STUDY OF THE RELATION BETWEEN THE CAPACITY OF A HELIOSTATIONARY INSTALLATION AND CLIMATIC CONDITIONS IN THE MANGYSTAU REGION

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Highlights

The study investigates how the Mangystau region's climate affects the heliostationary installations' capacity and evaluate the ways in which local weather patterns affect solar energy performance and efficiency.

Abstract

This paper attempts to theoretically investigate the desalination of water by solar distillation with solar preheating. Davis Pro2 weather station was used to determine the meteorological data. Ambient temperature, solar intensity, and wind direction and speed were obtained from the weather station. Mathematical calculations of desalination plant efficiency and thermal performance were performed using Engineering Equation Solver (EES) software, TRNSYS 18.0, and an in-house thermal balance algorithm. By the conducted mathematical calculations, the most efficient configuration of the experimental seawater desalination system was determined. Referring to the calculated data in winter, the heat fluxes for the components of the solar distiller are as follows: between the sun and the glass 15,24 W; between the sun and the water 77,41 W; between the sun and the absorber 171,59 W. Likewise, the similar values in summer are 41,95 W, 213,11 W, 472,40 W, respectively. The maximum solar radiation was 750 W/m^2, and the maximum outdoor temperature was 20^{0}C. With these weather station indicators, the capacity of clean water before 15:00 hours was 2.5 liters.

Keywords
ozonation, desalination, solar desalination, groundwater, salinity, water purification.

Introduction

Desalination is now being used to solve the problem of drinking water shortages, and reverse osmosis, in which water is passed through membranes to separate salt, is often used for this purpose. In this method, salt ions are forced through the membrane using an electric current [1].

Seawater desalination is mainly used in the Gulf countries in the Middle East, the Caribbean, but also in the United States, Australia and Spain and in large urban agglomerations such as city-states like Singapore or Hong Kong [2][4].

Considering the fresh water supply across the country, the prospect of desalination and seawater purification is unquestionable [3] [26].

Solar distillers have been investigated by many scientists for seawater desalination in various glazed surface configurations - single tilt, double tilt, spherical shape, prismatic shape, multi-stage configuration, etc. [31][21]. Such distillers have been mainly investigated for tropical climatic regions where there is a demand for fresh water [6][8][23].

Based on the identified disadvantages and costliness of the techniques, the most promising at the moment methods of distillation and reverse osmosis, the authors conducted research, the advantages are given to desalination of sea water by cooling the evaporator chamber with water sampled from a shallow depth (up to 5 m), using the conditions of hot climate of the region for its heating, which reflects the relevance [10][32].

The authors [12][33][34][25] have developed a solar collector and obtained a RK patent on the results of obtaining desalinated water using solar plants and obtaining fresh water by cooling the volume of the evaporation chamber [5][22][35].

The method [25] differs on the physical laws of temperature difference between sun-heated sea warm water and colder water taken from deep sea [7]. On the basis of this method, a desalination unit was developed, with an adjacent solar water heating pad.

To efficiently produce clean drinking water through solar energy conversion, a system has been developed that includes a parabolic solar trough combined with a specially designed distillation device [9][24]. The incoming solar radiation from the sun is focused and concentrated on the receiving tube using the parabolic trough, heating the incoming impure water, after which it is atomized into a specially designed distillation device where it is vaporized and re-condensed into clean drinking water [11][13].

The electricity expenses for the water treatment and desalination process can vary from 30 to 60% of the operating costs, therefore, minor changes in electricity tariffs have a direct impact on the cost of treated water [15].

The authors of [14][20][27][28][29][30] carried out a study of direct solar heat pumps operating with R22 and its equivalents.

This paper is devoted to the theoretical study of water desalination by solar distillation with solar preheating [20]. The work is presented in the weather conditions of Aktau city for the Western region of Kazakhstan.

Methods of Research and Analysis

A weather station Davis Pro2 was used to determine the meteorological data. Data on ambient temperature, solar intensity, and wind direction and speed were obtained from the weather station [16].

