# Modern state of use of solar desalination

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**Abstract.** Water is the most necessary resource for mankind, animals and plants. Although 71% of the Earth's surface is covered by water, 97% of it is salt water, that is, water that is not suitable for consumption. Also, continuous pollution of surface and underground water is increasing the shortage of drinking water. In solving the above problems, desalination of salt water is an important way of increasing drinking water resources. However, the high energy consumption, increased greenhouse gas emissions, large amounts of wastewater and the high cost of fresh water in desalination limit the widespread adoption of desalination technology in the industry. To solve these limitations, solar energy, which is one of the renewable energy sources, is environmentally friendly, ubiquitous, convenient to use, safe and sustainable. Currently, several constructions of SD are proposed, the main part of which is a pool construction. This research paper presents the results of comparison of the constructional structures of one- and two-basin SD, their heat-technical parameters, device productivity and economic indicators.

## 1 Introduction

Three-quarters of the planet Earth is covered by water, and water makes up 60-70% of the mass of living organisms. However, 97% of the water on the Earth's surface is salt water, and most of it is in the oceans and seas. The remaining 2% of water belongs to the glaciers of the North and South Poles, and only 1% is drinking water [1]. It can be seen that the supply of drinking water is very low, and by 2025, about 2.8 billion people on the planet will face water shortages or live in water-scarce areas. By 2050, this figure will reach 4 billion, and the countries of South and Central America, Eastern Europe and Asia will face the greatest water shortage [2]. At the same time, rapid population growth, per capita consumption of fresh water and climate change are increasing the demand for water resources. In addition to drinking and domestic purposes, fresh water is also essential for agriculture, construction, hotels and restaurants, food processing, energy, and pharmaceuticals. Water scarcity is becoming a major global problem today, as the Global Risks Report (GRR) published by the World Economic Forum (WEF) has listed water crisis as one of the highest global risks in terms of impact since 2012 [3].

Currently, the demand for fresh water is increasing in all countries of the world. For example, the daily consumption of fresh water per person in the USA is 400 liters. Some developed countries have reduced water consumption to 150 liters with the help of

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restrictions and regulations. However, studies have shown that some areas of the world consume less water due to the difficulty of accessing fresh water resources. For example, fresh water consumption per person in Africa is 20 liters per day. The World Health Organization believes that consumption of 15-20 liters of fresh water per day is sufficient for human survival. The World Water Program estimates that by 2030, only 60% of the fresh water needed will be available. The Organization for Economic Cooperation and Development has predicted that this amount will reach 55% by 2050. By the end of the century, 40% of the world's population will live in water-scarce areas [4]. In general, the demand for fresh water is doubling every 20 years. Currently, about 70% of fresh water is contributed by agriculture, 20% by industry, and the remaining 10% by housing [5].

Oceans and seas are the only sources of water to meet the demand for fresh water, the main disadvantage of which is high salinity. Therefore, the most reasonable way to solve the problem of water shortage is to desalinate the salt water. Desalination is the process of reducing the amount of salt in seawater or brackish water. According to the World Health Organization, the permissible limit of salinity in water is 500 parts per million (ppm) and in some cases up to 1,000 ppm, with salinity up to 10,000 ppm in the majority of water on Earth. available [6]. The main purpose of the desalination process is to reduce the salinity of the brine to below the permissible level of 500 ppm.

In recent years, various methods of sweetening have been developed and tested all over the world. Most of this development is accelerating in countries with a shortage of fresh water, such as the Arab countries of the Middle East, African countries, China, Australia, and India [7]. It is known that energy is required to carry out the sweetening process. It is desirable to use different forms of energy in the desalination process, including renewable and sustainable energy sources such as solar energy, geothermal energy, wind energy and biomass energy. Among them, solar energy is economical and environmentally friendly [8]. This is because solar energy is naturally free energy that can be used directly for the desalination process. Because the use of other renewable energy sources involves complex mechanisms, resulting in increased capital costs and higher equipment costs. Solar desalinations have zero environmental impact, are easy to maintain, have low operating costs, and do not require highly skilled workers to operate.

