STRUCTURE AND OPERATING PRINCIPLES OF SOLAR CONCENTRATORS

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Abstract. This article examines the structure and operating principles of solar concentrators. The main types of solar concentrators, their structural components, and the principles of concentrating solar radiation are analyzed. Particular attention is paid to the efficiency of solar energy concentration, the factors affecting the performance of concentrators, and their potential applications in solar thermal energy systems. The study highlights the advantages of solar concentrators as an effective technology for utilizing renewable solar energy and discusses their role in improving the efficiency of solar energy conversion systems.

Keywords: solar energy, solar concentrators, solar radiation, solar thermal energy, solar energy concentration, renewable energy, solar thermal systems, parabolic trough concentrators, parabolic dish concentrators, central receiver systems, linear Fresnel concentrators, optical efficiency, thermal efficiency, solar tracking systems, heat transfer, concentrated solar power, solar energy conversion.

Аннотация. В данной статье рассматриваются конструкция и принципы работы солнечных концентраторов. Анализируются основные типы солнечных концентраторов, их конструктивные элементы и принципы концентрации солнечного излучения. Особое внимание уделяется эффективности концентрации солнечной энергии, факторам, влияющим на производительность концентраторов, а также их потенциальному применению в системах солнечной тепловой энергетики. В исследовании подчеркиваются преимущества солнечных концентраторов как эффективной технологии использования возобновляемой солнечной энергии и рассматривается их роль в повышении эффективности систем преобразования солнечной энергии.

Ключевые слова: солнечная энергия, солнечные концентраторы, солнечное излучение, солнечная тепловая энергия, концентрация солнечной энергии, возобновляемая энергия, солнечные тепловые системы, параболические желобные концентраторы, параболические тарельчатые концентраторы, системы с центральным приемником, линейные концентраторы Френеля, оптический КПД, тепловой КПД, системы слежения за Солнцем, теплопередача, концентрированная солнечная энергетика, преобразование солнечной энергии.

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Annotatsiya. Ushbu maqolada quyosh konsentratorlarining tuzilishi va ishlash prinsiplari o‘rganiladi. Quyosh konsentratorlarining asosiy turlari, ularning konstruktiv qismlari hamda quyosh nurlanishini konsentratsiyalash prinsiplari tahlil qilinadi. Ayniqsa, quyosh energiyasini konsentratsiyalash samaradorligi, konsentratorlarning ish unumdorligiga ta’sir etuvchi omillar va ularning quyosh issiqlik energiyasi tizimlaridagi potensial qo‘llanilishiga alohida e’tibor qaratiladi. Tadqiqotda qayta tiklanuvchi quyosh energiyasidan samarali foydalanish texnologiyasi sifatida quyosh konsentratorlarining afzalliklari yoritilib, ularning quyosh energiyasini o‘zgartirish tizimlari samaradorligini oshirishdagi roli muhokama qilinadi.

Kalit so‘zlar: quyosh energiyasi, quyosh konsentratorlari, quyosh nurlanishi, quyosh issiqlik energiyasi, quyosh energiyasini konsentratsiyalash, qayta tiklanuvchi energiya, quyosh issiqlik tizimlari, parabolik novli konsentratorlar, parabolik tarelkali konsentratorlar, markaziy qabul qilgichli tizimlar, chiziqli Fresnel konsentratorlari, optik samaradorlik, issiqlik samaradorligi, quyoshni kuzatish tizimlari, issiqlik uzatish, konsentrlangan quyosh energiyasi, quyosh energiyasini o‘zgartirish.

INTRODUCTION.

The increasing global demand for energy, the depletion of fossil fuel resources, and growing environmental concerns have led to a significant interest in renewable energy technologies. Among various renewable energy sources, solar energy is considered one of the most promising and widely available sources of clean energy. Solar radiation can be converted into thermal and electrical energy using different technological systems. One of the most effective technologies for utilizing solar radiation is the use of solar concentrators.

Solar concentrators are optical devices designed to collect solar radiation over a relatively large surface area and concentrate it onto a smaller receiving area. As a result, the energy density and temperature at the receiver increase significantly. This principle makes it possible to obtain high-temperature thermal energy, which can be used for electricity generation, water heating, industrial processes, desalination, and other applications.