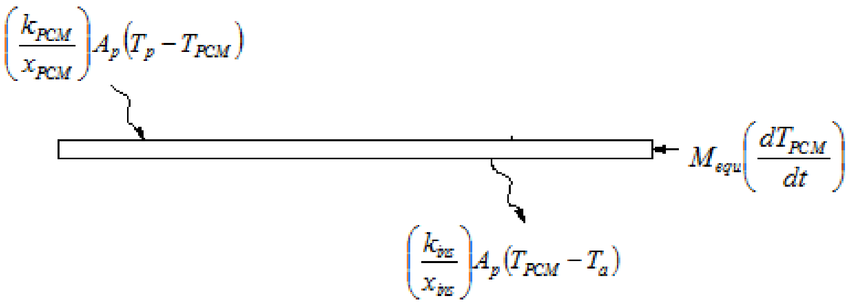
In order to perform the testing, electronic temperature sensors, electronic pressure sensors, and pressure gauges were installed in the regenerative solar-thermal desalination unit. The temperature sensors were installed on the following parts of the solar distiller: on the inner and outer sides of the inclined glazed surface, on the absorber surface, in the salty sea water above the absorber. Pt1000 temperature sensors with measurement range from -50 °C to 450 °C were used to realize temperature measurements. High pressure sensor with measuring range of 0-30 bar, low pressure sensor with measuring range of -0.5-7 bar.

Mathematical calculations of desalination system efficiency and thermal characteristics were performed using Engineering Equation Solver (EES) software, TRNSYS 18.0, as well as using proprietary heat balance algorithm [17].

The solar desalination performance evaluation method is based on a basic formula including mass flow rate of distilled water, total solar distiller efficiency, global solar radiation, latent heat of vaporization of water, absorber area of the pool absorber [18].

$$\left(\frac{k_{PCM}}{x_{PCM}}\right)(T_b - T_{PCM}) = \left(\frac{k_{ins}}{x_{ins}}\right)(T_{PCM} - T_a) + M_{equ}\frac{dT_{PCM}}{dt}$$

Energy balance of phase change material



The energy balance equation for basin with phase change material is expressed as:

$$\alpha_b \tau_g \tau_w I(t) A_b = m_b c_{pb,PCM}\frac{dT_b}{dt} + h_{c\ b-w}(T_b - T_w) + \left(\frac{k_{PCM}}{x_{PCM}}\right)(T_b - T_{PCM})$$

The desalinization installation was designed and assembled on the basis of mathematical calculations (Figure 1). The most efficient configuration of the experimental seawater desalination system was determined by mathematical calculations [19].

