Experimental studies of the efficiency of a solar system, including a passive water heater and an active seawater distiller

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ABSTRACT

In the hot climate of the Mangistau region, located on the eastern coast of the Caspian, there are no sources of freshwater. Of the available groundwater deposits, only three are suitable for drinking water supply. The scarcity is felt in remote areas and coastal areas, where the population uses groundwater.

The provision of the population is carried out by a seawater desalination plant. In the hot summer period, due to high temperatures, the productivity of desalination plants decreases (the water in the channels reaches 30 °C, and the plants are designed for 20 °C). This factor provides opportunities for the development of desalination plants using this heliopotential.

Easy to manufacture, environmentally and economically viable solar desalination plants are essential for coastal areas where water is scarce.

The article presents the results of experimental studies of the heliosystem, which consists of a passive solar water heater (SWH) and an active solar desalination plant (SW). Water is heated in the SWH pool and supplied to the lower SW pool-1, in which the desalination process is achieved by cooling the water pool-2.

By reducing the temperature in the SW volume, the condensation temperature is reached. The coating of 2 layers of glass with an air gap reduces heat losses and raises the temperature in the installations by 10–12 °C and keeps it at night. Horizontal glass coverings provide a large area for solar radiation to enter the pool surface. Heat transfer by convection, in the volume between the "cold" and "hot" basins, is determined using the convection coefficient, which depends on the product of the numbers G and Pr. According to the results of experiments, the daily productivity of the desalter was 1.97, 1.83 and 2.31 l/m² on the day of July 20, 21 and 22, 2019. The maximum value of the total heat transfer coefficient for SVN was 32.9 W/m² °C, for SW 49.4 W/m² °C.

1. Introduction

The works [1, 2, 3] describe the research, as well as the results of the development by the authors of the article of a method and device for desalination of seawater.

The Mangistau region, located on the eastern coast of the Caspian Sea, produces 25 % of Kazakhstan’s oil. There are no natural surface and underground sources suitable for consumption in the region. In almost all groundwater deposits, salinity averages 27 g/l, which requires desalination and deep purification with decontamination [1, 2]. The need of the region and districts in all types of water is provided by the Mangyshlak nuclear power plant “MAEK”, where seawater is desalinated by SIDEM installations (France). However, the problem of drinking water shortage in the region is especially acute for districts and coastal zones remote from the regional center. It should be noted that desalination plants are designed for seawater with a temperature of +20°C, but on summer days, in hot climates, the water of the Caspian Sea heats up to +28–30 °C, which leads to a decrease in water production up to 15 % [1]. This makes it possible to use natural energy for the development and implementation of efficient solar seawater desalination plants to provide coastal areas with drinking water.

Consider the experience of experimental research in the development of solar watermakers using environmentally friendly and natural energy of the Sun.

In the former USSR, under the leadership of Doctor of Technical Sciences, Professor Baum V.A, since 1960, experimental research has...
been carried out on the development and use of solar desalination plants at the Institute of the Sun of Turkmenistan (Baum, 1960, 1961) [4,5,6]. In 1968, in the village of Bakhraden in the Kara-Kum desert in Turkmenistan, the 1st experimental production solar installation for sheep farms was built. Installation with an area of 600 m², in the summer, gave from 2.4 to 4.0 l. freshwater from 1 m² of the pool area.

As for desalination using cooling, back in 1975, Sherwood et al., in [7], presented the processes of heat transfer during evaporation of water in a desalination tank by cooling a glass cover with a thin layer of water, under which a pool with heated water. In practice, the most economical solar desalination method has been developed. The watermaker is very simple in design, does not require costs, and consists of a mini-pool, located in a volume hermetically sealed with a 5 mm thick glass cover, while the thickness of the cooling water layer is 1.3 mm. Research by Mousa and Bassam., Focused on achieving high-efficiency rates, with a temperature difference between cold water on a glass cover and heated water in the volume of a solar desalination plant [8]. Tiwari and Bapeshwara, also studying the efficiency of water evaporation when cooling the glass surface, concluded that the amount of distillate depends on the flow rate and the thickness of the cooling water flow. It was found that low water consumption caused a thinner uniform layer of water and the volume of the distillate doubled [9]. Abu-Hijleh [10], used cold water to lower the temperature of the glass and found that the temperature of the coating glass and the cooling water should be at the same temperature. High performance in the desalination plant was ensured with a glass

