqova suvlarining issiqligini samarali utilizatsiya qilish orqali energiya tejamkor texnologiyalarni joriy etishda muhim ahamiyatga ega.*

Kalit so'zlar. *parabolasilindrik quyosh kontsentratorlari, oqova suv, "Sho'rtan GKM" MChJ oqova suvlari, ikkilamchi issiqlik.*

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ОЦЕНКА ВОЗМОЖНОСТЕЙ УТИЛИЗАЦИИ ТЕПЛОТЫ ПРОМЫШЛЕННЫХ СТОЧНЫХ ВОД И ПОЛУЧЕНИЯ ТЕХНИЧЕСКОЙ ВОДЫ НА ОСНОВЕ ПАРАБОЛОЦИЛИНДРИЧЕСКОГО СОЛНЕЧНОГО КОНЦЕНТРАТОРА

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Аннотация. Введение. *В данной работе проведена оценка возможностей повторного использования вторичной теплоты сточных вод промышленных предприятий на основе параболоцилиндрического солнечного концентратора (ПЦСК).*

Методы и материалы. *В исследовании проанализированы возможности поэтапного повышения температуры сточных вод за счет эффективного использования солнечной энергии, генерации высокотемпературного пара и получения на его основе технической воды.*

Результаты. *Процессы теплопередачи решены с использованием метода конечных элементов, а радиационный теплообмен смоделирован на основе метода Монте-Карло.*

Заключение. *Полученные результаты имеют важное значение для определения оптимальных конструктивных параметров высокотемпературных солнечных энергетических установок, а также для внедрения энергоэффективных технологий за счет эффективной утилизации теплоты промышленных сточных вод.*

Ключевые слова: *параболоцилиндрический солнечный концентратор, сточные воды, сточные воды ООО «Шуртан ГХК», вторичная теплота.*

Introduction

Currently, world experience shows that parabolic trough solar concentrators are widely used for steam generation. In the USA, Germany, China and other countries, there are high-power thermal power plants, one of the structural elements of which is parabolic trough solar concentrators. Parabolic trough solar concentrators are connected in series to gradually increase the temperature of wastewater, and their focal axis is located horizontally [1-6].

Here, parabolic-cylindrical solar concentrators are arranged in a series configuration. To optimize solar energy capture, the concentrator can be positioned across two planes. An efficient way to harness thermal energy at the focal point is by employing a thermosyphon, which functions as a heat pipe (absorber tube). This research explored the potential for generating high-power steam and purified technical water by harnessing the residual heat from wastewater produced by "Shurtan GChC" LLC in the Guzar district of the Kashkadarya region. The analysis, grounded in the research's methodologies, considered the region's abundant solar radiation [1,2].

Methods and Materials.

Experimental determination of the radiation properties or accuracy parameters of the elements of the receiving system of a parabolic cylindrical solar concentrator requires complex experiments, there are significant limitations in the interpretation of the results (distance to the Sun, radiation spectrum, accuracy of the mirror surface). Therefore, the development of a mathematical model that allows calculating the properties of complex mirror systems, taking into account operating conditions, design features and surface roughness, is of particular importance. Mathematical modeling provides a significant reduction in material costs associated with the design and development of such systems compared to traditional research methods. The ability to consider a large number of options as a result of mathematical modeling made it possible to create a rational design of high-temperature solar power plants, ensuring maximum energy and mass efficiency [7-11].

The main characteristics of the parabolic-cylindrical solar concentrator (PCSC) receiving system element and high-temperature solar energy device. In practice, geometric η_g and energetic η_{kp} energy effeciency (EE) are distinguished. The geometric EE of the concentrator-receiving system elements is defined as the ratio of the thermal power N_0 falling on the receiver to the total thermal power N_0 returned from the working surface of the concentrator:

$$\eta_g = \frac{N_p}{N_0}. \tag{1}$$

The useful thermal power of the system is defined as the ratio of the N_s heat output transmitted from the energy receiver to the converter to the N_c heat output incident on the working surface of the mirror concentrator system.

$$\eta_{kp} = \frac{N_s}{N_c}. \tag{2}$$

The value of η_{kp} depends on the geometric and optical-mechanical parameters of all elements of the concentrator-receiver system and takes into account the loss of thermal power in the receiver as a result of heating from radiation that differs from the geometric FIK.

Results.

The steady-state heat transfer equation in a closed medium [6-10] has the following form.

$$K_{xx}\frac{\partial^2 T}{\partial x^2} + K_{yy}\frac{\partial^2 T}{\partial y^2} + K_{zz}\frac{\partial^2 T}{\partial z^2} = 0 \tag{3}$$

Where, T is the temperature; K_{xx}, K_{yy}, K_{zz} are the thermal conductivity coefficients in the X, Y, and Z axes.

