

Design of a Solar-Powered Water Purifier Optimized for Oman's Arid Climate

Raj Jighnesh Surti¹ and Alok S Shah^{2*}

¹Indian School Muscat, Muscat, Oman

²University of Chicago, USA

***Corresponding Author:** Alok S Shah, University of Chicago, USA.

Received: November 19, 2025; **Published:** December 17, 2025

Abstract

Overview: This study presents a solar-powered water purifier engineered for Middle Eastern countries like Oman. It consists of a hexagonal basin with a mesh filter for effective purification. This design is made up of different kinds of materials for strength, durability and to withstand harsh desert conditions.

Summary: Oman is a country located on the southeastern coast of the Arabian Peninsula in West Asia and the Middle East. Its neighboring countries are Saudi Arabia, the United Arab Emirates, and Yemen. Most of these countries have historically experienced predominantly arid, desert-like climates. With temperatures reaching as high as 50°C, evaporation takes place at an increasing rate. These countries receive very low annual rainfall, ranging from less than 100 mm to little more than 300 mm [5]. Global Warming has only worsened the situation by further reducing the amount of rainfall and increasing the temperatures. Given the severity of these environmental conditions, finding effective methods for water purification has become of utmost importance. This solar-powered water purifier aims to do just that. This purifier was designed in SolidWorks. This design is different compared to traditional solar-powered water purifiers. It contains a hexagonal basin instead of a regular rectangular basin for greater surface area, volume, durability and strength. It also incorporates a perforated mesh plate for filtration, circular vents for airflow, and a drainage hole. The purifier is topped with an angled 4 mm thick glass cover to enhance condensation and water collection efficiency. This design was created with the climate of Oman in mind, where high temperatures and scarce freshwater sources pose a great threat. This solar-powered water purifier will be highly sustainable and cost-effective, especially in remote or underdeveloped areas.

Keywords: SolidWorks; Water Purification; Solar Desalination; Sustainable Design

Introduction

As global development progresses, access to clean water remains vital for public health, environmental sustainability, and economic prosperity. Clean water and sanitation are fundamental to human well-being. However, 2.2 billion people [1] around the world still lack reliable access to safe drinking water, leading to severe health and environmental consequences. Clean water is a basic human need and critical to societal progress. Biologically, water regulates body temperature, transports nutrients, and removes toxins—functions essential for health and survival [2]. Drinking contaminated water can cause dehydration, digestive problems, and serious illnesses. Ensuring access to safe drinking water is essential for maintaining optimal health. Contaminated water is a vehicle for the transmission of diseases such as

cholera, dysentery, and typhoid fever [3]. According to the World Health Organization (WHO), lack of access to clean water and adequate sanitation is responsible for around 485,000 diarrheal deaths annually among children under 5 [4]. Countries like Oman get very less rain ranging from less than 100 mm to just above 300 mm [5]. Thus, it is crucial to preserve and purify water. Thus, it is crucial to preserve and purify water. This is illustrated in graph 1, which compares average annual rainfall across several Middle Eastern countries [6]. While annual rainfall amounts in Oman have shown a modest decline in both frequency and total amount, rainfall patterns are becoming more extreme and unpredictable, with occasional heavy storms leading to flash floods. Recent climate studies indicate that Oman’s annual rainfall has been steadily decreasing by approximately 9.4 mm per decade since the late 20th century, amounting to a general decline of around 7 - 9% per decade [7]. Conventional water purification systems though useful and sufficient in most scenarios are ineffective in dry and arid regions. One of the major disadvantages of reverse osmosis is that it removes 92 - 99% of minerals including useful minerals like calcium and magnesium. It only recovers 25% of water and 75% of water is rejected [8]. It’s also very expensive to install, costing about 20,000 dollars [8]. Distillation processes can be energy-intensive. If not properly maintained, distillation equipment can become a source of contamination, affecting the purity of the final product. Distillation processes may generate wastewater and vapors that require proper treatment and disposal, posing environmental concerns [9]. Ultra Violet light is only able to remove microorganisms and does not remove any other contaminants like heavy metals, salts, chlorine or man-made contaminants. Ultra Violet purifiers also need electricity which may not be accessible in remote areas [10]. Due to these drawbacks, it has become essential to develop sustainable and economic ways of purifying water. This research presents a solar-powered water purifier that requires minimal cost and maintenance and does not require electricity.

