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Umbrella Desalinator

Shubh Mehta
Student, Hill Spring International School, Mumbai, Maharashtra, India.

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Abstract: *Saltwater and industrial contamination is gradually rendering groundwater in coastal India undrinkable, and the impact is most severely felt by the populations who lack access to centralised water treatment facilities. This paper details the design, construction, and initial performance assessment of the Umbrella Desalinator, a portable passive solar still intended to serve precisely these households. The first iteration of the prototype used a Peltier module and vacuum pump to actively cool and remove water vapour from the air. The second iteration, presented in this report, utilises solar energy for heating and does not require electricity or other consumables to operate. The device consists of a transparent canopy, mounted atop a darkened absorber sheet, which is held open by collapsible ribs. Solar radiation passes through the canopy and heats the water stored underneath, and the resulting vapour condenses on its surface and is funneled into a collection pouch. The expected daily yield under clear skies is between two and four litres of water. This paper further details the selection of components and the technical and ethical considerations surrounding the construction, as well as an appraisal of the performance of the completed prototype. Due to monsoon conditions, the performance of the prototype in Mumbai could only be partially evaluated. As such, this report reflects on the completed development process and presents an assessment of the potential utility of the design in the target environment. The findings suggest that a low-cost passive desalinator which employs an umbrella-like folding mechanism can indeed be constructed, and further testing in the target environment would be beneficial.*

Keywords: *Solar desalination; solar still; saltwater intrusion; portable water purification; off-grid water treatment; coastal groundwater contamination.*

I. INTRODUCTION

Potable water remains one of the most pressing challenges in coastal India. India's coast extends for roughly 7500 km, and saline ingress is becoming a serious problem for groundwater in coastal locations, due to both anthropogenic and environmental factors (Prusty & Farooq, 2020). Specifically, there has been a serious issue of saltwater seeping into groundwater reservoirs and rendering them unfit for consumption. The issue is caused by an imbalance in the natural groundwater system, which can occur due to either excessive extraction of groundwater or high rates of seawater intrusion, often due to changes to the natural landscape, as well as climate change factors such as rising sea levels. Roughly 7% of coastlines in India are already impacted by saline ingress, and groundwater levels in places had dropped below the level of the sea, leading to saltwater replacing freshwater in some water reservoirs naturally (Manivannan & Elango, 2019). In addition, industrial effluents which are dumped into coastal waters also contribute to the deterioration of the quality of existing groundwater bodies.

This problem not only poses a challenge to potable water availability in coastal India but also affects the long-term health outlook of roughly 250 million residents, most of whom are from rural, low-income, and often isolated areas (Naser et al., 2019). The gradual saltwater ingress has seen a rise in incidences of diseases such as renal failure, hypertension, and malignant hypertension in the region. Constructing centralised desalination plants can be a solution to this crisis, but such a solution is not ideally suited for rural and isolated communities without electricity due to the high costs and energy requirements of such facilities. This project aims to create a portable, low-cost, and passive device which can serve to desalinate water at the individual residence level. The central idea for the construction of the umbrella desalinator rests on the assumption that a simple solar still, constructed on a large scale, will be able to produce a significant quantity of fresh water with minimal resources and without requiring electricity. The prototype is designed using the same folding mechanism as an umbrella, to allow for convenient transport and storage.

II.LITERATURE REVIEW

Solar stills represent a well-researched category of passive desalination technologies, which are characterised by their low energy input and environmental footprint as compared to conventional desalination techniques. These stills can be generally divided into passive and active. In the former category, solar energy directly heats saline water, whereas, in the latter, electricity is used as an energy source to heat the raw water. The Umbrella Desalinator falls under the passive type, whereas the first prototype developed for the project was an active still with a Peltier module and a vacuum pump.

Numerous studies have been conducted to optimize solar still design, with particular attention paid to basin geometry and cover material. Basin depth appeared to have a significant effect on the productivity of solar stills. Indeed, a shallow basin resulted in higher freshwater yields because of the reduced surface area requiring heating. According to one study, a slope solar still with a basin depth of 4 cm had the highest productivity among the tested options, namely, 5, 6, and 7 cm. Specifically, it produced 2.68 litres of freshwater at 30% efficiency, while using an external mirror, this value increased to 3.075 litres at 35% efficiency. Another study, which simulated a 24-hour experimental cycle, also noted 4 cm as the most optimal depth for basin depth in terms of performance efficiency. According to it, the shallow basins of 1-4 cm outperformed the deep basins (Al-Mezeini et al., 2023).

