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The Heat and Mass Exchange Modeling of a Solar Pond for Fish Breeding

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Abstract. In this research, an artificial solar pond in the shape of a truncated pyramid, intended for breeding fish, was studied, its depth is 1.27 m, the length of the edge is 1.32 m, the length of the base is 7.13 m, and the width is 5.84 m, foundation is 4.24 m long and 3.25 m wide, and it is made of concrete with a thickness of 10 cm. Balance equations for solar ponds were formulated and solved using numerical methods. In this case, when the changes of the ambient temperature during the month and the amount of solar radiation falling on one m2 surface are included as a boundary condition for finding unknown temperatures, the change of water temperature for the months of October and November was determined. When analyzing the results of two months, it was observed that the number of days when the water temperature was below 15°C was 34 days. Calculations were performed using the Python computer program.

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INTRODUCTION

With the increase in population, the demand for food products is increasing day by day [1]. Food products rich in protein for consumption are eggs, soybeans, fish, meat and grain products [2]. It can be seen from this that providing the population with fish products, which is one of the consumer products, is one of the urgent issues at the moment. Fish is considered a high-protein food product, despite the fact that more than a thousand different types of products are made from fish. and fish products are about 20 kg per capita per year worldwide [3].

Most fish require a water temperature of 15°C or higher to reproduce and develop, but fish can naturally adapt to seasonal changes at 0°C in winter and 20°C to 30°C in summer, but when the temperature does not change sharply, that is, when the water temperature changes to 12°C, they go into a state of shock, and in such conditions, the fish may become paralyzed or die [4-5]. If fish are transferred to cold water of 8°C or more after feeding, the digestive system slows down or stops, and if the feed is not fully digested, gas is produced, causing the fish to bloat, the body balance is disturbed, and eventually leads to their death [6-8]. Therefore, keeping the water temperature from sudden changes is necessary for all fish to gain maximum weight and increase [9].

Taking these into account, artificial reservoirs are created for fish breeding, and many works are being done to create favorable conditions for them [10]. The main of these is the need to provide additional energy to fish in artificial ponds to maintain the necessary water temperature. If traditional fuel is used as an energy source, it also causes many difficulties.

Climate change and depletion of traditional fuels are one of the big problems of today, and in this regard, technical and financial resources that help to increase energy efficiency in the use of renewable energy sources are widely discussed in the world and solar energy is one of the most promising substitutes for traditional energy sources [11-12].

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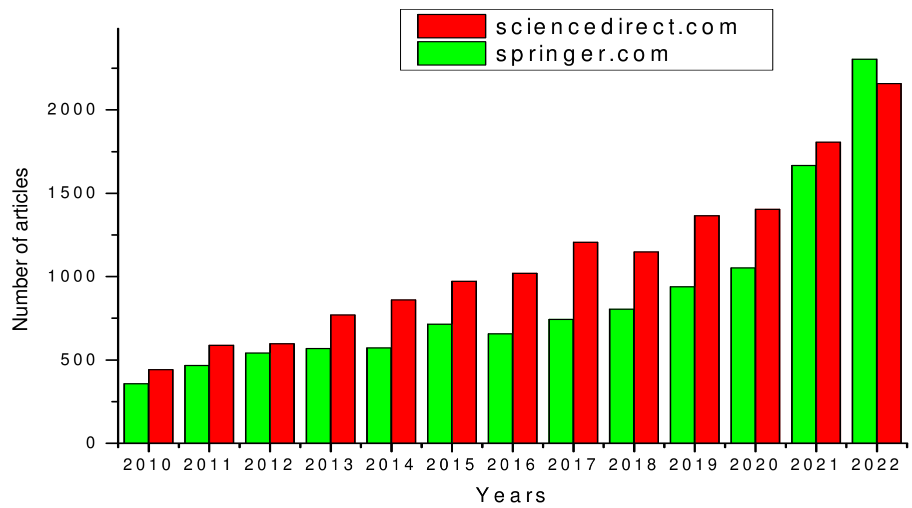


