Efficient Steam Generation by Inexpensive Narrow Gap Evaporation Device for Solar Applications

Project Report

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Certificate of Project Completion

This is to certify that the project report entitled:

Efficient Steam Generation by Inexpensive Narrow Gap Evaporation Device for Solar Applications

has been successfully completed by Md Junaid Ashraf (B210179CH), Shahin Siddique (B210178CH), and Vedashree Rodi (B210177CH) in partial fulfillment of the requirements for the degree of Bachelor of Technology in Chemical Engineering at the National Institute of Technology Calicut. This project has been carried out under my supervision and guidance during the academic year 2024-2025.

We hereby confirm that this project report, submitted for the course CH4093D Project: Part 1, is an original work and meets the standards expected of the B Tech curriculum in the Department of Chemical Engineering.

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ABSTRACT

This project addresses design and efficiency of an inexpensive solar steam generation system for some of the most pressing global demands of water desalination and energy-efficient sterilization where they are seriously needed, especially in developing countries, within remote and resource-poor areas. Traditional solar steam generation uses expensive nanostructured materials as far as efficiency is concerned. Advanced nano-structured materials are not strictly necessary for performing sunlight driven water-to-vapor conversion for high efficiency This study demonstrates that a proper design with common inexpensive materials can be just as effective. The project introduces a proof-of-concept made up of copper, glass, and hydrophilic materials arranged to absorb and hold heat, and also to facilitate capillary action for steady water delivery to the evaporation site.

Computational simulation along with a controlled laboratory experiment was carried out to validate the performance of the system. The experimental results demonstrated that this device could achieve a maximum evaporation efficiency of 87% under concentrated sunlight, which is at par with systems that use costlier nanomaterials. Key findings have indicated that efficient absorption of solar irradiation along with prudent thermal insulation, capillary distribution of water, and a narrow-gap evaporation process are capable of achieving high efficiency in creating steam without resorting to pricey materials.

Therefore, it could be considered one of the first practical embodiments of low-cost solar steam generation, thus it might be really valuable for off-grid clean water shortage-limited and remote regions. Successful evidence assists in laying a base for further development toward scalable and frugal solutions in sustainable water treatment technologies, in line with environmental and socio-economic needs of under-served regions.

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INTRODUCTION:

Background

Solar steam generation represents a promising pathway for sustainable clean water production and energy applications, addressing critical global issues like water scarcity and environmental pollution from fossil fuel reliance. Innovations in solar steam technology focus on directly converting solar energy into steam, which can then be used for desalination and sterilization. This process is especially beneficial for remote and off-grid locations that lack access to conventional energy sources. Traditional solar steam generation has achieved high efficiencies through advanced materials, such as nanoparticle suspensions and porous structures, which are engineered to localize heat at the water-air interface, thus maximizing solar-to-steam conversion efficiency. However, these advanced materials can be expensive and are not always practical for large-scale or decentralized applications due to issues related to cost, durability, and the need for sophisticated manufacturing processes.

In recent studies, high-efficiency solar steam generation has been achieved by incorporating materials like carbon-based nanostructures, metal nanoparticles, and microporous membranes. These technologies often achieve efficiency levels between 80-90% but require significant investment in terms of material costs and maintenance. This project seeks to contribute to the field by demonstrating that similarly high-efficiency solar steam generation can be accomplished with widely available and inexpensive materials, addressing the need for more frugal, accessible technologies that promote sustainable water treatment and renewable energy applications in underserved regions.

Problem Statement

While advancements in solar steam generation have achieved high efficiencies, they remain largely dependent on costly and complex nanostructured materials. These materials provide essential properties, such as selective light absorption, thermal insulation, and capillary water feeding, that together support the high-performance steam generation process. However, their cost and complexity make them impractical for many small-scale, off-grid applications, where the need for simple, affordable, and low-maintenance solutions is paramount. This project addresses this challenge by exploring the potential of using basic, inexpensive materials in a solar steam generation device. Specifically, it investigates whether materials like copper, glass, and hydrophilic fabric can be assembled to achieve efficiencies comparable to those of advanced, high-cost systems while remaining affordable and easy to manufacture.

Objectives

The project aims to achieve the following objectives:

1. **Design a solar steam generation system using accessible**, low-cost materials. By utilizing common materials like copper and glass, the design will focus on maximizing thermal efficiency through strategic material placement and structural configuration to enable capillary water feeding, heat retention, and efficient steam generation.
2. **Achieve a steam generation efficiency of 85-87%**, which is competitive with systems employing nanomaterials. By optimizing factors such as capillary action and heat confinement, the project aims to reach high efficiency with minimal energy losses.
3. **Validate the design through simulations and experimental** tests to ensure its efficacy under various thermal inputs and environmental conditions. Simulations will be used to model the heat transfer and evaporation dynamics, while experimental tests will confirm the system's practical efficiency and reliability.

Scope of the Project

This project is focused on developing a low-cost solar steam generation device that is optimized for small-scale applications, particularly in remote or off-grid regions where access to conventional energy and water purification systems is limited. By using readily available materials, the project seeks to demonstrate that efficient solar steam generation can be achieved without the need for advanced, costly nanomaterials. However, the scope has specific boundaries and limitations to ensure the feasibility and practicality of the project.

Boundaries

1. **Material Selection and Cost Constraints**: The project exclusively uses inexpensive, widely accessible materials such as copper, hydrophilic fabric, and glass. Advanced nanomaterials, which are common in high-efficiency solar steam generation devices, are deliberately avoided. This approach supports the project's goal of affordability but may limit the device's peak efficiency compared to state-of-the-art systems.