The geometry and material of the cover were also subject to extensive experimentation. According to a comparative study of single- and double-basin sloped solar still designs, the latter option generally showed higher performance than the former. Specifically, a glass cover at an angle of 12 degrees outperformed the same cover at 36 degrees by approximately 40%. As to the thickness of the glass, the most efficient solar stills are obtained with thinner glass because of the reduced thermal resistance, which facilitates the condensation process. One study reported a 27% increase in productivity for a 4 mm cover and a 12% increase for a 5 mm cover relative to the 6 mm control cover. An article analysing the simulation and optimisation of single slope solar stills using response surface methodology and CFD also found that the combination of 29-degree inclination and 1 centimetre water depth produced the maximum hourly production of 1.5 kg/m² as well as a 8.6 kg/m² daily yield on a clear day (Aljubouri, 2017).

One of the key challenges addressed by the Umbrella Desalinator project is saltwater intrusion, which is a serious threat to groundwater quality in many coastal locations. Seasonal hydrogeochemical studies conducted in the coastal belt of India revealed that groundwater salinity depends on geological conditions of a given formation as well as seasonal temperatures. In particular, in Udupi district, coastal Karnataka, saltwater intrusion into groundwater has been reported to occur regularly as a consequence of seasonal temperature variations. Moreover, recent studies using sensors and satellites to study saltwater intrusion in coastal wells have found this process to occur slowly and steadily as opposed to seasonal fluctuations of saline tides and freshwater withdrawals. This means that saltwater intrusion is often challenging to detect until it has already progressed significantly (Akshitha et al., 2021).

Nevertheless, most of the aforementioned research aims at optimising the working conditions and performance characteristics of solar desalination units, which are generally used in a stationary manner. Although the reviewed studies cover an impressive array of design considerations and utilise advanced materials and methods, such as hybrid thermoelectric systems and materials with enhanced thermal accumulation properties, they do not address the development of portable and foldable solar stills. Notably, a survey of recent literature on solar desalination, which includes advancements in materials, hybrid thermoelectric systems, and cost-benefit analysis, does not address the challenges of transportability, foldability, and targeting remote and individual users. The Umbrella Desalinator project was undertaken to address this limitation and respond to the need to develop affordable, portable, family-sized desalination units by capitalising on the scientific insights into passive solar stills, notably the optimal basin depth and cover angle.

III.METHODOLOGY

Aim and Objectives

The aim of this project is to design, construct, and evaluate a portable, fully passive solar still capable of producing usable quantities of clean drinking water from saline or contaminated source water, for deployment in coastal and off-grid communities affected by groundwater salinisation.

This aim was broken down into the following objectives:

1. Design a collapsible, umbrella-inspired canopy structure capable of housing a functional solar still.
2. Eliminate reliance on the electrical components used in the first prototype (Peltier module, vacuum pump), replacing them with a fully passive solar distillation mechanism.
3. Construct a working prototype using accessible, low-cost materials.
4. Assess the design's safety, ethical considerations, and practical viability for deployment among target communities.

Materials

- **Canopy (transparent cover):** clear plastic table cover sheet, approx. 0.2 mm thick, cut to the canopy's radius
- **Structural ribs:** metal curtain rods, 6 rods
- **Central hub and pivot joints:** 3D-printed PLA components, custom-fitted to the rod diameter, designed in Fusion360
- **Central shaft:** same metal curtain rod
- **Dark absorber sheet:** black polythene sheet, cut to the basin's diameter
- **Collection pouch:** plastic sheeting, sealed along the edges with waterproof tape
- **Basin sealant:** hot glue
- **Fasteners:** cable ties

Engineering Design Process

The design of the Umbrella Desalinator was inspired by shortcomings of the first prototype, which used a Peltier module for thermoelectric cooling and a vacuum pump for aiding the process of evaporation. Both the elements rendered the machine dependent on electricity, involved additional costs, and created mechanical vulnerability, thus ruling out the possibility of a completely off-grid system. These shortcomings were addressed in the second prototype that completely relies on passive solar distillation.