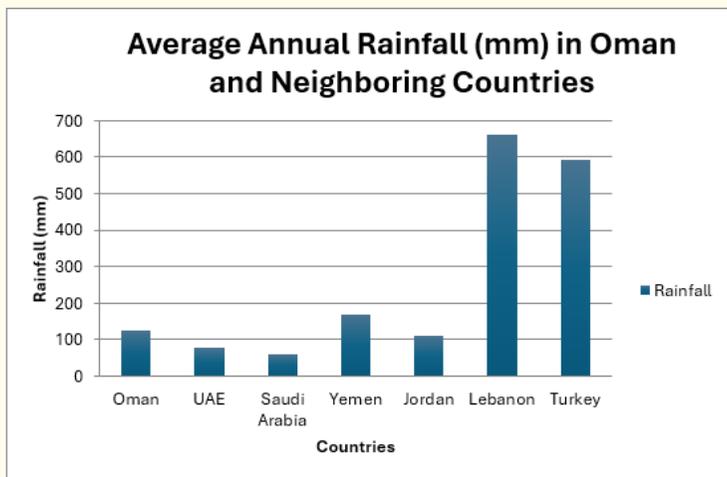


Figure 1: Average annual rainfall in middle eastern countries.

The data highlights a trend of low rainfall across the region, with Lebanon and Turkey being the clear exceptions. This pattern underscores the water scarcity challenges in countries like Oman.

Materials and Methods

The solar-powered water purifier was designed to maximize efficiency in arid climates. The hexagonal basin has a side length of 30 cm, a height of 10 cm, and an approximate volume of 5L, providing a compact yet efficient footprint (Figure 2). The bottom layer was made of high-density polyethylene (HDPE) with a 3 mm wall thickness to provide chemical resistance, durability, and stability under prolonged exposure to sunlight. HDPE was chosen for its low thermal conductivity, which reduces heat loss and improves evaporation.

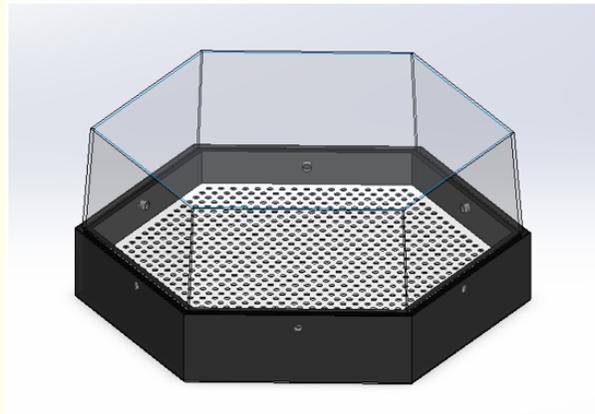


Figure 2: Solar-powered water purifier.

The solar-powered water purifier contains a hexagonal basin with a clear glass top, matte aluminum mesh plate, and HDPE bottom. A small HDPE side pipe serves as inlet/outlet, and the stainless steel base flange provides stability. Condensation gutters collect distilled water efficiently.

Inside the basin, a matte aluminum mesh plate, 1 mm thick with 5 mm openings, was placed 2 cm above the basin bottom. The mesh plate serves multiple purposes: it distributes water evenly, increases the surface area for evaporation, prevents water stagnation, and acts as a coarse filter to block larger debris and particulate matter from reaching the condensation surface, maintaining water quality and improving system efficiency. The top layer of the basin is of clear tempered glass, 4 mm thick, inclined at an angle of 30° relative to the horizontal. This inclination was selected to maximize solar radiation capture throughout the day while ensuring that condensed droplets naturally run down towards the collection gutters. Tempered glass was chosen for its high durability, optical transparency, and resistance to thermal stress.

A small HDPE side pipe with an inner diameter of 1 cm was integrated into the basin for water inlet and outlet. Its placement allows water to flow in without disturbing the condensation process and ensures easy removal of collected distilled water. The base flange was fabricated from satin-finish stainless steel (SS304), measuring 2 cm wide and 0.5 cm thick. Stainless steel provides mechanical strength, resistance to corrosion, and stability to the overall structure under outdoor environmental conditions, including high heat and occasional dust storms. Condensation gutters, 2 cm wide and 1 cm deep, were installed along the edges of the hexagonal basin to channel condensed water efficiently towards the collection container. The hexagonal geometry was strategically chosen because it provides 13 - 15% more surface area than a square or a rectangular basin of similar perimeter, increases water exposure to sunlight, reduces the distance for condensed droplets to travel, and evenly distributes mechanical stress. A sectional view of the purifier design and internal structure is shown in figure 3. This geometric design enhances the structural integrity of the purifier and allows it to withstand extreme desert conditions.