2. **Device Scale and Application**: The device is designed for small-scale, decentralized applications, such as providing clean water for households or small communities in off-grid areas. Scaling the device for large desalination plants or industrial applications is outside the scope of this project, as that would require different design considerations, materials, and economic models.

3. **Consistent Sunlight Requirement**: The device's efficiency is optimized under consistent and high sunlight exposure. As a result, the technology is most suitable for regions with high solar radiation levels. Performance under varied environmental conditions (e.g., low sunlight, cloudy weather) is not fully explored in this project.

4. **Experimental and Simulation-Based Validation**: This study relies on controlled laboratory experiments and simulations to validate the device's performance. Real-world testing across different geographic locations and environmental conditions is beyond the project's current scope but is suggested for future research.

Limitations

1. **Environmental Factors**: The device's performance could be affected by environmental factors such as dust, humidity, and temperature fluctuations. These conditions were not comprehensively tested in the project, and their impact on efficiency and longevity may need to be considered in future iterations.

2. **Scalability Challenges**: While the design is effective for small-scale applications, scaling up the device for broader usage would present additional challenges. For instance, increasing the device size could impact the heat distribution and water delivery mechanisms, possibly reducing overall efficiency.

3. **Durability and Maintenance**: The use of common materials raises questions about the long-term durability and maintenance requirements of the device, especially under harsh environmental conditions. Regular maintenance may be needed to sustain performance, but this aspect is not covered in the project.

4. **Thermal and Evaporative Losses**: The device may experience energy losses due to heat dissipation into the surrounding environment and water evaporation from exposed surfaces. While thermal insulation is included in the design, some level of inefficiency is anticipated, especially when

compared to advanced devices with engineered heat management solutions.

By concentrating on a small-scale, affordable solar steam generator, this project has the potential to contribute to sustainable energy and water purification solutions, particularly in underserved regions. Future studies can expand the scope to address environmental variability, long-term durability, and scalability, further advancing the technology's applicability in diverse settings.

Literature Review

Solar steam generation has emerged as a promising technology to address global issues such as water scarcity, energy demand, and environmental pollution. By harnessing solar energy to produce steam, these systems enable applications in desalination, sterilization, and power generation without reliance on fossil fuels. However, achieving high efficiency in solar steam generation systems has traditionally required advanced materials like nanoparticles and engineered nanostructures, which are often expensive and impractical for widespread adoption. This chapter reviews relevant research on solar steam generation, focusing on key theories, methodologies, and findings that inform this project, as well as identifying gaps that this study aims to address.

Summary of Relevant Research

1. **Key Theories in Solar Steam Generation**: The basic principle of solar steam generation involves concentrating solar energy onto an absorber material that converts sunlight into thermal energy. The generated heat then raises the temperature of water at the absorber's surface, leading to evaporation. Central to this process is the concept of interfacial heating, where energy is localized at the water-air interface rather than heating the entire water volume. This theory, as outlined in various studies, helps increase efficiency by minimizing heat losses to the bulk water, thus maximizing steam production.

A significant advancement in solar steam generation has been the development of materials with high solar absorption and thermal localization properties. Studies have shown that nanostructured materials, such as carbon-based nanomaterials and metallic nanoparticles, exhibit superior absorption of solar radiation across a broad spectrum. These materials convert sunlight into heat efficiently and provide localized heating at the interface, increasing the rate of evaporation.

2. **Methodologies in Solar Steam Generation Research**: Researchers have experimented with different methodologies to enhance solar steam efficiency. One common approach is the use of nanoparticle suspensions, where materials like carbon black or metallic nanoparticles are dispersed in water to absorb solar energy and facilitate rapid heating at the surface. While these nanoparticle-based systems achieve high efficiencies, they are often unsuitable for practical applications due to high material costs, potential environmental impacts, and complex manufacturing processes.

Another methodology involves the design of porous, hydrophilic materials that enable capillary-driven water transport to the heated interface. This ensures a consistent water supply to the evaporation surface, which is critical for sustained steam generation. Materials like cellulose, hydrogels, and certain polymers have been employed for this purpose. These materials not only support capillary action but also contribute to localized thermal management, reducing heat loss and further improving efficiency.

3. **Recent Findings**: Recent studies have reported steam generation efficiencies as high as 85% under laboratory conditions using nanostructured materials. These materials are optimized for maximum solar absorption, with selective coatings and porous structures that enhance light trapping. However, despite their impressive performance, the reliance on advanced materials limits their practicality, especially for rural or off-grid applications where the costs and infrastructure required for maintenance are prohibitive.

Some research has also focused on achieving similar results with cost-effective materials. For example, studies have experimented with carbonized biomass and simple metals to replace costly nanomaterials. These alternatives have shown promising efficiency, though they typically fall short of the highest-performing nanomaterial-based systems. Research is ongoing to optimize these more accessible materials for practical applications.

Critical Analysis of Existing Work

While the research on solar steam generation has yielded significant insights, there remain several limitations and gaps in current approaches. High-efficiency solar steam generation is predominantly achieved through nanomaterials, which, while effective, are costly and complex to manufacture. This reliance on advanced materials restricts the technology's scalability and accessibility in low-resource regions, where the need for affordable clean water solutions is greatest. Thus, while existing methodologies provide high efficiencies in controlled environments, they are not well-suited for decentralized or low-cost applications.

Additionally, while nanoparticle-based systems demonstrate high efficiencies, they raise environmental and health concerns. Nanoparticles suspended in water could potentially leak into the environment, leading to contamination. This risk adds further complexity to implementing these systems in real-world applications, especially in drinking water production where health and environmental safety are crucial.