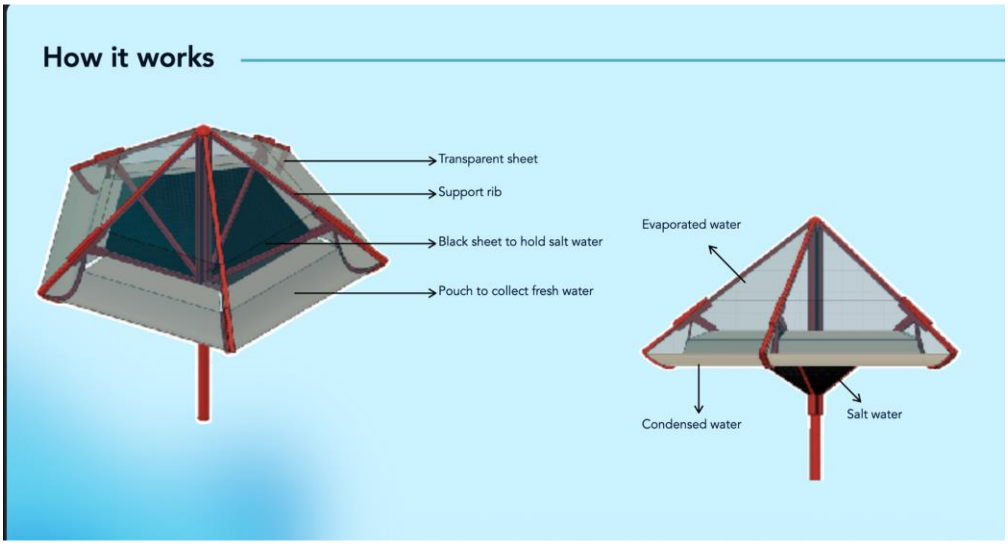

Figure 1: Labelled diagram of the umbrella desalinator

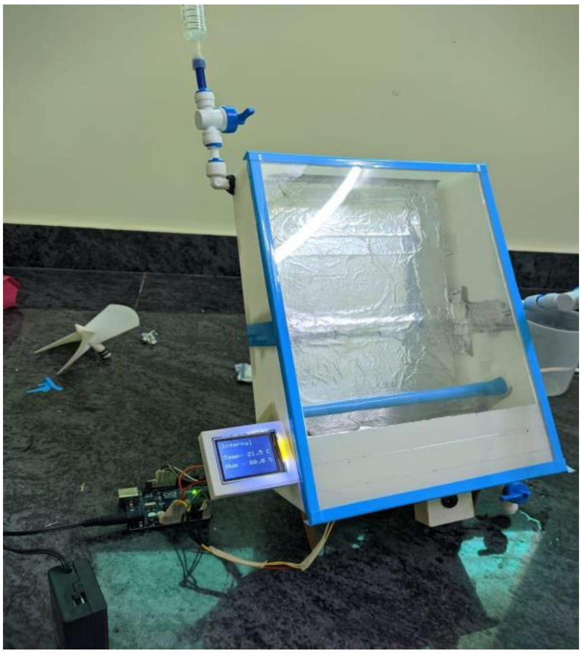

Figure 2: Prototype 1, with temperature and humidity sensor pictured.

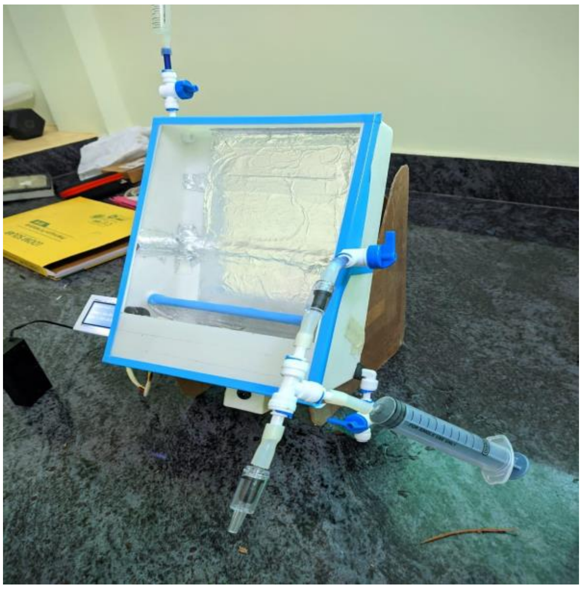

Figure 3: Prototype 1, with vacuum pump pictured

The working mechanism of the second and final protype is similar to conventional solar stills, but it includes an innovative umbrella-like canopy, fabricated from transparent material, which is elevated above the basin of blackened sheet by means of a set of vertical ribbons. The black colour of the basin is consistent with the established principle of solar still design that recommends using dark materials for basin lining in order to ensure maximum heat absorption. Solar radiation heats the basin, thus evaporating the feed water, which is then condensed by the cooled canopy, trickling down along its slope into a collection pouch, isolated from the salt water.