## 2 Materials and methods

Solar desalination (SD) has been known for a long time, and the first research work was carried out in 1551 by an Arab chemist. A very comprehensive review of the history, theory, application and economics of SDs is Talbert et al. [9] prepared by. This review examines the work done in different countries from 1872 to 1970. The analysis of scientific and research works carried out in the last decade in the field of SDs [8, 10-11] are cited in works.

SD is used to convert salt water into fresh water using solar energy through a series of thermal processes. As shown in Figure 1, the SD consists of a simple container, the inner surface of which is covered with a black painted sheet and the upper part is covered with a transparent glass cover.

The container is filled with salt water and placed under sunlight, the sunlight is transmitted to the interior of the container through the transparent coating and is absorbed by the inner black material of the container, resulting in the heating of the brine by convection. The salt water inside the vessel evaporates, and the vapor rises up and collides with the transparent coating and condenses under the transparent coating. The resulting water drops are collected in a special container through a side-mounted drain [12].

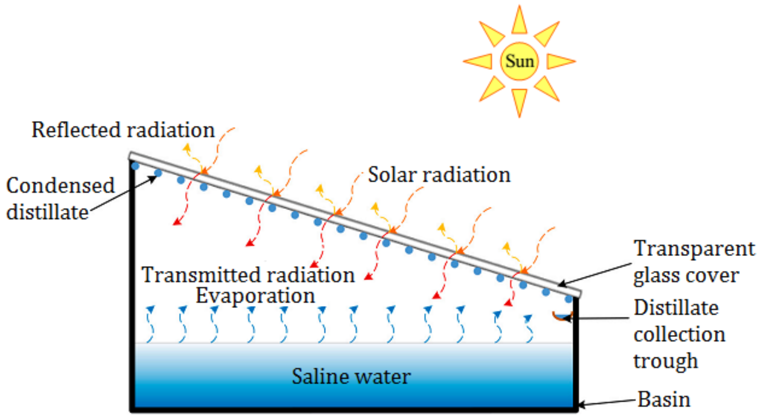


**Fig. 1.** Scheme of a simple SD.

SD can be divided into two types: indirect and direct [13]. Evaporation and condensation occur without the help of external energy in direct SDs. Electric power is consumed due to the presence of additional elements - a pump, a fan and external condensers in indirect SDs. Currently, despite the simplicity of construction, low energy consumption, and relatively low cost, among other methods of obtaining fresh water, SDs make up a very small share, due to the low efficiency of SDs.

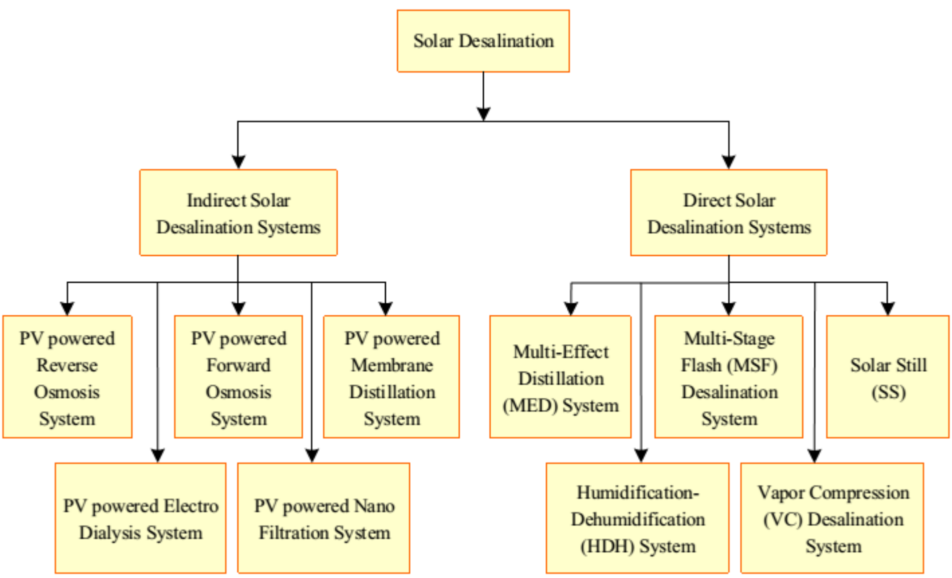


**Fig. 2.** Classifications of SD.

Thus, based on the above scientific studies, the following was determined:

- Current scientific research is mainly focused on improving the evaporation chamber.
- Very little research has been done on the factors influencing the productivity of solar collectors.
- Little attention has been paid to the integration of solar collectors with solar collectors and solar photovoltaic panels.
- Studies on the energy efficiency of solar heaters are presented in few sources.

Single-slope basin SD. This device is the most common one, where distillation and heat collection are carried out in one device [14]. One of the advantages of this device is that the least expensive water is obtained due to the simplicity of its construction (Figure 1). Its absorber part is painted black, the upper part of the basin is covered with a transparent glass or plastic cover, and the device is completely hermetic. Solar radiation passes through the coating and is absorbed by the black absorber. As a result of absorption of solar radiation, the water in the basin evaporates. The steam rises up until it collides with the inner surface of the transparent coating, condenses on contact with the transparent coating and collects in the fresh water collection tank [15]. This type of device allows people living in remote areas to get a large amount of water. One of the main disadvantages of this device is low FIK value from 20 to 46%, productivity does not exceed 6 l/m$^2$/day. According to these values, to ensure the basic consumption of fresh water for one person, a SD device with a surface of at least 1 m2 is necessary [16]. This low efficiency is due to condensation heat loss to the environment through the glass cover and heat loss with hot condensate. At very high and low latitudes, a single-slope solar array collects more solar radiation than a double-slope solar array.

Types of glass coatings. In several studies, all structural solutions are aimed at maximum absorption of solar radiation and offer improved solutions for condensation surfaces. Various constructions and materials have been proposed for the transparent coating in different climatic conditions. The transparent coating of SD devices should have the following properties, that is, it should be high transparency, high transmission coefficient, heat resistant, convenient and cheap. Usually, the transparent coating is made of tempered glass, and it provides high light transmission and transparency [17]. Several constructions of coatings are shown in Figure 3. In terms of fragility, price and safety of coatings, the main focus is on transparent polymers, that is, on the use of acrylic sheets. Many studies show that acrylic has a low flow of fresh water due to its low permeability.

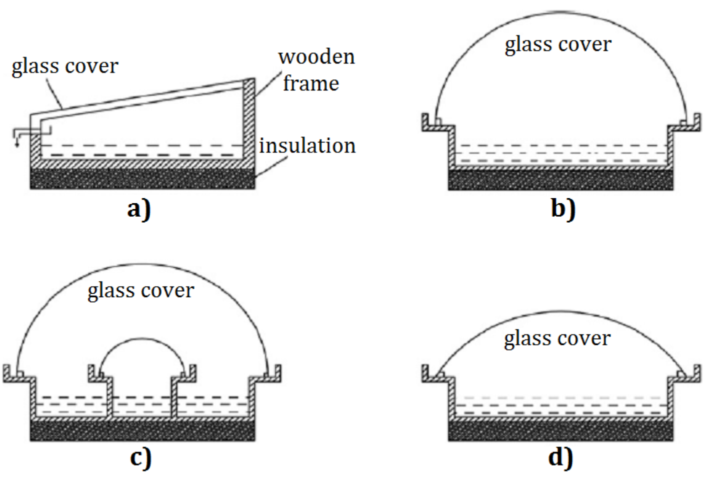


**Fig. 3.** Types of SD devices with different transparent coating: a-flat inclined coating; b-spherical coating; s-two-layer coating; d-slightly folded coating.