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glass, with a gap of 2.5 cm between them. Soft glass transparent PVC film of the Achilles Vinistar FR series (Japan), with optical clarity. In this work, we denote it as “glass”. In the center of the second layer of the glass cover, a ball 3 is laid, creating a slight slope so that the condensate drains into the pool channel. The pool itself 4, on the sides, as well as in the places of inlet and outlet of seawater, has holes 5, for all 5 channels of the pool, into which silicone pipes are inserted for water overflow. Thermal insulation 6 (foam thickness 3.0 cm, foam layer 2.0 cm) is laid at the bottom of the water heater.

It should be noted that all positions of the solar desalination unit (SW) are practically the same as in the SWH, except for 7 and 8. The SW is also made of boards, but the height of box 1 is 15 cm, taking into account the upper pool-2 (position 7), from a profile with triangular corrugations, with condensate collectors 8, on its lower surface facing the lower basin-1 (position 6), for heated in SWH. Pool-1 (position 6) is made the same as in the SWH (Figure 2). The experimental installations were installed on timber frames with thermal insulation of the base with mineral wool. The timber frames with thermal insulation of the base with mineral wool.

The water level in the SWH and SW basins and the pressure in their volume were measured with a transparent U-shaped liquid manometer. The water level was measured every 30 min using a thermometer, Pt 100 SMD RTDs. The maximum measuring range of thermocouples is 150 °C, with a probe length of 1.0 m and a cable of 2.0 m. To measure the temperature of the water in the absorber and siliconic nozzle, a testo 905-T contact thermometer was used, with a submerged penetration probe with a length of 30 cm. Under the experimental conditions, the amount (flow) of water supplied to the SWH and SW was controlled using Acatel clamps, which were used in experiments. The clamps are made of durable plastic and have serrated lips.

The water level in the SWH and SW basins and the pressure in their volume were measured with a transparent U-shaped liquid manometer. Measurements of the flux density of solar radiation incident on the surface of the installations were carried out using a silicon pyranometer.

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This is a very accurate universal pyranometer SP-Lite (manufactured by Kipp & Zonen). Accounting for the yield of distillate in ml was accounted for by weighing the container on an electronic balance every 12 h. The temperature regime of installations is influenced by the conditions for the entry of solar radiation onto their surface. In this regard, the installations are located in an open area, with no shading, and are oriented with a long axis to the south-north (Figure 3).

The site coordinates are 43° 49'6.26 "N, 51° 1'51.45" E. (43° 49'N 51° 1'E).

3. Research and analysis of thermal processes of HS installations

One of the widespread methods of using solar energy in the processes of heating and desalination of seawater is direct or passive heating of heat receivers designed to absorb and convert solar energy into thermal energy.

Covering the pools of installations with glass and the formation of an air gap creates a system in which mass transfer processes occur in the volume of installations.

The heat of solar radiation passing through the glass is accumulated by the surface of the heat receiver (pool) and heats the seawater. The energy generated in the process of moisture condensation on the inner surfaces of the glass in the SWH, and the upper cooling pool-2 in SW, also participate in water heating. Joint heat transfer in the volume of solar installations due to convection and heat conduction determines convective heat transfer in general. In work [17], Dunkle (1961), gives an empirical expression for calculating the heat transfer coefficient by convection, which is widely used in calculations.

The values of the coefficient C and the exponent n, in the equation for calculating the Nusselt criterion, were calculated from the experimental results. Thus, heat exchange in the volume of installations is carried out mainly by convection, radiation, evaporation [18].