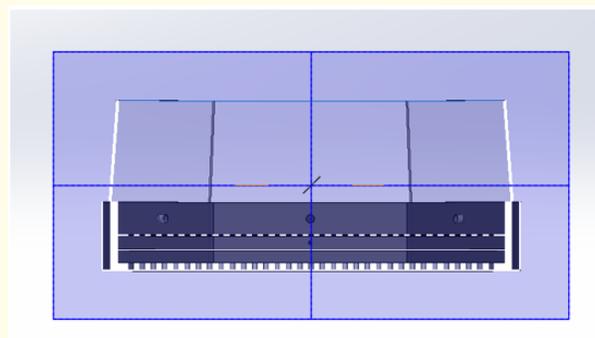


Figure 3: Sectional view of the solar-powered water purifier.

The solar-powered water purifier depicts water flow over the matte aluminum mesh plate, evaporation through the clear glass top, condensation on the glass surface, and collection via the side gutters. The HDPE basin bottom and stainless steel base flange provide structural support.

The overall assembly combines these materials and design-features to create a durable, efficient, and low-cost water purification system suitable for small communities and households in off-grid regions. Each component was carefully selected to balance performance, durability, and cost while ensuring that the system can be easily fabricated with readily available materials.

Quantitative analyses, such as purification efficiency, were not performed in this study. Observations focused on water recovery, condensation behavior, and the structural performance of the purifier under outdoor conditions.

Result

This study introduces a solar-powered water purifier specifically designed to operate without electricity and with very low maintenance. The system features a hexagonal basin, which enhances surface exposure to sunlight and contributes to a more efficient distillation process. Unlike conventional distillation systems that rely on 0.8 to 2.5 kWh of electricity per cubic meter of water treated [11], this purifier operates entirely on solar energy, requiring 0 kWh of external power, making it environmentally sustainable and suitable for off-grid locations. Similarly, low-temperature distillation systems require between 80 and 200 kWh of thermal energy per cubic meter [14], which this design completely avoids due to its passive solar mechanism. Traditional systems reject majority of the water as brine [8]. This purifier, by contrast, is designed to achieve nearly a 100% recovery rate, while all reverse osmosis (RO) systems typically recover only 10% to 25% of the input water, thus wasting the input water. RO systems generally maintain a 1:4 recovery ratio, where one liter of clean water results in three to four liters of wastewater, while the solar purifier functions at a 1:1 ratio, maximizing efficiency [12]. Although large industrial RO plants can reach 80% - 90% recovery using advanced energy recovery methods, these are usually only feasible in centralized infrastructure and not accessible in remote or underserved areas [13]. The system will also show a passive yield of around 2 - 5 liters per square meter per day under full sunlight conditions [14]. Additionally, current global desalination plants discharge over 150 million cubic meters of brine per day, harming marine ecosystems due to high salinity and chemical pollutants [15]. In contrast, the solar-powered purifier is designed to produce nearly zero discharge, emit no greenhouse gases, and generate no brine waste, making it a cleaner alternative. These efficiency and environmental benefits are illustrated in figure 4 and 5, which compare water recovery rates and energy consumption across purification methods. In today’s world, one of the biggest threats faced by earth is from carbon dioxide emissions. The global average carbon dioxide set a new record high in 2024 which was 422.7 parts per million [16]. The increase over 2023 amounts was 3.75 ppm—the largest one-year increase on record. Over the past six decades, atmospheric CO₂ concentrations have risen at a rate approximately 100 times greater than historical natural increases observed during deglaciation periods like the last ice age’s conclusion (11,000-17,000 years BP).

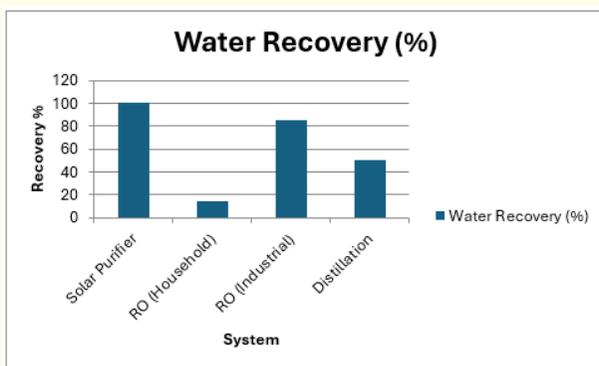


Figure 4: Water recovery comparison between different purification systems.

