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The Performance of Solar Stills Using Different Absorbing Materials: A Review

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ABSTRACT

Solar stills are considered an inexpensive, effective, and environmentally friendly technique for generating fresh water from seawater or polluted water by utilizing solar energy. But the applicability of these devices is hindered due to the inefficiency of distillation process and low thermal efficiency of solar stills. The choice of appropriate absorbing materials is one of the important techniques to enhance the effectiveness of solar stills through increasing the absorption of solar radiation, heat transfer, and evaporation process. In this paper, the performance of solar stills with various absorbing materials has been critically analysed, including black cotton cloth, jute cloth, cotton and jute wicks, black stones, pebbles, charcoal, black metal sheets, and other porous and thermally conducting materials. The effect of the properties of absorbing materials such as absorptivity, porosity, thermal conductivity, wettability's, and water retention capability on evaporation rate, daily fresh water output, and thermal efficiency has been explained. The comparative analysis of the reported experiments shows the benefits and drawbacks of different types of absorbers depending on the climate, depth of water bodies, and operation modes. Economic feasibility, availability of materials, resistance to corrosion, maintenance, and environment friendliness are also taken into account during the review. The results show that the selection of proper absorbing materials could increase the productivity of desalination of fresh water using solar energy in comparison with conventional solar stills. This review describes the most important research gaps and suggests additional studies in order to create efficient, sustainable, and cheap desalination devices.

Keywords: Solar still, absorbing materials, production of fresh water, solar distillation, wicking materials, efficiency in heat, distilled water output.

INTRODUCTION

Availability of clean and drinkable water has been a big problem in most parts of the world. Growth in population, industrialization, agriculture, groundwater pollution and rainfall patterns have increased the need for fresh water. Desalination processes like reverse osmosis and multistage distillation processes involve lots of energy consumption and maintenance. Hence, solar desalination is a renewable energy process used to produce freshwater.

Solar still is a device which uses solar energy to evaporate water and then condense it back to freshwater. It consists of a water chamber, an absorber plate, thermal insulator, glass cover, and a distillate collector. Solar energy enters through glass cover, causing heat in water and the absorber. The vaporized water gets condensed on the inner side of the glass cover due to lower temperatures compared to the absorber plate.

Though the simple design and low operational costs of a normal solar still make it very effective, productivity of the same still is restricted by factors such as evaporation rates, heat loss, depth of water, and the temperature difference between water and glass cover. Hence, there have been various methods tried by scientists to improve the efficiency and amount of fresh water produced.

One of the methods used in improving the performance of the solar still is by choosing proper absorbent materials. These materials absorb the solar energy and help in heat transfer, water distribution, evaporation, and heat storage. Examples of materials which have been studied include black cotton cloth, jute cloth, sponge, charcoal, pebbles, metal meshes, and absorbent coatings.

But their performance is dependent on their optical properties, thermal conductivity, porosity, wettability, thickness, and durability. In addition, they depend on the climatic environment, shape of the basin, and depth of water.

This paper reviews the performance of solar stills that use various absorbing materials based on heat transfer, experimental results, freshwater yield, economic viability, sustainability, and knowledge gaps. The aim of this paper is to come up with the appropriate absorbing materials for solar desalination system.

2. Working Principle and Thermal Performance of Solar Stills

2.1 Basic Working Principle

The working principle of the solar still utilizes the phenomenon of natural evaporation and condensation. Sun rays fall on the glass cover, which heats up the basin, absorbing substance, and water. Rise in the water temperature leads to evaporation, and then the resulting vapor rises towards the inner surface of the glass cover. The vapor gets condensed in the form of water drops that run down along the inclined glass surface collecting as distilled water. Soluble salts and other non-volatile substances stay in the basin [1].

2.2 Role of the Absorbing Material

The absorber material is very significant in determining the efficiency of a solar still because it absorbs solar radiation and converts it to heat energy which is transferred to the water. The ideal absorber material should be able to absorb most solar radiation, be a good conductor of heat energy, experience minimal heat loss and last long. While the blackened pan absorbs solar radiation effectively, the flat surface might not allow for more evaporation space. Porous and fibrous materials disperse water over a wide area where evaporation can take place due to the formation of films.

3. Classification of Absorbing Materials Used in Solar Stills

The absorbing materials used in the solar stills can be classified on the basis of physical form, heat transfer property, and functional purpose.

3.1 Traditional Blackened Basin Absorbers

Traditional solar stills have basins made up of metals which are blackened with black paint to absorb the sunlight and transfer the heat to water. These absorbers are economical, simple, and easy to fabricate. But due to the smooth surface of the basin, evaporation surface is limited. Suitable coatings must have high solar absorptivity, thermal stability, non-corrosive nature and safety when kept in contact with saline water for long duration.

3.2 Textile Based Absorbing and Wicking Materials

Various textile materials like blackened cotton cloth, jute, flannel, and coir matting are utilized as absorbing and wicking material. The textile material has the ability to keep thin films of water and increases evaporation surface. But thick wicks tend to hinder vapor transport. In addition to that, salt deposition and biological growth and repeated drying cycles make it less durable.

3.3 Porous and Granular Materials

Porous materials like sponges, charcoal, activated carbon, volcanic stones, porous ceramics, and granular materials like pebbles, gravel, and sand may improve the performance of solar stills. The former class absorbs sunlight due to its dark surface, while the latter increases the water distribution surface. The materials with appropriate heat capacity absorb and give off heat energy. However, there might be too much water retention, evaporation heat losses, poor vapor transfer, and deep immersion which lower efficiency.