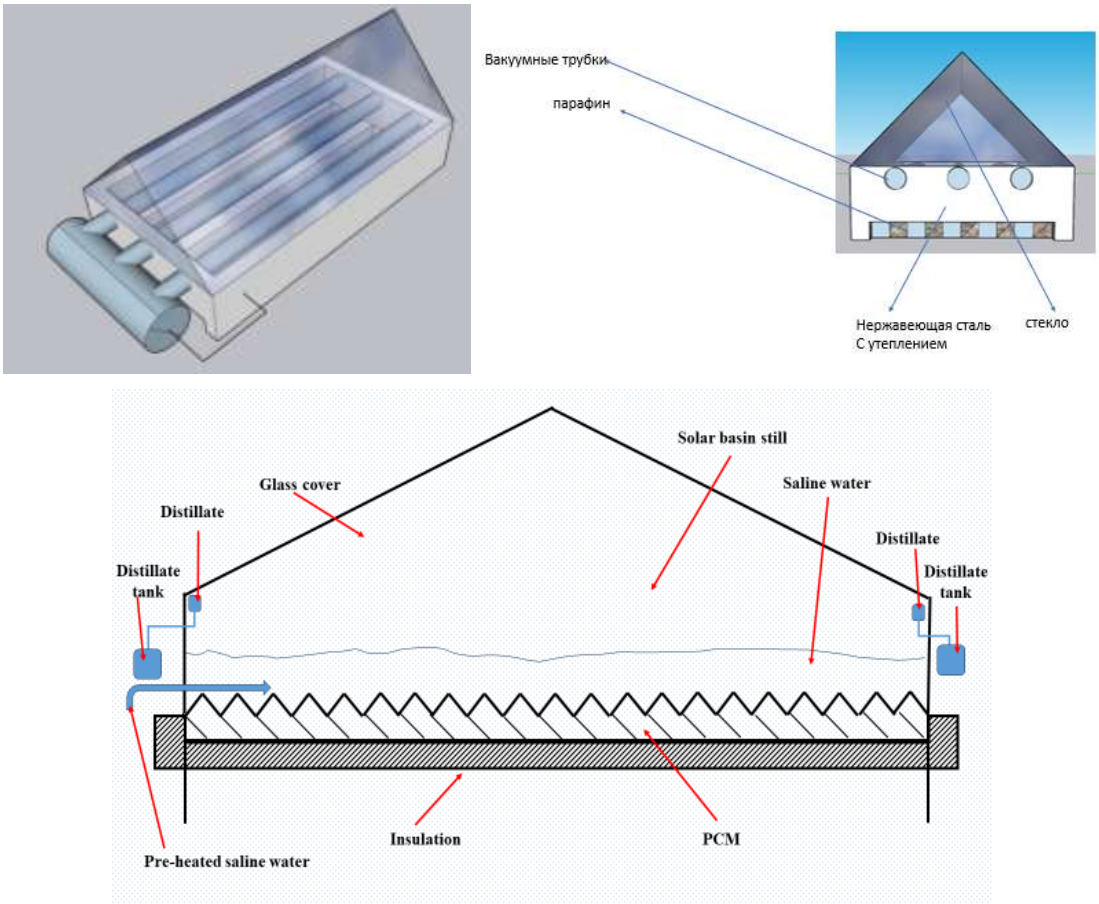


Figure 1. Solar desalination using an efficient corrugated absorber pool

The system consists of two parts, the first part is a solar vacuum heater where the raw water is supplied for preheating. The second part is a solar distiller. Phase change material (PCM) is used to improve the performance. The solar vacuum heater can heat the raw water up to 90˚C.

The length is 2 m, the length with insulation is 2.20 m. Width 1 m, width with insulation 1.20 m. Depth 30 cm, depth with paraffin 40 cm, depth with insulation 50 cm. Bottom is gorfied with paraffin. Vacuum tubes with circulation of sea water, which after preliminary heating in vacuum tubes gets into the tank.

Experimental Section

Temperature changes of different parts of the solar desalination plant were measured for climatic conditions of Aktau city (Kazakhstan). Aktau is located on the eastern shore of the Caspian Sea. Numerical calculations were performed for meteorological data for February and July 2023-24, obtained from a weather station installed on the campus of Esenov University in Aktau.

Calculations for climatic conditions were carried out. Average daily global solar radiation for Aktau city area is typically 18,0 MJ/m^2 (Figure 2).

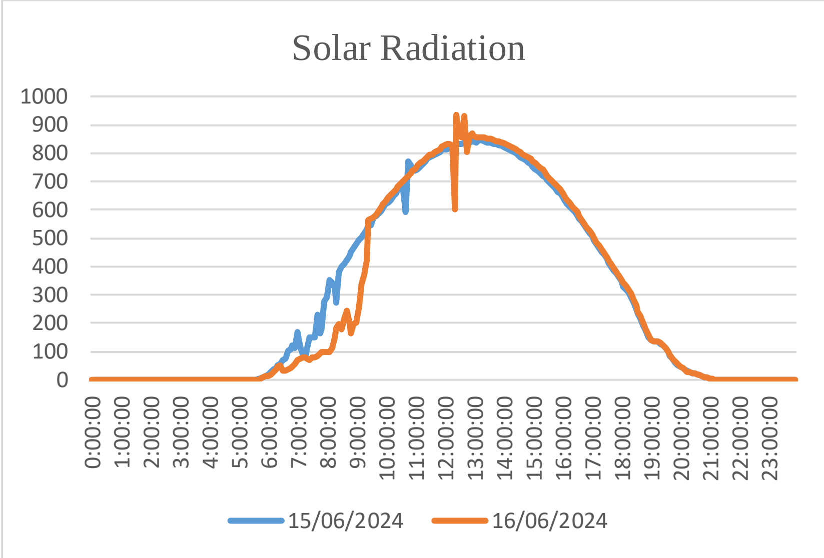


Figure 2. Diurnal solar intensity graph

The preliminary calculations have been carried out for a solar desalination plant for the Aktau area during the summer period, where there is an excess of solar radiation, in order to obtain the maximum distilled water yield. The efficiency of a solar desalination plant typically varies from about 30% to 50%.