In the research of Tayeb [18], experiments were conducted on four solar panels with an effective solar absorption area of 0.24 m$^2$ and a condensation area of 0.267 m$^2$, and with different geometries of the glass cover (Figure 3). According to the research results, the fresh water output on sunny days was approximately 1.25, 1.1, 1.2 and 0.83 kg/m$^2$/day. These values apply to inclined flat glass coating, hemispherical coating, double layer hemispherical coating and arched coating.

Phadatare and Verma [19] prepared a single slope single basin SD. The bottom and all sides of the evaporation chamber are made of plexiglass (thickness 3 mm). Sealed to reduce heat loss to the outside environment. The bottom and four sides of the evaporation chamber of the SD are made of acrylic. External dimensions of the evaporation chamber: length 176 cm, width 8 cm, bottom height 32 cm, top height 60 cm, evaporation chamber area 1.446 $m^2$ and cover area 1.44 $m^2$ (Figure 4, a).

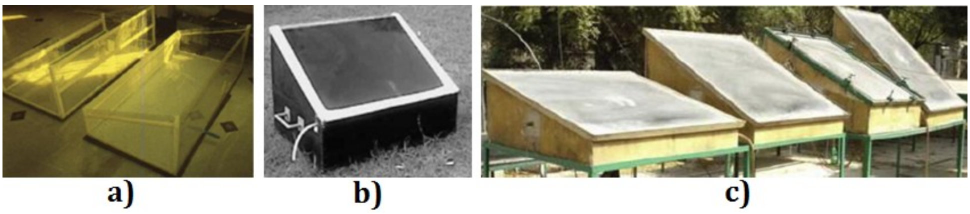


**Fig. 4.** Types of single-slope single-basin SD.

Ali Samee et al. [20] prepared a simple single basin SD (Figure 4, b). The evaporation chamber has an area of 0.54 $m^2$ and is made of galvanized steel sheet with a thickness of 18 mm. The daily productivity of the solar cooker is 1.7 l/day, the average FIK is 30.65%. Dev and Tiwari [21] conducted an experimental study on the condensation rate of one-slope passive solar evaporator covers at different slope angles (15°, 30°, 30°, 45°), the optimal water level in the evaporation chamber (0.04 m) to improve the efficiency of the solar evaporator. (Fig. 4, c). When the device has the highest performance, the optimal angle of inclination is 45°.

Experimental studies during 24 hours of summer, autumn and winter months were conducted by Husham [22]. A simple single-sloped SD device with a useful area of 1 $m^2$ was compared with SD of the same size and transparent coating with a 20° slope, in which a passive cylindrical condenser was installed at the back of the second SD. Experimental devices are shown in Figure 5. According to the results, the productivity increase in the device connected from the top to the condenser was 15.1, 15.08 and 16.6% in summer, autumn and winter, respectively. At the same time, when the condenser was connected from the middle and lower part, the efficiency was 30.54, 33.6 and 35.8% in summer, autumn and winter, respectively.

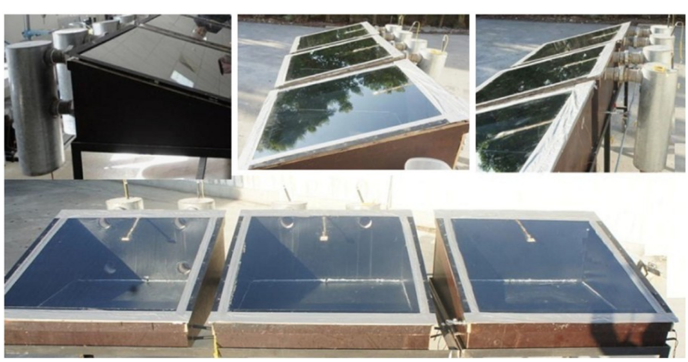

**Fig. 5.** Single-slope SD device combined with one and two passive condensers.

Double basin SD. In this device, an additional glass sheet is placed between the basin absorber and the glass cover (Figure 6, a) [23]. The main purpose of this additional glass sheet is to use it as an additional container for salt water. Thus, a stack of such SD devices represents a simple SD device stacked two on top of each other. The efficiency of the SD device is increased due to the efficient use of the latent heat of steam generation.