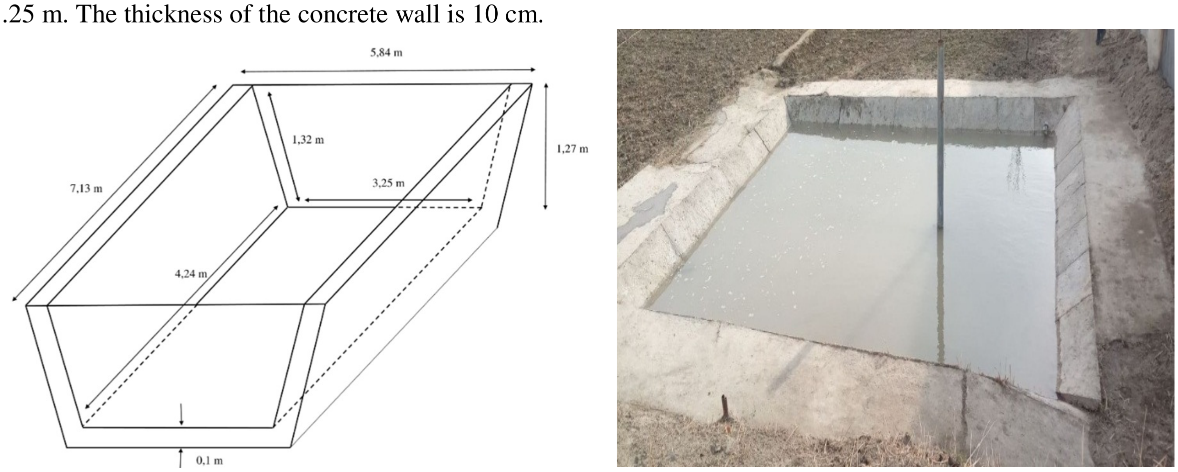
FIGURE 1. Sciencedirect.com and Springer.com scientific electronic databases, the number of articles devoted to the study of the solar pond, by year.

The annual analysis of the number of articles devoted to the study of solar ponds (2010-2022) in the scientific electronic databases Sciencedirect.com and Springer.com is presented in Fig.1. It can be seen that in 2010, 441 articles were published in Sciencedirect.com scientific electronic database, 356 articles were published in Springer.com scientific electronic database, and by 2022, Sciencedirect.com has 2158 articles and Springer.com has 2304 articles.

This shows how important the use of solar ponds has been over the years, the increase in energy demand and the need to use renewable energy devices, as well as the current relevance of research in this field [13-14]. Taking into account the above circumstances in artificial water ponds, it is necessary to use solar devices as an additional source of energy to maintain water temperature.

Experimental Setup.

An artificial solar pond for fish breeding has been created in Bukhara region. The geometric dimensions of the water pond are given below.The structure is made in the form of a pyramid, the depth is 1.27 m, the length of the ribs is 1.32 m, the length of the base is 7.13 m, the length is 5.84 m, the length of the second base is 4.24 m and the length is 3.25 m. The thickness of the concrete wall is 10 cm.



(a) (b)

FIGURE 2. General view of the solar pond: (a) schematic view; (b) with water.

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MATHEMATICAL MODEL

Heat balance equations for temperature of water in a solar pond (T_w) can be written as [15]

$$c\rho V\frac{dT_w}{d\tau} = (h_c + h_b)F_c(T_o - T_w) + h_r F_c(T_n - T_w) + U_1F_1(T_e - T_w) + U_2F_2(T_e - T_w) + \alpha_w F_c q_\Sigma \quad (1)$$

where, c, ρ, V and T_w - are the specific heat capacity, density, volume and temperature of water, respectively; τ- time; h_c, h_r, h_b- heat exchange coefficients with convection, radiation and evaporation between water and ambient air; U_1, U_2- heat transfer coefficient from water to the environment and to the ground; F_c- is the free surface of water evaporation; F_1, F_2- surface area of the internal side and bottom parts of the solar pond; T_o- ambient temperature; T_e- earth temperature; α_w- s the radiation absorption coefficient of water; q_Σ- incident total solar radiation on a horizontal surface.