Hence the mass flow rate of distilled water per square meter of area can be calculated, which is 2.34 liters. The average productivity for tropical climatic regions varies from 2.3 to 3.0 l/m2/day. The continental climate of Mangistau region corresponds to the minimum productivity of tropical countries.

According to the calculation results, the average distilled water consumption is about 0,25 liters/hour or 2,4 liters per day. During 7 days about 15,75 liters of distilled water were produced. These consumption rates are directly related to the area of the distiller, the efficiency of the installation, and the average daily solar radiation. In order to identify the influence of solar radiation on the mass flow rate of the desalination plant, calculations were made for a day and for 12 months. For continental climate of Kazakhstan the value of average daily solar energy varies from 2 to 5 MJ/m^2in winter period of the year, and in summer solar radiation reaches up to 22 MJ/m^2, which is the maximum value for this area. According to the results obtained, the mass flow rate of the desalination plant is calculated for 12 months, and the results confirm a direct relationship with the amount of solar radiation, showing a minimum value of 0,1 L/day in the winter period and a maximum value of 2,9 L/day in the summer period of the year. In the modeling, the results were also obtained for each month separately, taking into account the average monthly solar radiation per 1 $m^2$and the mass flow rate.

The minimum value of solar radiation is in December, which is about 45 MJ/m^2per month at the same time the mass flow rate is 4,8 liters/month for this month, and the maximum value of solar energy is in June, which is about 500 MJ/m^2per month and accordingly the mass flow rate of desalination is about 67 liters/month.

The average daily temperature variation was determined (Figure 3).

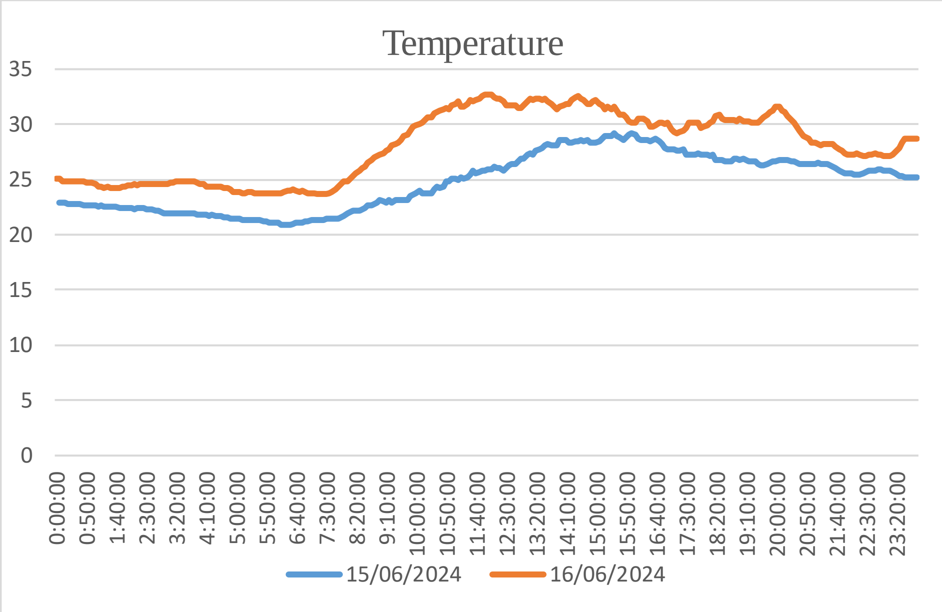


Figure 3. Diurnal temperature variation graph

The highest temperature is observed from 10.30 to 16.30 time of day.

Calculations for solar vacuum water heater:

To heat 1 liter of water by 1 ˚C would require 4200 J of energy approximately 1.16 W.