The solar purifier achieves near-complete water recovery through distillation, while conventional systems like reverse osmosis suffer from significant water loss as brine waste.

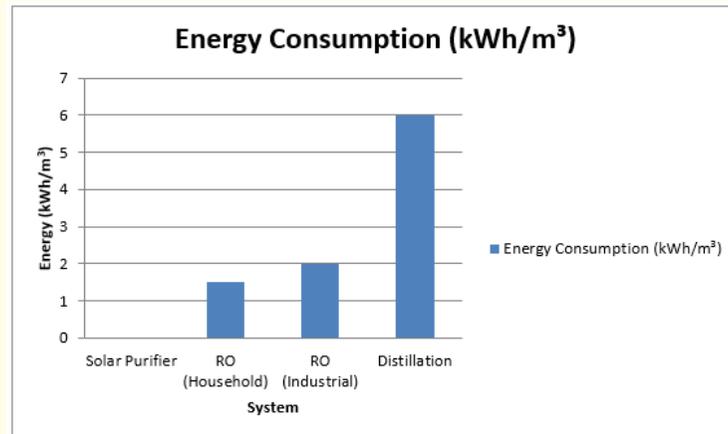


Figure 5: Energy consumption comparison between different purification systems.

The solar purifier consumes 0 kWh/m³ compared to conventional systems which consume significant amount of energy. This shows that the purifier is a sustainable and economically viable solution, particularly in regions with high solar insolation but limited energy infrastructure.

Discussion

The aim of the study was to compare the efficiency of the solar-powered water purifier to traditional or conventional water purification methods. The main benefit of the solar-powered water purifier is that it is environmentally sustainable and does not use any fossil fuels and also does not use electricity. All other water purification methods need some form of fuel for it to operate. Compared to other water purification methods, the solar-powered water purifier has a design that recovers nearly 100% of the distilled water, with losses primarily due to evaporation. On the other hand, the conventional water purifiers like reverse osmosis (RO) systems reject 75-90% of input water as brine [12]. The solar-powered water purifier is designed to produce nearly zero discharge, emit no greenhouse gases, and generate no brine waste, making it a cleaner alternative, whereas desalination plants discharge over 150 million cubic meters of brine per day, harming marine ecosystems due to high salinity and chemical pollutants [15]. The hexagonal geometry of the solar-powered water purifier has several benefits. A hexagon encloses 13 - 15% more surface area than a rectangle or a square of similar perimeter. It has a greater surface area compared to rectangle and square. Hence, more water will be exposed to solar radiation, leading to higher evaporation rates. The condensed droplets on the glass have to travel a shorter distance in hexagonal basin to reach the collection gutters compared to the distance travelled by them in a rectangular or a square basin. The condensation angles in a hexagonal basin can improve recovery by 10 - 15% compared to a square or a rectangular basin. The distribution of mechanical stress is more even in a hexagon compared to rectangles and squares. This strength helps to combat the harsh weather of the desert regions with extreme heat and occasional high winds. Hexagonal structures are known in engineering for their maximum strength-to-material ratio.

However, the solar-powered water purifier is not without limitations. The present design is based on a small-scale conceptual model, and challenges may arise when attempting to scale it up for larger applications. Since the system relies entirely on solar radiation, evaporation and condensation cannot occur during cloudy conditions or at night, making its performance seasonal and less effective in winter months. Although the purifier is designed to achieve nearly a 100% water recovery rate, it requires a longer operating time compared to conventional purification methods like reverse osmosis or distillation units, which can process greater volumes of water in shorter intervals of time. This constraint makes the purifier better suited for households in villages or small towns rather than as a replacement for large-scale industries. In terms of durability, the glass cover is vulnerable to breakage, and insulation materials may

degrade under prolonged exposure to extreme desert conditions. Using higher-quality materials could extend the water purifiers lifespan, but may also increase production costs and make it less economically viable. Furthermore, efficiency could decline if dust accumulates on the glass surface, a common issue in arid regions such as Oman, while inadequate cleaning could promote bacterial growth. Finally, while the purifier is effective for saline or brackish water, it may be less effective for water sources contaminated with industrial or chemical pollutants, which would require additional pre-treatment.

