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#### “SOLAR STILL TECHNOLOGY FOR WATER PURIFICATION: A REVIEW OF DEVELOPMENT, THERMAL BEHAVIOR, AND PERFORMANCE IMPROVEMENT”

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#### ABSTRACT

*Global water scarcity has intensified the demand for low-cost, decentralized desalination technologies. Solar stills, which mimic the natural hydrological cycle, offer a sustainable solution. This review examines the progress in solar still technologies up to 2019, analyzing the thermal efficiency of passive and active designs. We investigate the impact of climatic parameters, basin depth, and heat storage materials on the distillate yield. The review further evaluates hybrid systems and the integration of nanomaterials to overcome the low productivity associated with conventional stills.*

**Keywords:** Traffic water, hydrological cycle, cost, productivity, passive and active.

#### I. INTRODUCTION

##### 1.1 The Global Water Crisis and the Desalination Imperative

As of 2019, the global community faced a dual crisis of population growth and diminishing freshwater reserves. Statistical data from the World Health Organization (WHO) and UNICEF indicated that nearly 2.2 billion people lacked safely managed drinking water services. While the Earth is abundant in water, 97.5% of it is saline, residing in oceans and seas, while a significant portion of the remaining freshwater is trapped in glaciers. This geographic and chemical mismatch has led to the "Water-Energy-Nexus" challenge: the regions with the highest water stress are often those with limited access to centralized electrical grids or fossil fuel resources.

Conventional desalination technologies, such as Reverse Osmosis (RO) and Multi-Stage Flash (MSF) distillation, have dominated the industrial landscape for decades. However, these systems are capital-intensive, require high-grade energy, and produce significant carbon footprints. For decentralized, rural, and arid coastal communities, these large-scale solutions are often economically and logistically unfeasible. This is where solar distillation, specifically the solar still, provides a compelling alternative. By leveraging the most abundant energy source on Earth—solar radiation—solar stills offer a path toward water sovereignty.

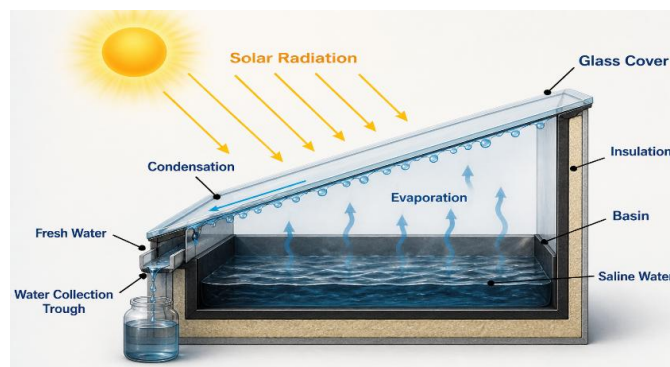


Fig. 1. Solar Still Technology for Water Purification

## 1.2 Fundamental Principles of Solar Distillation

The solar still is essentially a biomimetic technology; it replicates the natural hydrological cycle within a controlled environment. The process is governed by the principles of the greenhouse effect and phase-change thermodynamics. A typical basin-type solar still consists of a shallow basin painted black to maximize solar absorption, covered by a transparent airtight cover (usually glass or plastic).

As solar radiation penetrates the cover, it is absorbed by the basin liner and the brackish water. This increases the internal energy of the water molecules, leading to evaporation. The resulting water vapor, which is free of non-volatile impurities, salts, and pathogens, rises to the cooler underside of the transparent cover. Upon contact with the cooler surface, the vapor loses its latent heat of vaporization and condenses into pure liquid droplets. Gravity then directs these droplets into a collection trough. This elegant process accomplishes three tasks simultaneously: heating, purification, and collection, with zero moving parts and zero operational carbon emissions.

## 1.3 Historical Evolution: From Las Salinas to Nanotechnology

The history of solar distillation is marked by a transition from rudimentary survival tools to sophisticated thermal machines. While historical records suggest that Aristotle and early Arab alchemists utilized basic solar evaporation, the first true industrial-scale application was documented in 1872 in Las Salinas, Chile. Designed by Charles Wilson, this facility spanned 4,700 square meters and provided 22,700 liters of fresh water per day for miners using high-salinity brackish water.