The absorption of the solar vacuum collector is considered to be 100% from this follows:

$$K = E_s/1.16$$

This ratio shows how much water can be heated by how many degrees in 1 hour in a solar collector with an area of 1 m^2.

The following equation shows how long it takes to heat a certain amount of water depending on the initial temperature.

$$\frac{m * (T_2 - T_1)}{A * K} = h$$

where m is the mass of water to be heated,T_1- initial water temperature, T_2 – is the required water heating temperature, A – is the area of the vacuum solar water heater, h – is the heating time.

The daily preheating temperature is shown in Figure 4. The water heated by the solar water heater enters the solar distiller for desalination.

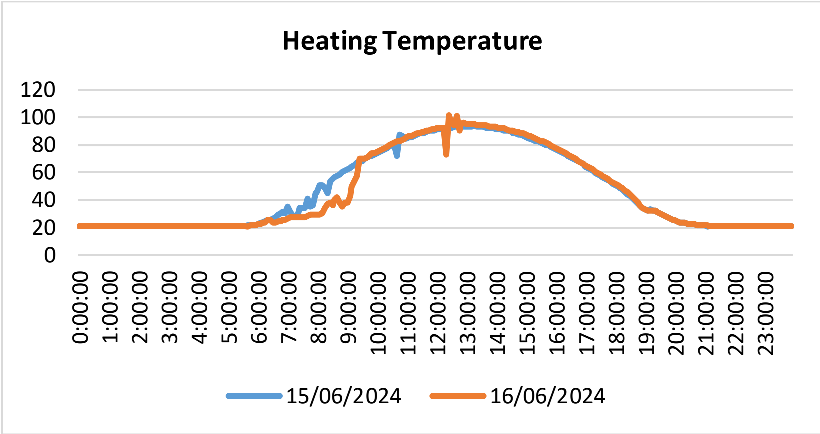


Figure 4. Daily distiller preheating temperature

According to the results, where the average solar radiation was 600 W/m^2, and the average outdoor temperature was 27^{0}C, the maximum solar radiation was 900 W/m^2, and the maximum outdoor temperature was 35^{0}C. With these weather station values, the capacity of clean water was 60 liters. Figures 5, 6 show the total distillate production rate.