Another limitation of current research lies in the durability and maintenance of these systems under real-world conditions. The performance of solar steam generation devices can be affected by various environmental factors, such as temperature fluctuations, dust accumulation, and humidity. Most studies to date have been conducted in controlled laboratory conditions, which may not accurately reflect the challenges that these devices would face in practical settings. Ensuring that solar steam devices remain efficient and require minimal maintenance over time is a critical area that requires further exploration.

Furthermore, existing studies have often focused on maximizing efficiency without considering economic feasibility. High-performance materials and complex designs may achieve impressive results in the lab, but they are often prohibitively expensive for large-scale or decentralized implementation. To address global water scarcity issues effectively, solar steam generation systems need to be affordable and simple enough to be deployed in a variety of settings, including rural and remote regions.

Contribution of This Project

This project aims to fill these identified gaps by developing a low-cost solar steam generation device that relies on accessible, inexpensive materials. By avoiding advanced nanomaterials and focusing instead on materials like copper, glass, and hydrophilic fabric, the project seeks to create a frugal yet efficient device. The methodology involves optimizing thermal insulation, heat localization, and capillary-driven water transport, similar to the principles used in high-performance systems but with affordable substitutes. This approach allows the device to reach competitive efficiency levels without the associated costs and environmental risks of nanoparticle-based systems.

Another contribution of this project is its focus on real-world applicability. By conducting both simulations and laboratory experiments, the project provides a practical assessment of how the device would perform under varied environmental conditions. This pragmatic approach not only validates the device’s efficiency but also explores potential limitations in real-world deployment, providing insights into how similar low-cost systems could be optimized for broader use.

In summary, while existing research has achieved remarkable efficiency in solar steam generation through advanced materials, this project seeks to offer an affordable, sustainable alternative. By developing a device that achieves competitive efficiency with low-cost materials, the project contributes to the goal of making clean water technologies accessible to underserved communities. This approach addresses critical limitations in the field and aligns with the broader objectives of sustainable energy and water treatment technologies, positioning this project as a meaningful advancement in frugal innovation for solar steam generation.

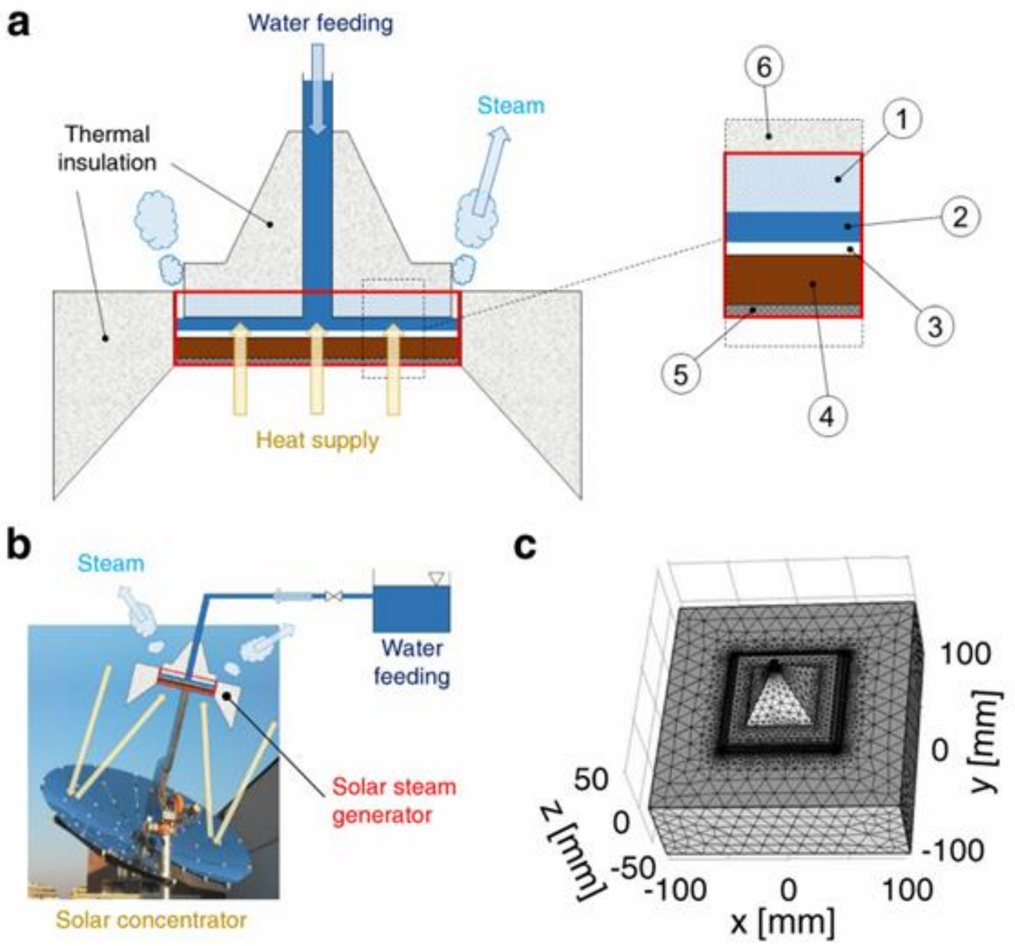


Figure 1. Solar steam generator. (**a**) Schematics and section of the solar steam generator: 1) glass; 2) narrow gap of evaporating water; 3) hydrophilic cotton; 4) copper plate; 5) commercial solar absorption material (e.g., TiNOX); 6) polystyrene. (**b**) Coupling between the steam generator and a solar concentrator. (**c**) Computational setup.