3.1. Passive solar water heater (SWH)

3.1.1. Convective heat transfer

In the work, the “soft glass” of the coating was designated as “glass”, and the absorber-tray as a basin. SWH - passive installation. The process of heat transfer in the volume of the SWH occurs by natural convection, due to the temperature difference ΔT, water and the inner surface of the glass. The heat flux arising as a result of convective heat transfer between water and the lower surface of the second layer of glass is found from the equation given in [19]:

\[ Q_{cw} = h_{cw-g} \cdot A_b \cdot (T_W - T_{g,i2}) = h_{cw-g} \cdot A_b \cdot \Delta T \]

where \( h_{cw-g} \) is the coefficient of convective heat transfer between water and glass (W/m² °C); \( \Delta T \) is the temperature difference between water and the inner surface of the glass - the driving force of the heat exchange process (°C); \( A_b \) - pool area (m²); \( T_W \) - water temperature; \( T_{g,i2} \) - a temperature of the inner surface of the lower glass (2nd layer) (°C).

The numbers Nu, Re, Gr and Pr have given in the calculations are the most important similarity numbers as applied to convective heat transfer and determined by the method of the similarity theory. We calculate the Nusselt number by the formula given in [20], which is written not in terms of the usual Grashof number \( Gr \), but in terms of the modified Grashof number \( Gr^* \), which makes it possible to use this formula for our case:

\[ Nu = \frac{(h_{cw-g} \cdot X_c)}{K_c} = C(Gr^* \cdot Pr)^n \]

where \( X_c \) is the average characteristic for solar installations, the height from the evaporation surface to the moisture condensation surface, (the distance between the surfaces of water and glass (m); \( K_c \) is the thermal conductivity of water vapor in the volume of the SWH (W/m °C); \( C \) and \( n \) - constants in the Nusselt formula; \( Gr^* \) - modified Grashof number; \( Pr\) - Prandtl number.

The convective heat transfer coefficient between water and glass is represented as follows:

\[ h_{cw-g} = \frac{K_c}{X_c} \cdot C(Gr^* \cdot Pr)^n \]

In formula (2), the Prandtl number takes into account the influence of the physical properties of water and is a dimensionless parameter. Dunkle in [17] presented a modified Grashof number, convection heat
transfer for a vapor-air humid environment providing mass transfer of particles with low molecular weight. The modified Grashof number \( (Gr^* ) \) and the Prandtl number \( (Pr) \) are found from formulas (4) and (5)\(^{(5)} \), which were generalized and proposed by Dwivedi and Tiwari in \(^{(21)} \):

\[
Gr^* = \beta \varepsilon \mu_k^2 \Delta T
\]

(4)

where \( \beta \) is the coefficient of volumetric expansion of the medium (1/K); \( \mu_k \) is the viscosity of humid air.

The parameters in (4) by the method of mathematical modeling of the measured data, as well as the study of their properties and relationships (regression analysis), are determined in \(^{(22)} \), Kumar and Tiwari \( (1996) \). For expression (3) With the criteria \( Gr^* \) and \( Pr \), Dunkle \( (17) \) established the ratio of the convective heat transfer coefficient \( h_c \) with the temperature difference during evaporation of water with moisture condensation on the glass surface.

\[
h_{c,w-g} = 0.884 \cdot (\Delta T)^{1/2}
\]

(5)

where \( P_{w} \) is the partial pressure of the vapor-air mixture \( (N/m^2) \); \( P_{g} \) - partial pressure of the vapor-air medium on the surface of the coating glass \( (N/m^2) \).

The coefficient of convective heat transfer of the glass coating with the environment, taking into account the wind speed, is calculated by the formula from the work of Zurigat and Abu-Aradi \( (23) \):

\[
h_{c,w-g} = 2.8 + 3 \cdot V
\]

(6)

3.1.2. Radiation heat transfer

In connection with the fact that the coating of 2 layers of glass has a slight slope, we will consider the coating parallel to the pool. The rate of radiant heat transfer for the water surface in the pool and the bottom glass of the coating is determined by the expression obtained in \(^{(24)} \):

\[
q_{r,w-g} = h_{r,w-g} (T_w - T_{g1})
\]

(7)

where \( h_{r,w-g} \) - is the coefficient of radiative heat transfer between water and glass \( (W/m^2 \cdot ^\circ C) \); \( T_{g1} \) is the temperature of the inner surface of the clear coating glass \( (^\circ C) \).