Heat balance equations for water in a solar pond

$$c\rho V\frac{dT_w}{d\tau} = (h_c + h_b)F_c(T_a - T_w) + h_r F_c\left(T_p - T_w\right) + (U_1F_1 + U_2F_2)(T_e - T_w) + (\alpha\tau)_w F_c q_\Sigma \quad (2)$$

where T_a- air temperature above the solar pond; T_p- temperature of polyethylene; h_r- is the coefficient of heat exchange with radiation between water and polyethylene.

$$h_{p-o}\left(T_o - T_p\right) + h_r\left(T_w - T_p\right) + (h_{c1} + h_b)\left(T_a - T_p\right) = 0 \quad (3)$$

where, h_{p-o}- heat transfer coefficient from polyethylene to the environment; h_{c1}- is the coefficient of heat exchange by convection between the air above the solar pond and polyethylene.

$$c\rho V\frac{dT_a}{d\tau} = (h_c + h_b)F_c(T_w - T_a) + \left(h_{b1}F_p + h_{c1}F_c\right)\left(T_p - T_a\right) + (\alpha\tau)_a F_{p1} q_\Sigma \quad (4)$$

where, $(\alpha\tau)_a$- radiation transmission efficiency of polyethylene film; h_{b1}- heat transfer coefficient with convection; F_{p1}- is the surface area of polyethylene.

Heat transfer coefficients between the elements of the installation under consideration and the environment are determined using the formulas given in the literature [15-16].

Validation of the mathematical model was carried out by comparing the experimental data given in [17-19].

RESULTS AND DISCUSSION.

The following research works were carried out to evaluate the temperature regime of artificially created open reservoirs intended for fish breeding in the climatic conditions of Bukhara region. The above balance equations for solar ponds were solved using numerical methods using the successive approximation method. In this case, the changes in the temperature of the environment during the month and the amount of solar radiation falling on one m^2 of the surface were included as a boundary condition for finding unknown temperatures, and the change in water temperature was determined. Calculations were performed using the Python computer program.

Fig.3 shows the results obtained from the mathematical model for October 2023. In this month, the maximum value of the ambient temperature is 34°C and the solar radiation falling on 1 m^2 surface is 870 W/m^2, the temperature of the water in the basin is 21°C. we can see that the temperature was around 15°C, and there were 9 days when the water temperature was below 15°C.

In November, the maximum temperature rise of the environment is 19°C and the solar radiation falling on 1 m2 surface is 800 W/m2 (Fig. 4.). The water temperature in the pool has dropped from 15°C after 5 days and appears to be around 6°C.

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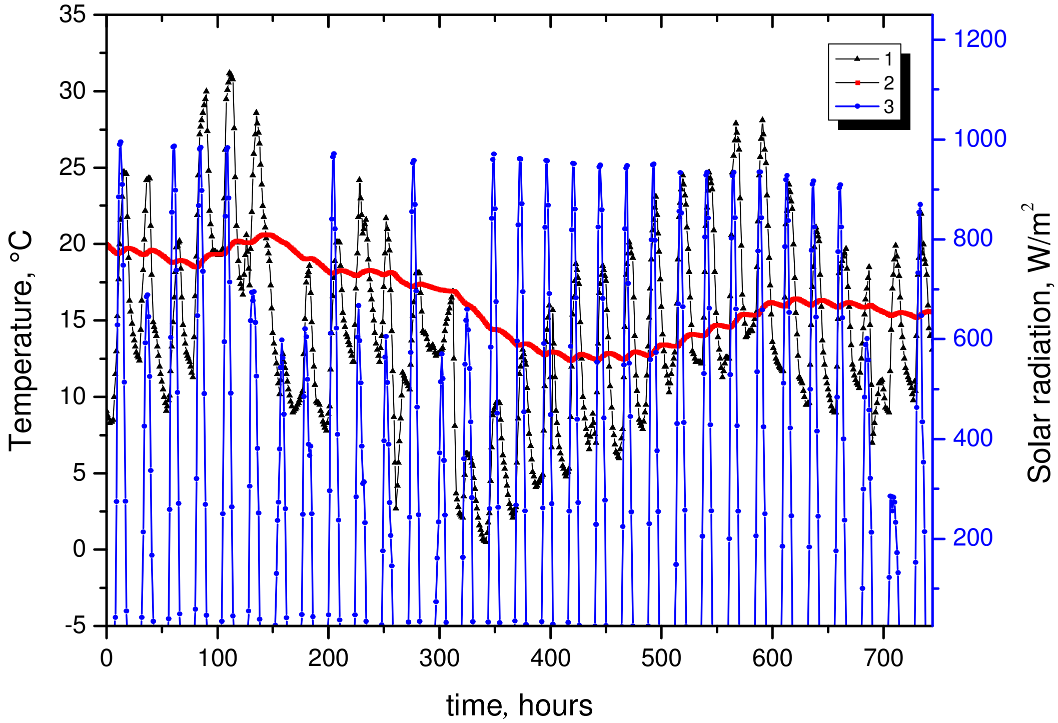

FIGURE 3. Changes in ambient temperature (1), water temperature (2) and solar radiation (3) for October.