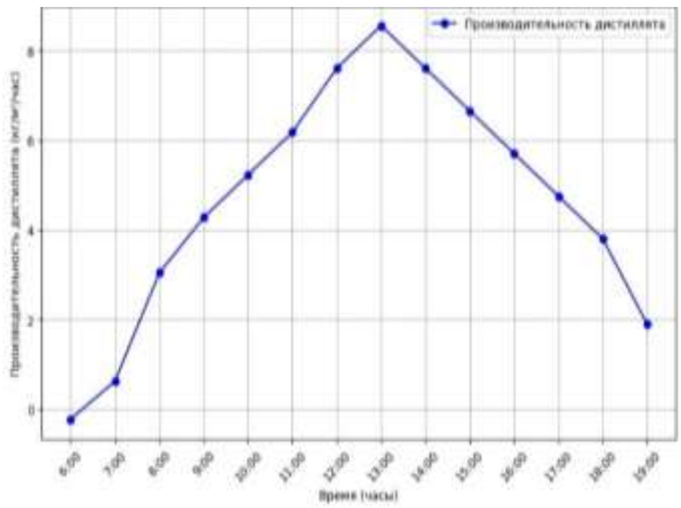


Figure 5. Distillate performance during the day

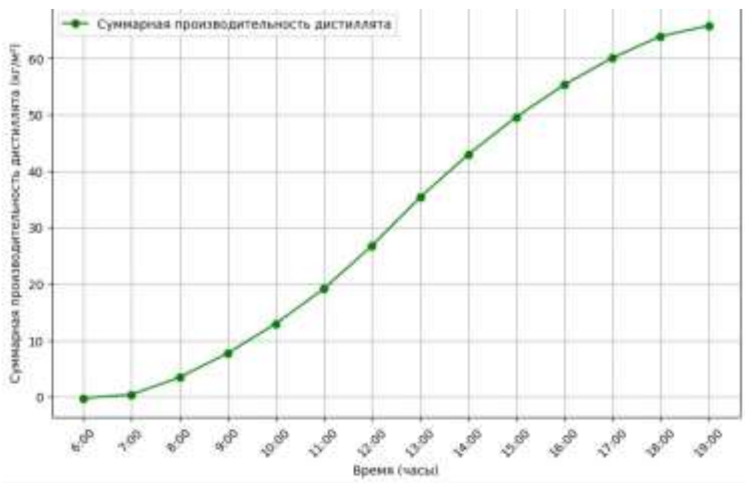


Figure 6. Total distillate productivity during the day

The highest temperature is observed from 10.30 to 16.30 time of day.
Calculations for a solar desalination installation

$$Q_d = \sum_{t=6}^{19} (A * G(t) \frac{T_{water}(t) - T_{env}(t)}{L} * t)$$

Where Q_d – distillate throughput, A – absorber area, G – solar intensity from time, $T_{water}(t)$- water temperature from time, $T_{env}(t)$- ambient temperature from time, L – latentheatofvapourizing.

In the unit, water undergoes distillation and ozonization sequentially, which guarantees a high degree of reliability of its operation. The water treated in the unit retains its original salt composition and has improved organoleptic characteristics (Table 1).

Table 1. Characteristics of water desalinated in a solar plant

№	Indicator to be determined	Content, mg/l
1	pH	6
2	Fe (iron)	0,07
3	PO_4 (Phosphates)	0,02
4	NO_2 (Nitrites)	0,004
5	NO_3 (Nitrates)	0,6
6	NH_4 (Ammonium ions)	0,016
7	Вз. substances .	2
8	Mn(Manganese)	0
9	Cl(Chlorides)	70
10	SO_4(Sulfates)	0
11	Cu(Copper)	0
12	Cr(Chrome)	0,02
13	Ni (Nickel)	0,011
14	Zinc	0,1
15	COD, mg/cubic dm	15
16	BOD, mg/cubic dm	3,0
	Microbiological analysis	
17	coliform bacteria, total mg/l/100 ml	No
18	coliform bacteria, E.coli	No

The novelty of the work consists in the development of a helio-preservoir using an effective corrugated absorber-basin, which allows to achieve high temperatures with the use of solar energy. In comparison with the existing analogs, including the world analogs, the recommended in the work helio-preserving plant has the following advantage:

- high energy saving and efficient cleaning;
- perfect in design, reduction of harmful emission into the atmosphere, unique simplicity in application of engineering technological solutions of the device, high performance.

The unit does not use any consumables and reagents and does not introduce contaminants into the treated water. The modular principle of construction provides the possibility of manufacturing units of different capacity (1, 2 and 3 m^3/h) and routine maintenance without disconnecting the working units and assemblies.

The installation is space-saving and low-energy; it has a system of indication and automatics, providing easy and reliable maintenance; it is designed for long-term operation. To ensure normal conditions of operation of the installation, preliminary filtration of treated water from mechanical impurities and suspended particles is carried out. These filters can be installed by the consumer independently or, at his request, can be supplied in the set of the installation.

Utilizing solar energy not only provides fuel savings, but also reduces carbon dioxide emissions, which contributes to the greenhouse effect.

Conclusion

Optimal parameters of solar system design for complex water treatment according to climatic conditions have been calculated. Based on mathematical calculations, the most efficient configuration of the desalination system prototype was determined.

The data establishing dependence of specific productivity of the installation and climatic conditions were obtained, a mathematical model taking into account these effects was developed, and the physical influence of temperature and hydrodynamic regimes of the process on the efficiency of seawater desalination was experimentally revealed and explained.

According to the calculated data in winter, the heat fluxes for the components of the solar distiller are as follows: between sun and glass15,24 W; between sun and water 77,41 W; between sun and absorber 171,59 W. The similar figures in summer are 41,95 W, 213,11 W, 472,40 W, respectively.

The maximum solar radiation was 750 W/m^2, and the maximum outdoor temperature was 20^{0}C. With these weather station indicators, the capacity of clean water before 15:00 hours was 2,5 liters.

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