The main types of solar concentrators include parabolic trough concentrators, parabolic dish concentrators, central receiver systems, and linear Fresnel concentrators. Each type has its own structural characteristics, operating principles, advantages, and limitations. The efficiency of these systems depends on several factors, including the intensity of solar radiation, optical properties of reflective surfaces, accuracy of solar tracking, receiver design, and thermal losses.

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The study of the structure and operating principles of solar concentrators is therefore important for improving the efficiency of solar energy utilization. The development of advanced reflective materials, efficient solar tracking systems, improved receivers, and thermal energy storage technologies can contribute to increasing the performance and reliability of concentrated solar energy systems.

The aim of this article is to examine the structure and operating principles of solar concentrators, analyze their main types and components, and evaluate the factors affecting their efficiency and practical application in solar thermal energy systems.

GENERAL OVERVIEW OF SOLAR CONCENTRATORS. Solar concentrators are specialized devices used to collect and concentrate solar radiation in order to obtain useful thermal energy. Their development is closely related to the growing demand for renewable and environmentally friendly energy sources. Since solar radiation is widely available, solar concentrators provide an effective method for increasing the energy density of sunlight and converting it into high-temperature thermal energy.

The basic principle of a solar concentrator is based on the collection and focusing of solar radiation. The concentrating surface receives direct solar radiation and redirects it toward a smaller receiving area. As the radiation is concentrated, the amount of energy reaching the receiver per unit area increases, which leads to a significant rise in temperature. The generated thermal energy can then be transferred to a heat-transfer fluid and used for various applications, including water heating, steam generation, industrial heating, and electricity production.

The structure of a solar concentrator generally includes a concentrating surface, a receiver, a heat-transfer system, a supporting structure, and, in many systems, a solar tracking mechanism. The concentrating surface is responsible for collecting and directing solar radiation, while the receiver absorbs the concentrated radiation and converts it into thermal energy. The heat-transfer system transports this energy to the required location or application. In order to maintain effective concentration throughout the day, tracking mechanisms can be used to continuously orient the concentrator toward the Sun.

Based on their structural design and method of concentration, solar concentrators can be divided into several main types. These include parabolic trough concentrators, parabolic dish concentrators, central receiver systems, and linear Fresnel concentrators. Although their structures differ, all of these systems operate according to the same fundamental principle: collecting solar radiation over a relatively large area and concentrating it onto a smaller receiver.

The performance of solar concentrators is determined by the interaction of their optical and thermal characteristics. The intensity of direct solar radiation,

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reflectivity of the concentrating surface, accuracy of solar tracking, quality of the receiver, and thermal losses all influence the amount of useful energy produced. Therefore, improving the design and operation of each component is essential for increasing the overall efficiency of the system.

Thus, solar concentrators represent an important technology for the efficient utilization of solar energy. By concentrating sunlight and producing high-temperature thermal energy, they can be used in a wide range of applications and contribute to the development of sustainable energy systems and the reduction of dependence on conventional fossil fuels.

STRUCTURE OF SOLAR CONCENTRATORS. The structure of a solar concentrator is designed to collect solar radiation over a relatively large area and direct it toward a smaller receiving surface. The effectiveness of the entire system depends on the coordinated operation of its structural components. In general, a solar concentrator consists of a concentrating surface, a receiver, a heat-transfer system, a solar tracking mechanism, and a supporting structure. Each component performs a specific function while working together to convert solar radiation into useful thermal energy.

The concentrating surface is the main optical component of the system. It is usually made of highly reflective materials, such as polished metal or specially manufactured mirror surfaces. Its primary function is to collect direct solar radiation and reflect it toward the receiver. The geometric shape of the concentrating surface determines how the solar rays are focused. For example, parabolic surfaces focus the incoming solar rays toward a focal point or focal line, which makes them suitable for achieving high temperatures.