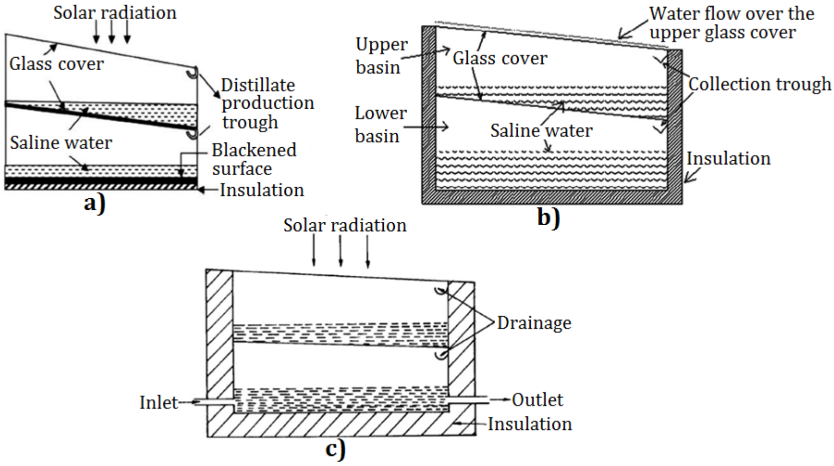


**Fig. 6.** Double basin SD.

Bapeshwararao et al. [24] analysed the effect of water cooling on the performance of glass coating of a single-slope, two-basin SD (Figure 6, b). When the cooling water flows over the glass coating, the temperature of the coating decreases, the rate of air circulation inside the evaporation chamber and the rate of evaporation increase. Also, due to the much lower temperature on the glass surface, the rate of condensation and productivity also increases.

SD with two basins and constant boiling water consumption was analysed by Gupta et al. [25] (Figure 6, c). The system consists of a single-slope two-way SD, in which the heat of the waste water flowing at a constant consumption is recuperated. As a result, it will be possible to heat the water in the tank even when there is no sunlight. This method of increasing the water temperature in the basin increases the temperature difference between the water and the bottom glass coating, resulting in increased rates of evaporation and condensation. According to the authors, increasing the temperature of the wastewater moving at a constant speed increases the productivity.

Three-basin SD devices. These devices consist of three basins filled with water: lower, middle and upper (Figure 7) [26-27]. These devices provide maximum daily productivity when the water mass is low in the lower and middle basin. The main disadvantage of these devices is the high maintenance cost and the need to install additional amplifiers to use additional pools. Detailed information about such devices is given in El-Sebai [26].

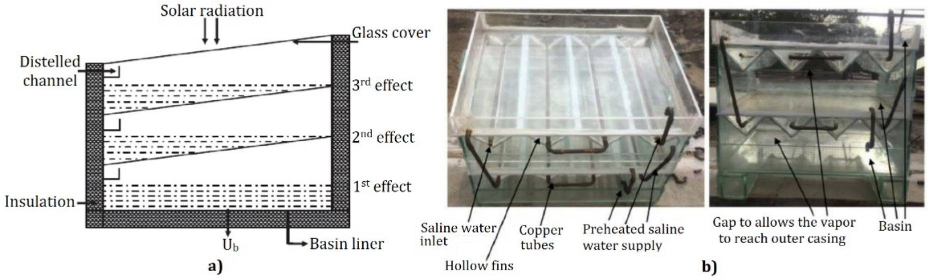


**Fig. 7.** Scheme (a-[26]) and overview (b-[27]) of the three-basin SD.

## 3 Results and Discussion

On the basis of the analysis of the designs of single basin SD proposed by many researchers were compared (Table 1). This table compares the results obtained by scientists for single basin SD.