If convective heat transfer occurs at the boundary or the heat flux density is specified, then the boundary condition can be written as follows.

$$K_{xx}\frac{\partial T}{\partial x}l_x + K_{yy}\frac{\partial T}{\partial y}l_y + K_{zz}\frac{\partial T}{\partial z}l_z + h(T - T_\infty) + q = 0 \tag{4}$$

where h is the heat transfer coefficient; T is the boundary temperature; $T\infty$ is the ambient temperature; lx , ly , and lz are the direction cosines of the vector normal to the surface; q is the heat flux density.

For an arbitrary-shaped concentrator-receiver system, it is convenient to solve the solution of equation (3) with boundary conditions (4) by switching to the finite element method. If we assume that the change in the curvature of a continuous surface is very accurately described by a surface consisting of small flat elements, then we can move from the three-dimensional problem of determining temperature fields in thin-walled structures to a two-dimensional problem.

Algorithm for modeling radiative heat transfer to a parabola-cylindrical solar concentrator-receiver system. The algorithm for modeling radiative heat transfer consists of the following steps.

Preparation of a geometric model of the research object (in the case under consideration - a concentrator-receiver system). Depending on the research goals, taking into account the mechanical, optical and other properties of the elements of the geometric model.

Preparation of a radiation model (radiation may consist of several elements). Setting the light field and the direction of incident radiation allows you to save on the study of the necessary areas and calculations. For example, setting the radiation wavelength for the Sun in monochromatic radiation or in the spectrum. Taking into account the number of sets of emitted rays for each radiation element.

Determine initial and boundary conditions based on research objectives.

We sequentially bypass all elements and consider them to have radiation on their surfaces. To do this, in accordance with the approach typical of Monte Carlo methods, we independently select random numbers R from a uniformly distributed series of numbers from zero to one, using the distribution law given for the spectral and energy characteristics of radiation. The direction of radiation is described by the angles θi and βi in the spherical coordinate system, the center of which is at the point of its emission.

By performing the following steps, we follow the direction of each ray until it leaves the system under study or is absorbed. We find the intersection point of the ray bundle trajectory with the geometric model. Let us assume that the surface area on which the ray falls has an absorption capacity α. In the general case, the value of α may depend on the wavelength and direction of the ray, the roughness parameters, and the surface temperature. We choose a random number Rα from a uniformly distributed sequence of numbers from zero to one. If this number satisfies the following condition:

$$0 \le R_\alpha \le \alpha,$$

If the random number Rα satisfies the following condition

$$\alpha < R_\alpha \le 1,$$

The distribution functions of the random variables Rθ and Rβ for each local value of the angles θ and β, depending on the optical properties of the surface at the point of incidence, are determined by the following method: if the surface is reflective, then reflection occurs according to the Descartes-Snell law [6].

$$\vec{l_r} = \vec{l_\iota} - 2\vec{l}(\vec{n} \cdot \vec{l_\iota}),$$

where $\vec{l_r}, \vec{l_\iota}$ are the direction vectors of the reflected and incident rays, and n $^{\rightarrow}$ is the normal vector to the surface.

- if the surface is rough, then the direction of reflection of the light is determined similarly to specular reflection, but with the addition of the standard deviation of the normal to the surface according to the rough- ness parameters.

- for the case of diffuse reflection, we write the following equation:

$$sin^2\theta = R_\theta \text{ и } \beta = 2\pi R\beta$$

Analyzing the paths of all rays and leveraging gathered statistical information allows us to characterize the radiation properties of the entire concentrator-receiver system, encompassing its working surfaces. This analysis yields key parameters such as reflection (surface scattering) coefficients, angular distributions, and heat flux patterns.

The analysis of the calculated data reveals a near-linear relationship between the power output of the parabolic-cylindrical solar concentrator and the peak temperature achieved at its focal point, both increasing proportionally with the intensity of solar radiation received by the concentrator's surface.

PCSC score results

The amount of solar radiation, W/m^2	PCSC Power, kW	Temperature at the focus of the PCSC, °C	EE PCSC
200	74,21	150	0,65
300	111,31	240	0,65
400	148,425	285	0,65
500	185,53	320	0,65
600	222,63	358	0,65
700	259,74	395	0,65
800	296,85	435	0,65
900	333,95	450	0,65
1000	371,06	465	0,65

The calculated heat flux values enable us to analyze heat transfer processes. Two-dimensional finite element analysis is employed to determine the temperature distributions.

A table below presents the calculated power, FIK, and temperature at the concentration point of a parabolic-cylindrical solar concentrator. These calculations consider varying levels of incoming solar radiation, assuming no heat loss to the surrounding environment.

Research has demonstrated the feasibility of generating thermal energy and technical water from a company's wastewater using a parabolic-cylindrical solar concentrator. Calculations indicate that with solar radiation levels between 600 and 900 W/m^2, the concentrator can achieve temperatures of 150 to 250 °C at its focal point. This temperature range is sufficient to produce high-temperature steam. The findings revealed a nearly linear relationship between solar radiation intensity and both system power and temperature. Implementing this technology at "Shurtan GChC" LLC could lead to annual thermal energy savings of 20-30% and a substantial decrease in environmental impact.

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