The heat flux leaving into the environment, through a coating of 2 layers of glass, with an air gap, during radiant heat exchange, is calculated by the formula:

\[
q_{r,w-g} = \epsilon_g \cdot \sigma \cdot (T_{g1}^{1/2} - T_{sky}^{1/2})
\]

(8)

where \( \epsilon_g \) is the emissivity of the glass; \( \sigma \) - Stefan-Boltzmann constant \( (W/ m^2 \cdot K^4) \); \( T_{g1}^{1/2} \) - average glass temperature \( (^\circ C) \); \( T_{sky} \) - sky temperature \( (^\circ C) \).

The coefficient of radiant heat transfer between the surfaces of water and a translucent coating can be described by the expression given in Sharma and Malik \( (20) \):

\[
h_{r,w-g} = \epsilon_w \cdot \sigma \cdot [(T_w + 273.15)^2 + (T_{g1} + 273.15)^2] \cdot [T_w + T_{g1} + 546.3]
\]

(9)

where \( \sigma \) is the Stefan-Boltzmann constant \( (5.669 \times 10^{-8}) \) \( (W/(m^2 \cdot K^4)) \); \( \varepsilon_w \) and \( \varepsilon_{g1} \) emissivity of water and glass with values 0.96 and 0.91, respectively, as well as \( T_w \) and \( T_{g1} \) - a temperature of the water and the inner surface of the 2nd (lower) glass layer \( (^\circ C) \).

3.1.3. Heat transfer by evaporation

In the volume of solar devices covered with translucent coatings, heat and mass transfer takes place, complicated by phase transformations on the surface of seawater and the inner surface of the coating glass.

The heat transfer between the water in the pool and the glass, during the evaporation of water and its condensation on the inner surface of the coating, will be calculated by the formula in \(^{(19)} \):

\[
q_{e,w-g} = h_{e,w-g} (T_w - T_{g1})
\]

(10)

The coefficient of heat transfer from water to glass, \( h_{e,w-g} \) \( (W/m^2 \cdot ^\circ C) \), can be calculated using the formula in \(^{(17, 25)} \), when simulating heat transfer due to evaporation:

\[
h_{e,w-g} = 16,273 \cdot 10^{-3} \cdot \frac{P_{w} - P_{g}}{T_w - T_{g1}}
\]

(11)

Malik et al. \(^{(26)} \), performed the correlation of the Lewis number, which characterizes the ratio of heat transfer by thermal conductivity, and presented it as:

\[
h_{e,w-g} = 0.013 \cdot h_{e,w-g}
\]

(12)

To determine the heat transfer coefficient, Kumar and Tiwari \(^{(22)} \) developed a model based on the temperature range of water, glass, and the location of the clear cover relative to the pool of water, which we will use. In expression (19), constants \( C \) and \( n \) are determined experimentally:

\[
h_{e,w-g} = 16.273 \cdot 10^{-3} \cdot \frac{K_w}{X_C} \cdot [(Gr^* \cdot Pr)^{1/3} \cdot \frac{P_{w} - P_{g}}{T_w - T_{g1}}
\]

(13)

3.2. Active solar watermaker (SW)

3.2.1. Temperature regime of coating from 2 layers of glass

Desalination of water into SW is achieved by washing the surface of pool-2 with cold water, under which pool-1 for hot water is located. In SW, the radiation force penetrates only to the pool-2 and to the water on its surface, while the radiant energy does not pass to the pool-1. The temperature regime in the SW volume will be determined by the amount of absorbed radiation and the amount of heat loss to the environment. We represent the heat balance equation in the form of the Dwivedi and Tiwari model \( (27) \):

\[
a_{r1} \cdot I_1 + h_{r,w-g} (T_{w1} - T_{g1}) - U_a \cdot T_{g1(mean)} = h_{r,g} (T_{g1(mean)} - T_{g1})
\]