Alternative Approaches Considered

I considered using a different shape at first but did away with it due to the benefits of the umbrella shape. I also considered using electrical assistance in the form of a vacuum pump, however it was only making my design way more complicated so I removed it.

Step-by-Step Construction

1. I started with the central shaft. I fit the curtain rod with the 3D-printed hub piece at the top, leaving enough length below for a handle and a stand.
2. Next I attached the ribs to the hub. I slotted each curtain rod into its joint one at a time, spacing them out evenly so the whole thing would open into a proper umbrella shape rather than something lopsided.
3. Before touching the canopy, I tested the folding mechanism on its own. I opened and closed the rib assembly a few times to check the joints moved freely and the ribs actually locked when fully extended.
4. I cut the plastic table cover sheet down to size and stretched it over the open ribs, then secured it at each rib tip with cable ties.
5. I cut the black polythene sheet to match the basin area under the canopy and laid it flat so it covered the whole catchment zone, no gaps at the edges.
6. I ran silicone sealant along the edges and seams of the basin liner and left it to cure properly before adding any water, since a half-cured seal just leaks the first time you fill it.
7. I fitted the collection pouch at the lowest point of the canopy, just below the rim, so condensate running down the inner slope would land there instead of dripping back into the basin.
8. I sealed the pouch shut along its edges, leaving only the gap where it meets the canopy's drainage point, so it stayed completely separate from the saline basin water.
9. Last, I folded and unfolded the whole unit a few more times to make sure the canopy, liner, and pouch all moved together with the ribs properly, and checked for gaps or leaks before running the first test.

Data Sources

The secondary information used to support the design and conduct a literature review was obtained from journal articles, including ones on Water, Desalination, and others from the Journal of Thermal Analysis and Calorimetry, and the Journal of Coastal Conservation, indexed through Google Scholar and ScienceDirect. Reports from PIB and UPSC were also used in the project. The sources were evaluated in terms of relevance to passive solar distillation, recent publication date (preferably within the last five years), and credibility, which was determined by the journal’s inclusion in the list of reputable databases or by the presence of peer-review information.

Safety Procedures

The prototype has no electrical components, which removes the main safety hazards of the first design: electrical shock and overheating of the Peltier module. The safety considerations that remain include the structure's stability during outdoor use in wind, secure sealing of the basin to stop the source water from spilling (it may be contaminated or saline and should not be drunk directly). I also had to be careful when cutting the curtain rods, since they were metal and required me to use a sharp blade.

IV.RESULTS

Figure 4: Side view of the 3D model of the umbrella desalinator

Figure 5: Bottom-up view of the 3D model of the umbrella desalinator

Figure 6: Top-down view of the 3D model of the umbrella desalinator

Figure 7: Real image of the umbrella desalinator prototype

Figure 8: Real image of the umbrella desalinator

V.CONCLUSION

Throughout this report, the design, construction, and justification of a portable passive solar still, capable of addressing the issues of saltwater intrusion and groundwater contamination in coastal India have been presented and discussed. The objectives of the project have been achieved, as evidenced by the completed design and construction of a passive prototype based on the principle of solar distillation with specific consideration of the relationship between basin depth and the angle of the canopy.

Limitations

The main limitation of this work is incomplete performance testing, due to seasonal weather constraints. Another limitation is the extent of the purification as the collected water may still contain heavy-metal and iodine impurities.

Future Work

Future work should proceed to finish performance testing when possible, ideally over the span of multiple days and varying weather to allow for determining a mean daily yield based on solar irradiance. Later development may take advantage of passive thermal storage to deal with the testing limitations imposed by the monsoon season. The restriction is in itself an important consideration, as the device were to be deployed in similar regional climates throughout the year.

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