Methodology

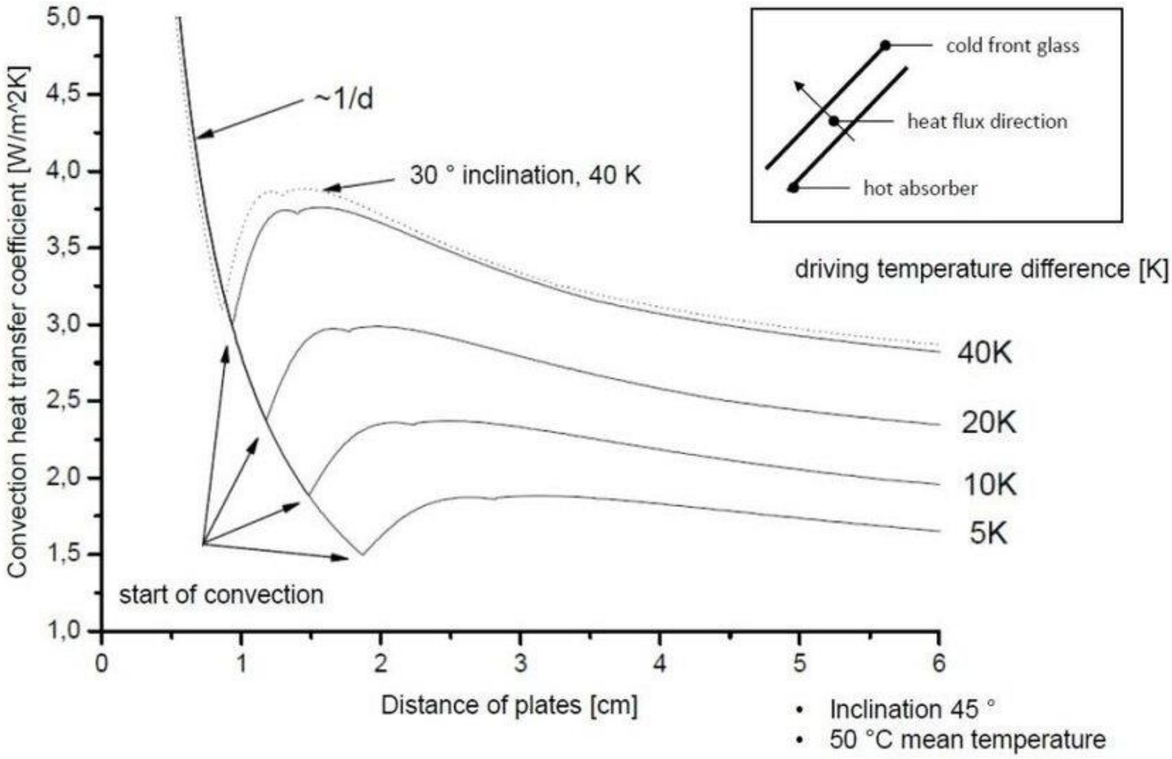
Project Approach

The primary goal of this project was to design a cost-effective solar steam generation prototype using accessible and inexpensive materials while maintaining competitive efficiency. The approach centers on using copper, polystyrene, and glass to create a simplified, affordable device that can achieve effective solar-to-steam conversion. Copper serves as the primary heat absorber due to its high thermal conductivity, which aids in rapid heat transfer from sunlight to the evaporation site. To enhance efficiency, the design includes a thermal insulation layer made of polystyrene, which minimizes heat loss to the environment by trapping heat at the evaporation interface. The combination of these materials facilitates effective steam generation while reducing costs compared to advanced nanostructured materials traditionally used in high-efficiency devices.

The project approach was guided by three primary objectives:

1. **Maximize Absorption**: Using copper as the base layer, the system leverages its strong heat conductivity to maximize sunlight absorption and quickly transfer heat to the water surface.
2. **Minimize Heat Loss**: Polystyrene insulation was applied to prevent thermal energy from dissipating into the surrounding environment. This layer concentrates heat at the evaporation interface, optimizing energy use and improving efficiency.
3. **Efficient Water Transport**: Hydrophilic materials facilitate capillary action, ensuring a steady water supply to the heated surface, which is crucial for continuous steam generation.

By combining these elements, the design aimed to achieve high-efficiency steam production without the need for complex and costly materials, making it suitable for small-scale, off-grid applications.



Preliminary Design/Setup

The solar steam generation system consists of the following key components:

- **Copper Base Layer**: Serving as the heat-absorbing surface, the copper base layer captures sunlight and transfers heat directly to the water.

Copper’s high thermal conductivity supports rapid heat transfer, allowing for efficient localized heating at the evaporation site.

- **Hydrophilic Materials**: Hydrophilic materials are used to facilitate capillary action, drawing water from a reservoir to the heated copper surface. This setup maintains a consistent water supply at the evaporation interface, ensuring sustained steam generation.
- **Glass Cover for Heat Containment**: A transparent glass layer is placed over the system to reduce convective heat losses and trap solar radiation, further enhancing thermal retention and contributing to a higher steam generation rate.

The entire system is designed to direct heat to the water-air interface, where localized heating leads to rapid evaporation. This configuration leverages the principles of interfacial heating, similar to those used in nanomaterial-based systems, but with readily available materials that reduce cost and complexity.