**Table 1.** Comparison of single basin SD.

| Type SD | Authors | Results |
|---|---|---|
| Single slope | Sahoo B B at all | The amount of fluorine decreased by 92-96%, the efficiency increased by 11% |
| | Swetha K at all | Freshwater productivity increased by 36% |
| | Phadatare M K at all | Maximum productivity 2.1 l/m$^2$/day, efficiency varied from 10 to 34% |
| | Tiwari G N at all | The slope of the glass cover is optimized, the maximum performance is obtained at 45° |
| | El-Sebaii A at all | Daily productivity increased to 9,005 kg/m$^2$ and efficiency increased to 85.3% |
| | Badran O O | 29% increase in productivity when using asphalt, 51% increase in total system productivity |
| | Abdallah S at all | The efficiency of the device is increased by 30% when using a recirculator inside the basin |
| | Samee M A at all | With a pool area of 0.54 m$^2$, the daily productivity was 1.7 l/day, with an average efficiency of 30.65% |
| Double slope | Tabrizi F F at all | Productivity increased by 12% |
| | Zeroual M at all | Condensation on the water-cooled north side increases productivity by 11.82% |
| | Rajamanickam M R at all | At a water level of 0.01 m, the maximum productivity was 3.07 l/m$^2$/day |
| | Aburideh H at all | The average productivity was 4 l/m$^2$/day |

The price of one liter of fresh water obtained from a SD is determined from the annual productivity in the following order.

Average daily productivity=m.

Annual productivity=m×working days

Cost per liter of water=Total costs/annual productivity

In the conditions of the city of Karshi, a working day can be accepted for 320 days in a year.

The economic indicators of one and two basin solar stills are shown in Table 2.

**Table 2.** Economic comparison of single and double basin SD.

| Type SD | Authors | System unit cost in US $ | Productivity | Price of 1 liter of water in US $ |
|---|---|---|---|---|
| Single slope | Panchal H N at all | 79,95 | 4.1 l/m$^2$/day | $0.065 |
| | Samee M A at all | 100 | 1.71 l/m$^2$/day | $0.196 |
| Double slope | Rajamanickam M R at all | 200 | 3.07 l/m$^2$/day | $0.217 |

As can be seen from the results of the comparison presented above, the efficiency of single basin SD is on average 2.1 to 9 l/m$^2$/day, the efficiency is on average 30-45%. The cost of making these devices is on average around of $80-100 and the price of one liter of fresh water obtained in them is on average of $0.065-0.2. The average fresh water productivity of double basin solar stills is 3-4 l/m2/day, and the efficiency is around 45-60%. Two-basin units cost an average of $200 to set up, and the cost of one liter of fresh water produced in these units averages $0.217. As you can see, single basin SD are preferred.

## 4 Conclusion

As a result of population growth and rapid industrial development, the demand for fresh water is increasing day by day. The most reasonable solution to this problem in the world is to use SD. In this analytical article, the structural features and economic indicators of single and double-basin SD were analyzed. Below are the general conclusions of this article:

- The main part of the research is focused on simple single-yard solar water heaters, which can provide villagers with 20 to 30 liters of fresh water per day due to cost-effective production.
- To increase the temperature of water, the rate of evaporation and condensation, it is necessary to use effective heat insulating materials and heat accumulators.
- It is necessary to carry out additional experimental studies on SD devices, taking into account the impact of various construction and operational costs. These parameters can include: water salt content, temperature, pressure, level change, use of PCM, etc.
- In a single-pool solar thermal unit, efficiency increases from 34% to 42% due to coating cooling, where efficiency depends on solar radiation and external environmental conditions.
- In a double-basin SD device, the productivity of fresh water is 3-4 $l/m^2$/day, in which the efficiency can be increased up to 30% due to additional heat recovery.
- The price of 1 litre of water obtained at the SD device is on average $0.13 in one basin and $0.2 in two basins, and these values are directly related to the costs of preparation and operation of the QSCH device.

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