Some improvements can be considered for future development of the solar-powered water purifier. Photovoltaic panels with batteries could be integrated, allowing the device to function even in the absence of sunlight. Applying dust-repellent coatings to the glass surface would help minimize accumulation of particles and maximize efficiency. To enhance thermal insulation, advanced materials such as polyurethane foam, UV-resistant EPDM, fiberglass, or aerogels may be used. In addition, chemical filters could be integrated to remove industrial or agricultural pollutants that cannot be addressed by solar distillation alone. Finally, simple sensors could be added to monitor the volume of purified water, detect bacterial growth, and track overall efficiency.

The solar-powered water purifier has significant impacts. Conventional water purifiers like reverse osmosis require 0.8 to 2.5 kWh of electricity per cubic meter of water treated and low-temperature distillation systems require between 80 and 200 kWh of thermal energy per cubic meter of water treated [11,14]. However, solar-powered water purifier operates on 100% solar radiation and requires 0 kWh of electricity. Since it is economically viable, electricity free and decentralized, it is suitable for towns and villages which don't have access to grid electricity and large industrial plants. The use of solar energy significantly lowers carbon emissions compared to conventional electrically powered water purification systems, contributing to decarbonization efforts. In the long term, the widespread adoption of solar-powered water purifiers could support sustainable water management, improve water security, and enhance the quality of life in arid and remote regions.

Water purification systems create far-reaching benefits at the global level. By providing safe drinking water, they help cut healthcare expenses by lowering the prevalence of waterborne diseases, which in turn supports a healthier and more efficient workforce [17]. Access to clean water also strengthens agriculture by enabling better irrigation, leading to more resilient crops, higher yields, and greater income for farmers, all of which contribute to wider economic growth. In addition, purified water is essential in many manufacturing industries, where it improves product quality, reduces contamination risks, lowers production costs, and encourages environmentally sustainable operations. While installation of such systems can require substantial upfront investment, the long-term returns in reduced medical costs, improved productivity, and overall operational efficiency make them a practical and cost-effective solution.

Conclusion

The aim of the study was to design a solar-powered water purifier tailored to middle-eastern countries which runs entirely on solar energy and is eco-friendly. Overall, the hexagonal basin, the angled tempered glass roof, and the aluminum mesh plate enhances strength, flow and efficiency. This study showed that the solar-powered water purifier is a much better alternative compared to traditional conservation systems in terms of cost and sustainability. However, this is a small-scale conceptual design, and complications may arise when implemented at larger scales. Furthermore, the design can be integrated with computer-based monitoring to track temperature, water yield, and system efficiency, thereby improving operational reliability and enabling future optimization.

Bibliography

1. World Health Organization. "Drinking Water Fact Sheet". World Health Organization (2025).
2. "The Importance of Clean Water and Sanitation". GENAQ (2025).

3. World Health Organization. "Cholera Fact Sheet". World Health Organization (2025).
4. Hutton Guy and Catharine Chase. "The knowledge base for achieving the sustainable development goal targets on water supply, sanitation and hygiene". *International Journal of Environmental Research and Public Health* 13.6 (2016): 536.
5. World Bank. "Oman - Climatology". Climate Change Knowledge Portal (2025).
6. World Bank. "Average Precipitation in Depth (mm per Year)". World Bank Data (2025).
7. Kwarteng AY, et al. "Analysis of rainfall trends in Oman". *International Journal of Climatology* 29.4 (2009): 439-449.
8. "Disadvantages of Reverse Osmosis (And How We Address Them)". A. O. Smith Blog (2025).
9. "Disadvantages of Distillation". SATHEE: Chemistry Distillation, IIT Kanpur (2025).
10. "Using Ultraviolet Rays for Water Treatment". Skillings & Sons, LLC (2025).
11. "Low-Temperature Distillation". Wikipedia (2025).
12. Smith Chris. "Does Reverse Osmosis Waste Water?" WaterTechAdvice (2025).
13. U.S. Department of Energy. Reverse Osmosis Optimization (Federal Energy Management Program Report). Energy.gov (2025).
14. "Comparison of Yield for Active and Passive Solar Still". ResearchGate, Figure 6 (2025).
15. "Desalination: The Costly Solution for a Thirsty World". Financial Times (2025).
16. National Oceanic and Atmospheric Administration (NOAA). "Climate Change: Atmospheric Carbon Dioxide". Climate.gov (2025).
17. "Economic Impact of Water Purification: Health, Industry, and Agricultural Benefits". Aegina-Pure (2025).

Volume 1 Issue 1 November 2025

©All rights reserved by Raj Jighnesh Surti and Alok S Shah.