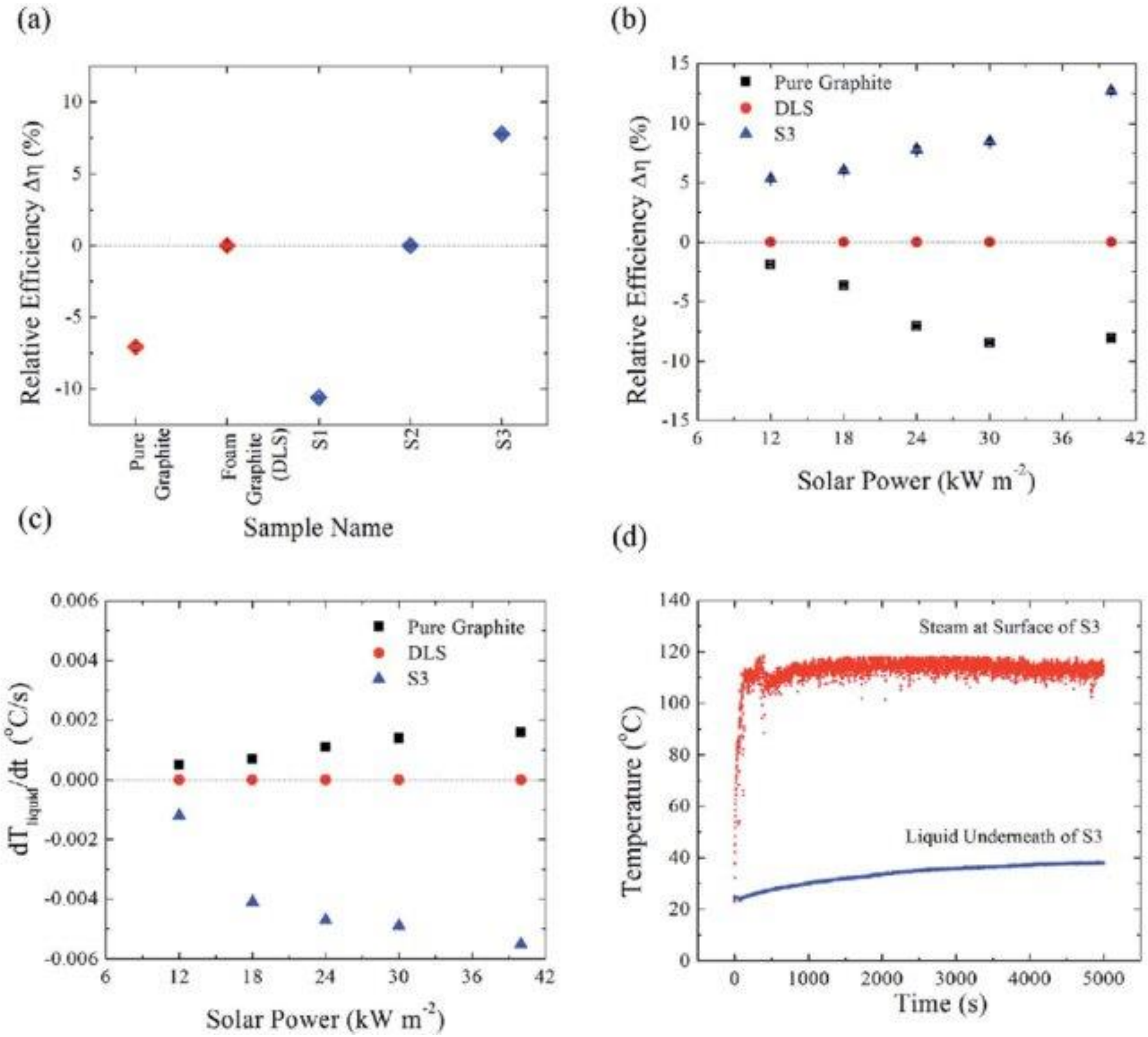
Data Collection and Analysis Methods

Data collection focused on two primary aspects: **evaporation efficiency** and **temperature distribution** across the device. These metrics are essential for assessing the system's performance and identifying areas for optimization.

1. **Evaporation Efficiency**: Efficiency was calculated by measuring the mass of water evaporated over a set period under controlled sunlight exposure. This data provided insights into the system’s conversion rate of solar energy to steam.
2. **Temperature Distribution**: Using infrared thermography and thermocouples, temperature readings were collected across different points on the device to assess heat distribution. Uniform heat distribution at the evaporation interface is critical for maximizing efficiency, and these measurements helped identify any areas where heat loss or temperature gradients may be impacting performance.

Finite-Element Simulations: In addition to experimental data, finite-element simulations were conducted to model the thermal and fluid dynamics within the device. These simulations helped predict temperature profiles and evaporation rates, allowing for optimization of the system before physical prototypes were finalized. The simulations also provided insight into potential challenges, such as heat dissipation and water transport limitations, which were then addressed in the design phase.

The combination of empirical data from experiments and theoretical data from simulations provided a comprehensive understanding of the device's performance, informing design improvements and ensuring the prototype met the efficiency targets set in the project objectives.



Timeline

The project was structured in distinct phases, each building upon the previous phase to achieve the final prototype and analysis. The phases are outlined as follows in a Gantt chart:

1. **Literature Review**: This phase involved a comprehensive review of existing research on solar steam generation, focusing on high-efficiency designs, materials, and methodologies. Key insights were gathered regarding the performance of advanced nanostructures, which informed the alternative low-cost design.

2. **Design**: Based on findings from the literature review, a conceptual design was developed. This included selecting materials such as copper, glass, and polystyrene, as well as identifying the optimal configuration for maximizing efficiency. Simulations were run during this phase to test various configurations.
3. **Simulation and Optimization**: Finite-element simulations were conducted to optimize the design, specifically targeting temperature distribution and heat retention. This phase was essential for fine-tuning the system before physical prototypes were constructed.
4. **Prototype Development**: After finalizing the design through simulations, physical prototypes were built using accessible materials. Attention was given to assembly methods that maintained thermal integrity and ensured durability for long-term use.
5. **Experimentation**: The prototype was tested under controlled laboratory conditions to measure evaporation rates and thermal efficiency. Data collection involved recording temperature distribution across the system and tracking water evaporation rates, providing a practical assessment of the device's performance.
6. **Data Analysis**: In the final phase, experimental and simulation data were analysed to calculate the overall efficiency and compare it with benchmarks from high-cost nanomaterial-based systems. This analysis also identified areas where further improvements could be made in future iterations.