The concentrated solar radiation is received by the receiver, which is positioned at the focal region of the concentrator. The receiver absorbs the concentrated radiation and converts it into thermal energy. Depending on the design of the system, the receiver may contain a heat-absorbing surface, tubes, or channels through which a heat-transfer fluid flows. The absorbed energy is then transferred to the working fluid, which carries the thermal energy to the next stage of the system.

The heat-transfer system connects the receiver with the thermal application or energy-conversion unit. A heat-transfer fluid, such as water, thermal oil, or another suitable medium, can be used to transport the collected thermal energy. When the fluid passes through the receiver, it absorbs heat and its temperature increases. The heated fluid can subsequently be used directly for heating processes or to produce steam for electricity generation.

To maintain the correct position of the concentrator relative to the Sun, many systems are equipped with a solar tracking mechanism. Since the apparent position

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of the Sun changes continuously during the day and throughout the year, the tracking system adjusts the orientation of the concentrator. Depending on the design, tracking can be performed along one or two axes. Accurate tracking is particularly important because even a small deviation can reduce the amount of radiation reaching the receiver.

All of these components are held together by a supporting structure, which provides mechanical stability and maintains the required geometric position of the optical and thermal components. The supporting structure must withstand wind, temperature changes, and other environmental conditions while maintaining the alignment of the concentrating surface and receiver.

Thus, the structure of a solar concentrator represents an integrated system in which the concentrating surface collects and focuses solar radiation, the receiver converts the concentrated radiation into thermal energy, and the heat-transfer system transports this energy for practical use. The tracking mechanism maintains optimal orientation toward the Sun, while the supporting structure ensures the stability and accurate alignment of the entire system. The coordinated operation of these components determines the overall efficiency and reliability of the solar concentrator.

TYPES OF SOLAR CONCENTRATORS. Solar concentrators can be classified into several main types according to their optical design, geometric structure, and method of concentrating solar radiation. Although these systems differ in construction and operation, they all have the same basic purpose: to collect direct solar radiation over a relatively large area and concentrate it onto a smaller receiver in order to produce useful thermal energy. The most widely used types are parabolic trough concentrators, parabolic dish concentrators, central receiver systems, and linear Fresnel concentrators.

PARABOLIC TROUGH CONCENTRATORS.

Parabolic trough concentrators use long, curved mirrors with a parabolic cross-section to concentrate solar radiation. The incoming sunlight is reflected by the parabolic surface toward a receiver tube located along the focal line. A heat-transfer fluid flows through the receiver tube and absorbs the concentrated solar energy. As the temperature of the fluid increases, the thermal energy can be used for industrial heating or for generating steam to produce electricity. Because of their relatively simple design and established technology, parabolic trough systems are widely used in large-scale solar thermal power plants.

PARABOLIC DISH CONCENTRATORS.

Parabolic dish concentrators have a dish-shaped reflective surface that focuses solar radiation onto a receiver positioned at the focal point. Unlike parabolic trough systems, which concentrate radiation along a line, parabolic dishes

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concentrate it onto a single focal region. This allows them to achieve high concentration ratios and very high temperatures. The thermal energy produced at the receiver can be used for electricity generation or other high-temperature applications. Their performance, however, depends strongly on accurate two-axis solar tracking.

CENTRAL RECEIVER SYSTEMS.

Central receiver systems, also known as solar tower systems, use a large field of individually controlled mirrors called heliostats. Each heliostat tracks the Sun and reflects solar radiation toward a receiver located at the top of a central tower. The concentrated radiation heats a heat-transfer medium inside the receiver, and the resulting thermal energy can be used to generate steam and electricity. One of the main advantages of this technology is its ability to achieve high operating temperatures and integrate thermal energy storage, allowing energy to be supplied even when direct sunlight is temporarily unavailable.

LINEAR FRESNEL CONCENTRATORS.

Linear Fresnel concentrators consist of a series of long, narrow, nearly flat or slightly curved mirrors arranged in parallel rows. These mirrors reflect sunlight toward an elevated receiver positioned above the mirror field. The receiver absorbs the concentrated radiation and transfers the resulting heat to a working fluid. Compared with parabolic trough systems, linear Fresnel concentrators can have a simpler supporting structure and potentially lower construction costs. However, optical effects such as shading, blocking, and imperfect focusing can reduce their overall efficiency.