(14)

where \( a_{r1} \) is the absorption capacity of the glass; \( I_1 \) - radiation intensity \( (W/m^2 \cdot ^\circ C) \); \( h_{r,w-g} \) is the total coefficient of heat transfer from water to the coating glass \( (W/m^2 \cdot ^\circ C) \); \( T_{w1} \), \( T_{g1} \) - temperature of water and an inner surface of coating glass \( (^\circ C) \); \( U_a \) is the total coefficient of heat loss in the SW from the coating \( (W/m^2 \cdot ^\circ C) \); \( T_{g1(mean)} \) - a temperature of the air gap (average temperature of 2 glasses of the coating) \( (^\circ C) \); \( h_{r,g} \) is the coefficient of heat transfer between coating glasses and SW; \( T_{a} \) - ambient temperature.

The total heat transfer coefficient is determined from the expression:

\[
h_{w-g} = h_{r,w-g} + h_{w-w} + h_{w-g}
\]

(15)

The heat transfer coefficients between water and glass: \( h_{w-g} \), \( h_{w-w} \) and \( h_{w-g} \) are given in expressions (3), (9) and (11), respectively.

3.2.2. Heat balance of the process of evaporation and condensation

Condensation of moisture on the bottom surface of pool-2 leads to its heating, while the water in pool-1 is cooled. That is, the heat loss of heated water takes place. In this case, the mass of the condensate outlet is determined by the useful energy transferred from the SW in the form of heated water, the amount of heat from this water and the heat losses of the heated water during cooling and through the bottom of the pool-1 into the environment \(^{(28)} \):

\[
M_a \cdot C_w \frac{d T_w}{dt} = Q_{w(SW)} + Q_{w(1)} + U_{w(1)-2} + U_{(1)-w}
\]

(16)
Table 1. Physical and technical characteristics of the elements of installations and water.

| Heat engineering parameters | Symbols | Water | Pool-1 (SWH, SO) | Pool-2 (CO) | Glass |
|-----------------------------|---------|-------|-----------------|-------------|-------|
| Absorption capacity         | \(a\)   | 0.05  | 0.93            | 0.93        | 0.03  |
| Transmittance               | \(\varepsilon\) | 0.93  | -               | -           | 0.94  |
| Emissivity                  | \(\varepsilon\) | 0.96  | -               | -           | 0.94  |
| Specific heat                | \(C_p\) | 4187  | 500             | 500         | 630   |

where \(M_{sw}\) is the mass of the condensate outlet (ml); \(C_w\) - specific heat capacity of water (J/kg °C); \(Q_{sw}(b.1)\) - the amount of heat transferred by heated water from pool-1 (W/m²°C); \(Q_{sw}\) - useful thermal energy from SWH in the form of heated water; \(U_{sw}(b.1) - b.2\) is the coefficient of heat loss from the water surface in the pool-1, when cooling the pool-2; \(U_{sw}(b.1) - b.2\) is the coefficient of heat loss of the pool-1 through its bottom.

The useful heat of the SWH is determined by the formula:

\[
Q_{sw} = F_h((ar)I_2(t)) - U_{sw}(SWH) \cdot A_{SWH} \cdot (T_w - T_a)
\]  

(17)

where \(F_h\) - coefficient of heat removal from SWH in the form of heated water; \((ar)\) - effective absorption capacity; \(A_{SWH}\) is the area of the irradiated surface of the heat receiver.

The amount of heat \(Q_{sw}(b.1)\) given off by the water from the pool-1 is expressed as:

\[
Q_{sw}(b.1) = U_{sw}(b.1) - b.2 \cdot h_{sw}(b.1) \cdot (T_w(t) - T_a(t))
\]  

(18)

where \(U_{sw}(b.1) - b.2\) - heat losses at the time \(t\), in the form of heat transferred by hot water to the cooled pool-2 (W/m²°C).