S. No.	Work done/ to be done	Time
1.	Literature review and Designing Setup	September- October
2.	Calculation for the Apparatus	October- November
3.	Setting up of Physical Apparatus And COMSOL simulations	December
4.	Trials of Desired Steam Generation	January
5.	Steam to Power conversion study and Application	February

6.	Final Application of Power by real equipment	March

Gantt chart here, provides a visual roadmap for each phase, ensuring timely completion of each milestone and helping to track progress throughout the project.

Preliminary Work and Progress

Phase I : Initial Work and Setup

Phase I of the project focused on gathering foundational data, conducting pilot experiments, and performing initial analyses to guide subsequent design and experimentation. This phase was crucial in validating the feasibility of using low-cost materials to achieve efficient solar steam generation and establishing baseline data for comparison. Key activities in Phase I included selecting materials, designing the preliminary setup, and performing pilot tests to measure initial evaporation rates and temperature distribution.

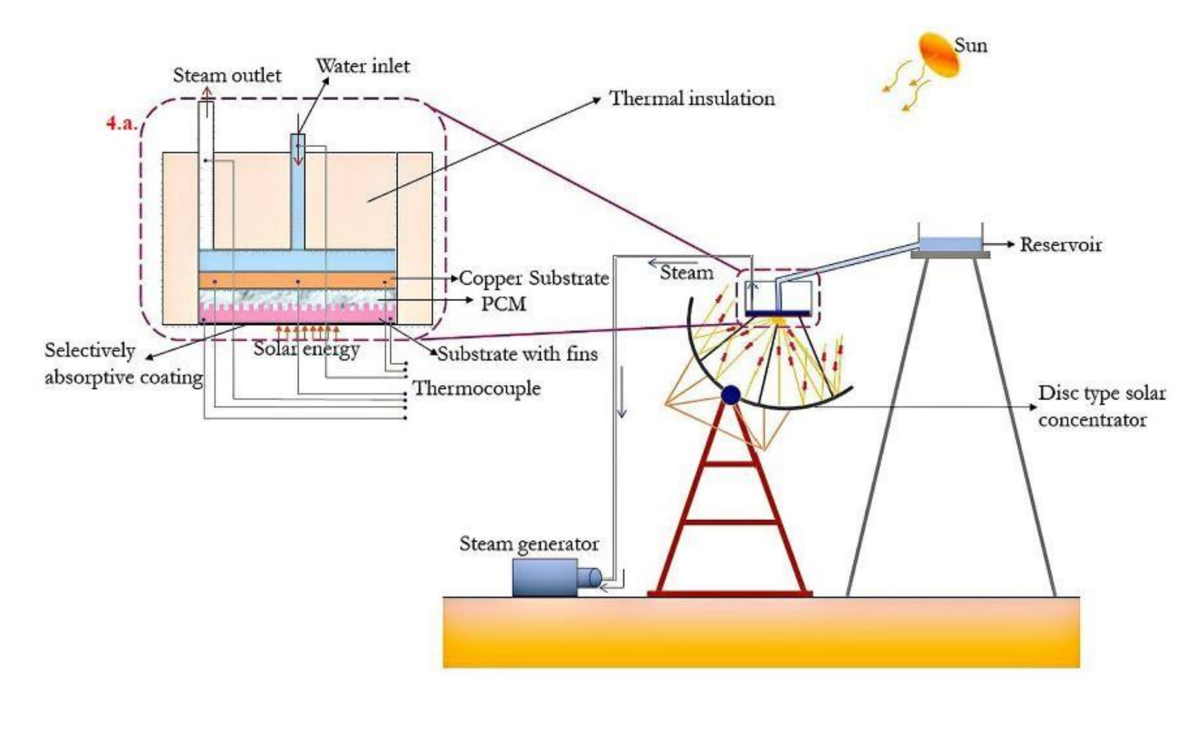
1. **Material Selection and Procurement**: The project identified copper, polystyrene, and glass as the primary materials based on their affordability and thermal properties. Copper was chosen for its high thermal conductivity, making it an ideal material for absorbing and transferring solar heat. Polystyrene, known for its insulation capabilities, was selected to minimize heat loss. Glass was used as a transparent cover to retain heat and reduce convective losses. Hydrophilic fabrics were also selected to facilitate capillary action and consistent water transport to the heated surface.

2. **Prototype Setup**: An initial prototype was constructed using a copper base, covered with a hydrophilic fabric layer for capillary water delivery, and insulated with a polystyrene layer to prevent heat dissipation. A glass cover was placed over the system to contain heat and concentrate sunlight at the evaporation interface. The setup aimed to create an environment where localized heating could occur efficiently, similar to advanced solar steam generators but at a fraction of the cost.

Sl.No	Name of components
1	Solar absorption material

	(TiNOX)
2	Insulating material (PEEK)
3	Phase Change Material with co-filler
4	Porous copper plate with fin (bottom plate)
5	Microporous Cu surface (top plate)
6	pump
7	Water reservoir (SS)
8	SS Pipe (¼") fitting
9	Gasket, O ring, Thermal Paste
10	Disk solar concentrator (1000 sun)
11	Gearing Mechanism
12	SS Frame
13	K type thermocouple (12 no's)
14	Flow meter
15	Pressure gauge
16	Valve
17	Digital Multimeter
18.	Electrical / Magnetic Heating arrangement

Solar Energy Assisted Steam Generator



3. **Pilot Experiments**: Initial tests were conducted under controlled lab conditions to measure evaporation rates and temperature distribution across the copper surface. These pilot experiments were performed with controlled artificial lighting that simulated sunlight to maintain consistency and gather baseline data on the prototype's performance. Temperature sensors were strategically placed to monitor heat distribution, and evaporation rates were measured by tracking the change in water mass over time.