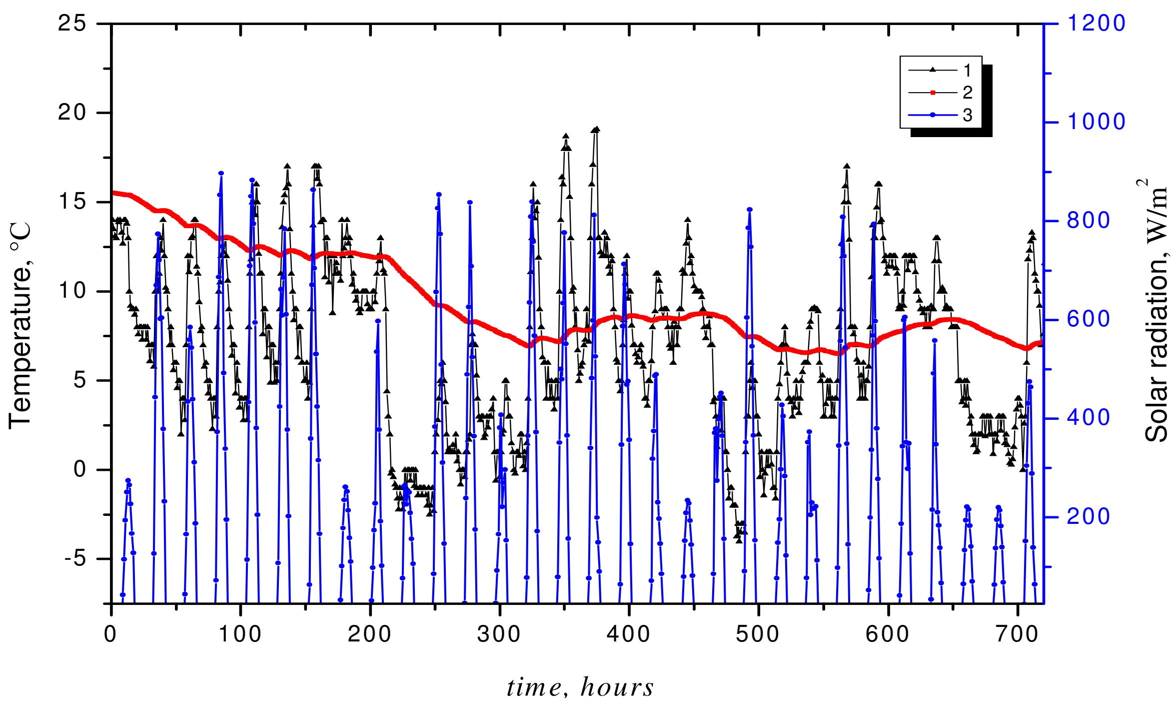

FIGURE 4. Changes in ambient temperature (1), water temperature (2) and solar radiation (3) for November.

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CONCLUSION

This study was conducted for the climatic conditions of Bukhara, and the research study investigated a truncated pyramid-shaped artificial solar pond for fish breeding. The depth of the artificially created water pond is 1.27 m, the length of the edge is 1.32 m, the length of the base is 7.13 m, the width is 5.84 m, the length of the base is 4.24 m and the width is 3.25 m, and the thickness is 10 cm made of concrete. The balance equations for the solar ponds were formulated and solved using the numerical method of successive approximation. In this case, when the changes of the ambient temperature during the month and the amount of solar radiation falling on one m^2 of the surface are included as a boundary condition for finding unknown temperatures, the change of water temperature for the months of October and November has been determined. When analyzing the results of two months, it was observed that the number of days when the water temperature was below 15°C was 34 days. Calculations were performed using the Python computer program. Such studies allow to evaluate the temperature regimes of solar ponds. From the analysis of the results of the research, it can be seen that one of the main factors is the assessment of the temperature regime of solar ponds, the presence of sufficient temperature for the development of fish grown in artificial ponds. The use of additional solar devices to ensure sufficient temperature allows for favorable conditions for the development of fish throughout the year. This will increase the efficiency of fish farming.

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