The coefficient of heat loss \(U_{sw}(b.1) - b.2\) of the pool-1 water, at a moment in time, that is, the amount of heat received by the pool-2 plate (when washing with cold water), taking into account the thickness \(L_{b.2}\), and thermal conductivity \(K_{b.2}\), and heat losses through the bottom of the pool-1 are determined by formulas (19) and (20) from [29, 30, 31]:

\[
U_{sw}(b.1) - b.2 = \frac{h_{sw}(b.1) \cdot L_{b.2}}{h_{sw}(b.1) + \frac{K_{b.2}}{L_{b.2}}}
\]  

(19)

By solving the above equations, the water temperature in the pool-1 was determined:

\[
T_w = \frac{\int_0^T \left[1 - e^{-aT} \right] + T_{w_{(2)}}e^{-aT}}{L}
\]  

(21)

The hourly condensate yield can be found from the expression in [32]:

\[
m_{bw} = \frac{h_{bw}(T_w - T_{a})}{L} \cdot 3600 \cdot A_{SS}
\]

where \(L\) is the latent heat of vaporization. For sea water heated to a temperature of more than 70°C: \(L = 3.1615 \cdot 10^6 [1 - 7.6160 \cdot 10^{-4} T_w]\) and less than 70°C \(L = 2.4935 \cdot 10^6 [1 - 9.4779 \cdot 10^{-4} T_w + 1.3132 \cdot 10^4 \cdot T_w^{1 - 7} \cdot T_w^{1} - 4.79740 \cdot 10^{5} \cdot T_w^{1}].\) Ass. - pool area-1 SW (m²).

4. Results and discussion

Experimental studies of the temperature regime and performance of solar installations of SWH and SW were carried out on July 20, 21 and 22, 2019, in the suburban area of Aktau RK (coordinates of the experimental site 43° 49'6.26 "N, 51° 1'51.45" etc.).

The weather conditions for these days are as follows. 07/20/2019 (pressure 759 mm Hg, wind 4.2 m/s, and 34% air humidity). 07.21.2019 (pressure 760 mm Hg, wind 3.2 m/s, humidity 37%) and 22.07.2019 (pressure 757 mm Hg, wind 4.5 m/s, humidity 38%).

Table 1 shows the thermal parameters of water and installation elements.

![Figure 4. Dynamics of changes in the temperature regime in the volume of the SWH solar water heater (July 20, 21 and 22, 2019).](image-url)
4.1. Passive SWH installation

The dynamics of changes in the temperature of the coating glass, the air in the volume of the installation, water and absorber-pool, under the influence of solar energy and outside air temperature are shown in Figure 4. The peak of radiation was observed at noon (850 W/m², 845 W/m² and 850 W/m², for 3 days, respectively. The maximum heat of the outside air (41 °C, 40 °C and 42 °C) for these days was recorded at 15.00. It was during this period that the maximum heating of water (70 °C) and the pool (76 °C). The temperature of the glass above the pool was 69 °C since the use of a coating of 2 layers of glass with an air gap significantly reduces heat losses. Thus, the air gap allowed maintaining the water temperature above 40 °C at night, until 23:00 on 20.07.2019 and until 01:00 on 22.07.2019. The accumulation of heat, due to a decrease in heat losses on the first day, provided an intensification of water heating in the following days.

The minimum distance between the glass and the pool (3.5 cm), the water level (3.5 cm), the material and shape of the pool in the SWH, made it possible to ensure the efficiency of water heating. The water level (3.5 cm) in the channels was below the shelf shelves (4.4 cm) high (Figure 1), which ensured the entry of solar radiation onto the surface of the shelves. So, 25% of the pool surface was heated simultaneously with water. It is known that a high temperature of heating water is provided by the presence of a heat-absorbing surface [33].