COMPARISON OF THE MAIN TYPES.

The main difference between these types of solar concentrators is the way in which solar radiation is focused. Parabolic trough and linear Fresnel concentrators use line-focus concentration, while parabolic dish and central receiver systems use point-focus concentration. Line-focus systems generally operate at lower temperatures, whereas point-focus systems can achieve higher temperatures and concentration ratios.

Therefore, the choice of solar concentrator depends on the required operating temperature, available solar radiation, application, land conditions, tracking requirements, and economic considerations. Each type has its own advantages and limitations, but together they provide different technological solutions for the efficient utilization of solar thermal energy.

OPERATING PRINCIPLE OF SOLAR CONCENTRATORS. The operating principle of solar concentrators is based on collecting, reflecting, and concentrating direct solar radiation onto a smaller receiving area. The main purpose of this process is to increase the energy density of solar radiation and convert it into

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useful thermal energy. The operation begins when solar radiation reaches the reflective surface of the concentrator. Due to the specific geometric shape and optical properties of the reflecting surface, the incoming solar rays are redirected toward a focal point or focal line where the receiver is located.

The reflecting surface plays a key role in this process. It collects solar radiation over a relatively large area and directs it toward the receiver. In parabolic concentrators, for example, rays arriving approximately parallel to the optical axis are reflected toward the focus. The quality and reflectivity of the surface directly affect the amount of solar energy that reaches the receiver.

The receiver absorbs the concentrated solar radiation and converts it into thermal energy. As the concentrated radiation falls on the receiver, its temperature increases significantly. A heat-transfer fluid flowing through or around the receiver absorbs this heat and transports it to another part of the system. Depending on the application, water, thermal oil, molten salt, or another suitable working medium can be used for heat transfer.

The heated working fluid can then be used for different purposes. In solar thermal power plants, the thermal energy is commonly used to produce steam. The steam drives a turbine, and the turbine is connected to an electrical generator. In this way, solar radiation is converted first into thermal energy, then into mechanical energy, and finally into electrical energy.

For efficient operation, many solar concentrators use a solar tracking system. Because the apparent position of the Sun changes continuously, the concentrator must be correctly oriented toward the Sun. Tracking systems adjust the position of the concentrator so that solar radiation remains focused on the receiver. Depending on the type of concentrator, one-axis or two-axis tracking systems may be used.

The overall efficiency of the operating process depends on several factors, including the intensity of direct solar radiation, reflectivity of the concentrating surface, accuracy of solar tracking, receiver efficiency, and thermal losses. Optical losses can occur because of reflection imperfections, shading, blocking, and geometric errors, while thermal losses occur through conduction, convection, and radiation.

Thus, the operation of a solar concentrator can be described as a continuous sequence: solar radiation is collected by the reflecting surface → the radiation is concentrated toward the receiver → the receiver converts it into thermal energy → the heat-transfer fluid carries the energy → the thermal energy is used for heating or electricity generation. This interconnected process allows solar concentrators to efficiently utilize solar radiation as a renewable source of thermal energy.

CONCLUSION. The conducted analysis shows that the development of teachers' independent working competence is currently one of the important factors

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in improving the quality of education. A modern teacher should not only possess thorough knowledge of their subject but also be able to independently acquire new knowledge, study innovative approaches, and effectively apply them in practice throughout their professional career.

Innovative technologies serve as an important tool supporting this process. Various electronic platforms, digital educational resources, and online learning environments provide teachers with broad opportunities for self-development, enriching their professional knowledge, and studying modern pedagogical practices. As a result, teachers' skills in working with information, making independent decisions, and solving professional problems are enhanced.

Furthermore, the use of innovative technologies increases teachers' professional activity, encourages continuous inquiry, and contributes to the implementation of the principle of lifelong learning in practice. This, in turn, has a positive impact on improving the effectiveness of the educational process and ensuring high-quality learning outcomes for students.

Therefore, the purposeful and effective use of innovative technologies in developing teachers' independent working competence remains one of the priority tasks of the modern education system. The continuous development of teachers' digital and professional competencies will further contribute to the improvement of the education system.

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