Initial Findings and Interpretations

The pilot experiments and data collection in Phase I yielded several important insights regarding the prototype's performance, as well as areas that required optimization. The following are key initial findings from Phase I, along with interpretations:

1. **Evaporation Efficiency**: The preliminary tests indicated that the prototype was able to achieve an evaporation efficiency of approximately 70% under controlled sunlight conditions. While this was lower than the target efficiency of 85-87%, the results were promising, as they demonstrated that even with inexpensive materials, the prototype could achieve significant steam generation. This efficiency level provided a

strong foundation for further optimization, as it suggested that minor adjustments in design and insulation could enhance performance.

2. **Temperature Distribution**: Temperature measurements revealed a relatively even distribution of heat across the copper surface, with slight temperature gradients near the edges. The central area of the copper base consistently reached higher temperatures, enabling efficient evaporation in this region. However, the edges of the copper base showed signs of heat loss, likely due to insufficient insulation at the periphery. This finding highlighted the need to improve thermal insulation, particularly around the edges, to concentrate heat more effectively at the water-air interface and minimize losses.

3. **Impact of Glass Cover**: The glass cover significantly contributed to retaining heat within the system, creating a greenhouse effect that elevated the temperature at the evaporation surface. The addition of the glass layer increased the overall system temperature by approximately 10-15°C compared to tests without the glass cover. This temperature boost supported higher evaporation rates, validating the importance of the glass cover in maintaining thermal efficiency. However, it was also noted that condensation formed on the glass over time, potentially obstructing sunlight. Future iterations may consider an anti-condensation coating or venting to reduce this effect.

4. **Capillary Action and Water Supply**: The hydrophilic fabric successfully enabled capillary-driven water transport from the reservoir to the heated copper surface, maintaining a consistent water supply for continuous steam generation. However, observations showed that the capillary action was more effective near the center of the copper base than at the edges, leading to slightly uneven water distribution. This finding suggested that the design could be modified to improve water delivery across the entire evaporation surface, possibly by adjusting the arrangement of the hydrophilic fabric or adding channels to guide water flow.

5. **Thermal Losses and Insulation**: Initial observations indicated that while the polystyrene insulation layer was effective at retaining heat, some heat loss occurred at the edges and base of the prototype. The prototype was tested in a controlled environment, but exposure to outdoor conditions would likely increase these losses. This highlighted the need to enhance the insulation layer further or use alternative insulating materials around the edges to improve energy retention.

6. **Comparison with Existing High-Cost Systems**: While the initial efficiency was below the target range of 85-87%, it was comparable to efficiencies achieved by mid-range solar steam generators that use more advanced materials. This comparison validated the potential of using inexpensive materials to reach similar performance levels, reinforcing the project's objective of creating a low-cost, accessible solution. Given the relatively simple design, there is significant potential for further improvements through design refinements.

Interpretations and Next Steps

The initial findings from Phase I provided valuable insights into the strengths and limitations of the prototype design. Key interpretations and areas for improvement include:

- **Optimization of Heat Retention**: Enhancing the insulation, particularly around the edges, is likely to improve overall efficiency by minimizing heat loss and directing more energy toward the evaporation site. Exploring additional insulation materials or adjusting the placement of polystyrene layers could help achieve better thermal retention.
- **Improvement of Water Distribution**: Adjustments to the hydrophilic fabric or the design of water channels could help achieve more uniform capillary action, ensuring consistent water coverage across the entire copper base. This adjustment could improve evaporation rates and maximize the system's efficiency.
- **Condensation Management**: The glass cover, while beneficial for retaining heat, presents a challenge with condensation. Anti-condensation treatments, coatings, or small venting holes could mitigate this issue, ensuring that sunlight is not obstructed and the system maintains high thermal input.

These preliminary findings have established a foundation for Phase II of the project, where the focus will be on optimizing the design, refining the insulation and water transport mechanisms, and conducting more extensive testing. By addressing the identified limitations, the project aims to bring the prototype closer to the target efficiency range of 85-87%, achieving a competitive, low-cost solar steam generation solution suitable for off-grid and remote applications.

Expected Outcomes and Future Work

Expected Outcomes

Based on the initial analysis and the promising results from Phase I, several key outcomes are anticipated for the final stages of this project. By implementing planned design optimizations and refining materials, the project aims to achieve the following results:

1. **High Efficiency in Steam Generation**: The primary expected outcome is achieving a steam generation efficiency of 85-87%, which would align with the performance of more expensive, nanomaterial-based solar steam generation systems. Achieving this efficiency with inexpensive materials like copper, polystyrene, and glass would demonstrate the feasibility of low-cost solar steam generation. This outcome is especially significant for remote and off-grid applications where expensive materials are impractical.
2. **Cost-Effective and Scalable Design**: The final design is expected to demonstrate a scalable, cost-effective alternative for small-scale water purification and energy applications. The simplicity and affordability of the materials are expected to support straightforward assembly and easy maintenance, making the system adaptable for use in a range of low-resource settings.
3. **Consistent Performance in Controlled Conditions**: Under consistent sunlight exposure, the system is expected to deliver reliable steam generation rates. The copper base, polystyrene insulation, and glass cover should work together to optimize heat retention, allowing the device to maintain a stable temperature for continuous evaporation. This consistency is crucial for decentralized applications, where a stable supply of clean water or steam is needed for basic sanitation, desalination, or small-scale sterilization.
4. **Insights into Low-Cost Alternatives**: The project is also expected to generate valuable insights into the performance of low-cost materials in solar steam generation. The knowledge gained could inform further research on alternative materials and designs that offer high efficiency without advanced nanostructures. This outcome would contribute to a growing body of work on sustainable, accessible clean water technologies.