Throughout the 20th century, research stagnated until the energy crises of the 1970s sparked a resurgence in renewable energy interest. By the early 2000s, the focus shifted from simple basin designs to "Active" systems. Researchers began integrating external energy sources, such as flat-plate collectors and solar concentrators, to decouple the evaporation area from the collection area. The decade leading up to 2019 represented the most prolific era in solar still research, characterized by the integration of materials science—specifically the use of Phase Change Materials (PCMs) for thermal energy storage and nanofluids to enhance the thermophysical properties of the water mass.

## 1.4 Theoretical and Technical Challenges

Despite the apparent simplicity of the technology, solar stills suffer from inherently low thermal efficiency and productivity. A standard passive solar still typically yields between 2 and 5 liters per square meter per day, which is often insufficient for a single household's needs without a massive surface footprint. The primary technical bottleneck is the "thermal inertia" of the basin water; a large mass of water takes a significant amount of time to reach the temperatures required for high evaporation rates.

Furthermore, the narrow temperature difference between the water surface and the condensing cover limits the driving force of the distillation process. Research up to 2019 focused on narrowing this gap by either heating the water more effectively (Active methods) or cooling the glass cover (Passive/Active cooling). Additionally, the accumulation of salt (scaling) on the basin liner reduces solar absorption over time, presenting a maintenance challenge that researchers have sought to solve through automated flushing and innovative liner materials.

### 1.5 Objectives of this Study

This review aims to provide a comprehensive synthesis of the state-of-the-art in solar still technology as of 2019. By categorizing the myriad of modifications—ranging from wick-type designs and multi-effect stills to the use of advanced heat storage—this paper serves as a roadmap for understanding how to optimize distillate yield. We will evaluate these technologies not only based on their thermal performance but also through the lens of economic viability (Cost per Liter) and environmental sustainability, ensuring that the transition to solar water purification is both technically sound and socially equitable.

### 1.6 Classification of Solar Still Technologies

#### A. Passive Solar Stills

Passive stills are the most basic form of solar desalination. They operate without external energy input, relying entirely on direct solar radiation. The most common design is the single-slope solar still, consisting of an airtight basin with a transparent cover. The primary limitation of passive systems is the high thermal inertia of the water mass in the basin, which restricts the rate of evaporation.

#### B. Active Solar Stills

Active systems integrate external devices such as Flat Plate Collectors (FPC) or Evacuated Tube Collectors (ETC) to increase the temperature of the basin water. By 2019, studies indicated that active solar stills could improve daily distillate production by 30% to 100% compared to passive counterparts.

#### C. Heat Transfer Mechanisms

The performance of a solar still is governed by internal and external heat transfer coefficients. The internal heat transfer includes radiation ( $h_r$ ), convection ( $h_c$ ), and evaporation ( $h_e$ ). The evaporative heat transfer is the most critical for distillate production.

$$Q_e = h_e (T_w - T_g)$$

Where  $T_w$  is the temperature of the water surface and  $T_g$  is the temperature of the condensing glass cover. Literature up to 2019 utilized Dunkle's model for estimating these values, though modified models for high-temperature active systems were increasingly adopted to improve predictive accuracy.

## II. DISCUSSION

### 2.1 Performance Augmentation Strategies

Table 1 Performance Augmentation Strategies

Technique	Mechanism	Effect on Yield
Phase Change Materials (PCM)	Latent heat storage for night-time production	+25% to +40%
Nanofluids	Enhanced thermal conductivity and absorption	+15% to +35%
Wick Materials	Reduction of thermal inertia via thin-film evaporation	+20% to +50%
External Reflectors	Concentration of solar flux into the basin	+10% to +20%

## 2.2 Economic and Environmental Impact

Solar stills are recognized for their low "Cost per Liter" (CPL), particularly in rural areas. While the initial capital cost for augmented systems (using PCMs or Nano-coatings) is higher, the amortized cost over the system's lifetime (typically 10-15 years) remains competitive. Furthermore, solar stills are carbon-neutral, significantly reducing the ecological footprint of water purification.

## CONCLUSION

The technological landscape of solar water purification up to 2019 demonstrated that while passive stills offer simplicity, the integration of heat storage materials and active collectors is necessary for meeting higher water demands. The focus on hybrid systems and nanotechnology continues to push the limits of solar-to-water efficiency.

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