3.4 Modified Metal Absorber and Metal Coatings

Modified metal absorbers are meshes of wires, finned surfaces, corrugated plates, and coatings of iron oxide. These absorbers increase heat transfer surfaces, water distribution, and solar energy absorption. Nonetheless, their effectiveness depends on the thickness of the layer, its adhesion, thermal properties, surface roughness, and operation conditions. Proper heat transfer to water is vital for reducing thermal losses.

4. Review of Literature for Solar Still with Various Absorbent Materials

4.1 Research Done on the Conventional and Modified Absorbent Surface

Conventional basin-type solar still is the basis of comparison when it comes to modified absorbent surfaces, but its efficiency depends upon evaporation surface area and temperature differential between water and glass. Researchers have tried various methods to enhance heat transfer, including dark surface, corrugation, fins, metal mesh, and porous material. According to Dhasan et al. (2023), freshwater production was 6.03 kg/m² against 3.85 kg/m² from a conventional solar still with the application of iron-oxide nanoparticles coating on the absorber. Modified solar still gave thermal and exergy efficiency of 47.67% and 4.53%, respectively, while freshwater production cost was 29.96% lower than that of conventional still.

4.2 Studies on Black Cotton Cloth

Black cotton cloth has been commonly used for wicks owing to their capillarity, flexibility, availability, and water retention property. The black cotton cloth spreads water films to increase the area of evaporation. In their study, Murugavel and Srithar (2011) looked into wick material and basin configuration; this paves the way for further studies on fabric-based absorbents. The black cotton cloth works well with proper operation conditions. Performance of the black cotton cloth is influenced by the thickness and placement of the material. The inexpensive nature and ease of replacing the material are some of its practical applications.

4.3 Jute Cloth Research Studies

Jute cloth is an environmentally friendly, biodegradable and cheap fabric that has been identified to be a good material for a wick with capillarity. In their research studies, Modi and Modi (2019) conducted experiments comparing jute and black cotton fabrics in single-slope double-basin solar stills with water depths of 0.01 and 0.02 m. The results indicated productivity increases of 18.03% and 21.46% for jute over the black cotton fabric [2,3]. These results show that jute fabric can perform well under certain experimental conditions but not universally better. The advantages of jute fabric are availability, water distribution, and cheapness.

4.4 Research on Sponge Sheets and other Porous Materials

The use of sponge sheets and porous materials is helpful in improving solar still efficiency through water holding capability and wetted surface area for evaporation. Factors that determine their efficiency include pore size, density, thickness, water holding capacity, and thermal conductivity. Too much water holding capacity increases the thermal mass and can lead to delayed heating, whereas thickness hinders heat transmission. There could also be concerns about the degrading of synthetic sponges under UV rays as well as chemical compatibility and contamination.

4.5 Pebbles, Rocks and Granular Material Studies

Pebbles, rocks and gravel contribute to solar still performance through their ability to absorb solar energy and retain sensible heat that can sustain evaporation as the intensity of sunlight reduces. The efficiency is dependent upon factors such as particle size, porosity, thermal conductivity and heat capacity. They can also be used in conjunction with textile absorbers for thermal storage and water distribution. Too much shading may limit evaporation. Cleaning is necessary to avoid contamination. Locally available pebbles provide cost-effective operation, but particle size and amount need more research.

4.6 Studies on Hybrid Cotton or Jute Fabric with Pebbles

The hybrid combination of textile absorbents with pebbles constitutes an excellent strategy since both materials serve different purposes. The cloth material helps spread the water in the basin and increases the evaporation surface area, whereas the pebbles help conserve sensible heat and facilitate the transfer of heat in the basin.

The experimental study referred to as "Experimental Investigation of the Performance of Solar Stills Using Different Absorbing Materials" compared a conventional solar still with those that include cotton fabric with pebbles and jute fabric with pebbles. The enhancement in freshwater production efficiency was found to be 50.00% in case of cotton fabric with pebbles and 46.15% in case of jute fabric with pebbles [5].

Such results indicate that the combination of absorbers may perform better than the normal basin under the stated conditions. However, the performance improvement cannot be attributed to either the cloth or pebbles alone until a separate control experiment is carried out. A proper comparison must involve both the normal basin, cloth only, pebbles only, and cloth plus pebbles setup under identical conditions [6-11].

The combined system would also need optimisation in terms of pebble size, cloth thickness, amount of water, and proportions of the materials used. Too many pebbles might lead to high thermal capacity, while too thick a cloth would hold too much water. The ideal configuration must involve the maximisation of evaporation surface, heat capacity, and heat transfer rate.

CONCLUSION

Absorption materials play a critical role in the efficiency and freshwater production of the solar stills. The traditional blackened basins act as reference material, while textiles like black cotton and jute fabrics increase the evaporation area due to capillary distribution of water. Porous materials, such as sponge and charcoal, help in retaining water, while pebbles and rocks act as thermal storage materials. Metallic materials like meshes, fins, and coatings may improve thermal conductivity and solar energy absorption.

Experiments have shown promising results under certain conditions. Higher productivity was noted for jute compared to black cotton fabric according to Modi & Modi (2019). An increase in the productivity of freshwater production from 3.85 to 6.03 kg/m² was observed when iron-oxide-coated absorber was used according to Dhasan et al. (2023). A productivity increase of 50.00% and 46.15% was noted using cotton fabric with pebbles and jute fabric with pebbles, respectively. However, differences in experiments make comparison difficult [2,3,4].

Further research should address the following aspects: standardised test procedures, wick-thickness optimisation, durability, water quality, validated modeling, and economics.

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