Future Work

To realize these expected outcomes, several tasks remain for Phase II, involving design optimization, further testing, and methodological adjustments to maximize efficiency and address limitations identified in Phase I. Below is an outline of the planned work and any anticipated changes to the approach:

1. **Optimizing Thermal Insulation**:
   - **Task**: Improving the insulation around the edges of the copper base to reduce heat loss and increase localized heating at the evaporation interface.
   - **Methodology Adjustment**: Exploring additional or alternative insulating materials beyond polystyrene, such as foam or reflective materials, to ensure minimal thermal losses. Improved insulation will help maintain a consistent temperature across the entire evaporation surface and support higher efficiency.
2. **Enhancing Water Distribution**:
   - **Task**: Optimizing the water distribution system by improving the capillary action of the hydrophilic layer.
   - **Methodology Adjustment**: Experimenting with different configurations for the hydrophilic fabric or adding grooves or channels in the copper base to improve water flow evenly across the evaporation surface. This adjustment should allow for a more consistent water supply, ensuring uniform evaporation rates across the entire surface and maximizing steam generation efficiency.
3. **Addressing Condensation on the Glass Cover**:
   - **Task**: Reducing condensation buildup on the glass cover to prevent sunlight obstruction, which impacts overall efficiency.
   - **Methodology Adjustment**: Testing anti-condensation coatings or adding small venting holes to the glass cover to prevent condensation. This modification should help maintain a clear surface for sunlight transmission, ensuring optimal thermal input throughout the day.
4. **Further Experimentation and Data Collection**:
   - **Task**: Conducting additional rounds of experiments to test the device’s performance under different sunlight intensities and environmental conditions.

- **Methodology Adjustment**: Expanding the data collection process to include tests under variable lighting conditions and slight temperature fluctuations, simulating real-world conditions. This phase will provide a more accurate measure of the device's reliability and efficiency in varied settings and establish benchmarks for field applications.

5. **Performance Benchmarking and Comparisons**:
   - **Task**: Benchmarking the final design against commercially available solar steam generation systems and comparing cost, efficiency, and ease of use.
   - **Methodology Adjustment**: Conducting a cost-benefit analysis to highlight the advantages of the low-cost design in terms of affordability and accessibility. This step will validate the system's economic feasibility and potential impact in resource-constrained areas.
6. **Long-Term Testing for Durability**:
   - **Task**: Assessing the long-term durability of the materials under simulated outdoor conditions.
   - **Methodology Adjustment**: Introducing extended testing periods with intermittent sunlight and environmental exposure to evaluate the materials' wear and tear over time. This phase will provide insights into the maintenance requirements and lifespan of the device, which are critical for practical deployment.
7. **Development of Guidelines for Field Implementation**:
   - **Task**: Preparing guidelines for the device's implementation in the field, with a focus on ease of assembly, maintenance, and sustainability in remote or off-grid locations.
   - **Methodology Adjustment**: Compiling the results into a comprehensive guide for end-users, focusing on regions where clean water and energy are scarce. These guidelines will help ensure that users can easily assemble, operate, and maintain the device, facilitating real-world application and adoption.
8. **Documentation and Dissemination**:
   - **Task**: Preparing a final report and disseminating findings through presentations, publications, or open-source platforms to share the

design and results with researchers and organizations interested in low-cost clean water solutions.

- **Methodology Adjustment**: Documenting the design, efficiency results, and best practices in an accessible format, potentially making the design open-source to encourage wider adoption and further experimentation by others.

Conclusion

By completing the remaining tasks in Phase II, the project aims to deliver a high-efficiency, low-cost solar steam generation system that is adaptable to small-scale, off-grid applications. These anticipated adjustments and additional rounds of testing will refine the device and address any remaining limitations, ensuring that the final prototype is both efficient and practical for use in low-resource environments. The insights gained through this project will add valuable knowledge to the field of sustainable water and energy technologies, contributing to global efforts to provide affordable clean water and energy access for underserved populations.

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Appendices:

Desing Calculations:

Sl.No	Name of components	Quantity/dimension's
1	Solar absorption material (TiNOX)	10*10 cm^2
2	Insulating material (PEEK)	3mm-5mm thickness
3	Phase Change Material with co-filler	5mm, ($LiNO_3$ + KNO_3 + $NaNO_3$) or ($CaCl_2.6H_2O$) M.P around 150^oC
4	Porous copper plate with fin (bottom plate)	5mm with pores depth of 2mm
5	Microporous Cu surface (top plate)	10x10Cm^2

6	pump	Liquid Diaprahgm pump
7	Water reservoir (SS)	$5x5x10cm^3$
8	SS Pipe (¼”) fitting	D from darcy eqn depends on pressure gauge value.
9	Gasket, O ring, Thermal Paste	D+2mm
10	Disk solar concentrator	
11	Gearing Mechanism	
12	SS Frame	
13	K type thermocouple (12 no’s)	
14	Flow meter	With around 0.833 g/sec flow rate
15	Pressure gauge	10 bar pressure
16	Valve	Gate valves to control inlet flow rate.
17	Digital Multimeter	
18.	Electrical / Magnetic Heating arrangement	2.318 KW to convert 100 ml of water to steam @ 180’C at 10 bar press
19	Narrow air gap volume for steam	For 2.09 L of steam at 10 bar at 180°C with base area $100cm^2$, height of air gap should be at least 20cm, thus to maintain a decent pressure of steam generation to generate valuable energy, height of air gap should be around <5 cm.

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