The results of studies of SWH, with a trapezoidal corrugation basin, are consistent with the conclusions in the work of Montazeri et al., [34], which substantiated the effectiveness of a new type of absorber, similar to that proposed by us in the work.

4.2. Active installation of SW

It is known that the higher the water temperature, the greater the speed of movement of particles and their energy, and the greater the number of fast molecules that leave the water surface per unit time [12, 17, 35]. When evaporated, its molecules form water vapor, which mixes with the air. The purpose of the experiment is to reach the condensation temperature at which the water vapor of the pool-1, when cooled, becomes saturated and begins to condense on the surface of the pool-2, in the form of drops.

In experiments with cooling water heated to 50–55 °C, the distillate yield was minimal, at a water temperature of 60 °C or more, the productivity increased by 25%.

Figure 5 shows the results (July 20, 21 and 22, 2019) for the desalination of seawater with a temperature of 60 °C–72 °C. Lowering the

![Figure 5. Dynamics of changes in the temperature regime in the volume of the solar desalination plant SW (July 20, 21 and 22, 2019).](image)

| Table 2. Values of heat transfer coefficients for SWH and SW. |
|-------------------------------------------------------------|
| Time (h) | Solar water heater SWH and SW (between the glass cover and the pool) | Solar desalination plant SW (between pools 1 and 2) |
|          | $h_{w-g}$ | $h_{w-g}$ | $h_{w-g}$ | $h_{w(h_1):h_2}$ | $h_{w(h_1):h_2}$ |
| 7.00     | 0.691     | 1.497     | 4.846     | 0.620             | -               |
| 9.00     | 0.993     | 3.973     | 5.392     | 0.892             | -               |
| 11.00    | 1.440     | 11.869    | 6.174     | 1.107             | -               |
| 13.00    | 1.974     | 23.628    | 6.758     | 1.841             | -               |
| 13.30    | 2.118     | 25.013    | 6.860     | 2.376             | 47.013          |
| 15.00    | 2.083     | 23.754    | 6.803     | 1.968             | -               |
| 15.30    | 2.014     | 21.611    | 6.671     | 2.583             | 53.106          |
| 17.00    | 1.981     | 18.136    | 6.244     | 1.854             | -               |
| 17.30    | 1.902     | 16.013    | 6.087     | 2.288             | 48.517          |
| 19.00    | 1.637     | 11.161    | 4.603     | 1.727             | -               |
| 19.30    | 1.594     | 8.272     | 3.496     | 2.109             | 46.273          |
| 21.00    | 1.271     | 6.527     | 0.803     | 1.206             | -               |
| 23.00    | 0.972     | 3.462     | -         | 0.841             | -               |

The total heat transfer coefficient in the volume of installations is determined by formula (14).
Combining the installations into a single solar system contributes to an increase in the yield of distillate in SW, due to additional energy in the form of heat supplied from the SWH.

3. The process of distillation in SW, when washing with cold water the surface of pool-2, located above pool-1 with water heated in the SWH, does not require high temperatures, besides, the heat of condensation of moisture is involved in the subsequent heating of pool-1.

4. Lowering the temperature in the SW volume with the use of cold water increases the condensation rate and increases the productivity of the desalter.

5. The shelves of the pools are also exposed to the direct influence of radiant energy through the transparent coating, since the water level is below them, which provides heating of 25% of the surface.

6. Analysis of the results obtained showed that the use of a two-layer coating provides a more stable temperature regime in the volume of solar installations, and also reduces the effect when the ambient temperature changes.

7. High performance in the desalination plant was ensured, with a cold water film thickness of 2.5 × 10⁻⁴ m, hot water. 3.5 × 10⁻⁴ and a water flow rate of 1.5 × 10⁻⁷ m²/s.

Declarations

Author contribution statement

Koibakova S.E. & Kenzhetayev G.J.: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Syrlybekkyzy S. & Suleimenova B.: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Tarasenko G.: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Tazhanova L.: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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