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Design and Fabrication of Setup for Harvesting Water from Atmospheric Air- A Review

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Abstract-

In numerous nations like India, accessing water resources for irrigation or other needs, particularly in arid regions, poses a significant challenge. Water scarcity is a prevalent issue worldwide, often stemming from insufficient rainfall. Conversely, in highly humid locales such as coastal areas, water can be procured through condensing atmospheric water vapour. This paper introduces a method for developing a water condensation system utilizing thermoelectric cooling technology. The system comprises cooling elements, a heat exchange unit, and an air circulation mechanism. Powered by a solar cell panel unit with a substantial output, the cooling elements are regulated through a control circuit. An Atmospheric Water Generator, a device capable of converting atmospheric moisture directly into potable water, operates on the principle of latent heat to transform water vapour molecules into water droplets. Although introduced earlier, it remains relatively uncommon in India and other regions. However, given the contemporary emphasis on renewable energy sources, its potential applications are considerable.

***Key words* :**Water condensation, Thermoelectric peltier, Dew condensation (latent heat), Solar energy, AWGs.

I. Introduction

Water scarcity is a growing threat impacting millions globally. Traditional sources like rivers and aquifers are under increasing pressure, leaving communities scrambling for solutions. Enter Atmospheric Water Generators (AWGs) – innovative machines that capture water vapor from the air, offering a potential lifeline in dry regions.

AWGs operate on a variety of principles, each with its own advantages and limitations. One approach utilizes desiccants, special materials with a high affinity for moisture. These desiccants attract water vapor from the surrounding air, much like a sponge soaks up water. Once saturated, the desiccant undergoes a regeneration process, typically using heat, which releases the captured water vapor as clean liquid water.

II. LITERATURE SURVEY

Atmospheric water generators (AWGs) are a promising technology for extracting potable water from ambient air moisture. Research efforts focus on improving efficiency across two main AWG technologies: condensation and desiccation. Condensation-based AWGs, similar to air conditioners, cool air to collect water vapor as condensation. Desiccant AWGs utilize materials like salts or zeolites that attract moisture from the air, releasing it later through heat. While both methods produce clean water, challenges remain in optimizing energy consumption for large-scale AWG adoption. New research explores using renewable energy sources and advanced materials to create more sustainable and efficient AWG systems.

1. Mohamed, Elashmawy et al-2020: The researcher delved into a novel application of a Tubular Solar Still (TSS) empowered by a parabolic solar concentrator for Atmospheric Water Harvesting (AWH) specifically targeting low humidity regions. This innovative approach aimed to address the challenge of extracting usable water from environments where moisture content in the air is scarce.

The design incorporated a rectangular trough constructed with black colored cotton cloth. This fabric, strategically chosen for its high moisture absorption properties, was then impregnated with a desiccant solution. The initial concentration of this solution was meticulously set at 30% to optimize water capture during the absorption phase.

The AWH process itself was conducted over a two-night period. This extended timeframe ensured that the desiccant solution reached a balanced concentration, a state where its moisture absorption capacity is maximized under the specific climatic conditions of Hail City, Saudi Arabia. The researcher closely monitored the absorption process throughout these nights, collecting data on the rate of moisture uptake by the desiccant solution.(1)

2. Xiaoli, Liu. et at.-2019: This paper delves into a cutting-edge dehumidification technology that utilizes liquid desiccants to absorb moisture from the air. Unlike traditional methods that directly contact air with the liquid desiccant, this approach leverages membranes to create a separation barrier. The review offers a comprehensive analysis, encompassing various aspects of membrane-based liquid desiccant dehumidification (MLDAD) systems.

Firstly, it explores the characteristics of different membranes and liquid desiccants employed within MLDAD systems. This analysis sheds light on the factors that influence the effectiveness of these components in moisture removal. Next, the design of heat and mass exchangers (HMXs) is examined. HMXs play a crucial role in MLDAD systems, as they are responsible for regenerating the desiccant's dehumidification capacity by removing the absorbed moisture. Following this, the review explores various configurations for MLDAD systems, outlining the advantages and disadvantages of each. Understanding these configurations is essential for selecting the most suitable system for specific applications.(2)

3. Sangita, Mishra-2019: This study addressed a critical challenge in semi-arid regions: identifying a sustainable water harvesting structure that doesn't rely on scarce rainfall. Researchers evaluated various options and identified the Warka Water Tower as the most promising solution due to its affordability, low maintenance needs, and readily available construction materials. The Warka Water Tower operates by capturing atmospheric moisture through condensation. The design utilizes a mesh net to collect airborne water droplets, which then accumulate in a reservoir at the tower's base. Notably, the current discharge rate is 100 liters per day, but the study suggests that optimizing conditions could potentially enhance its efficiency. A feasibility analysis revealed that the Warka Water Tower thrives in environments with temperatures around 40 degrees Celsius and a relative humidity range of 50-70%. While the initial cost of a single tower is approximately 33,000 rupees, the long-term economic benefits and potential for wider implementation in water-scarce regions make it a compelling solution. Large-scale adoption of Warka Water Towers could provide a sustainable source of drinking water for communities struggling with water scarcity.(3)

4. Liu, Y. et al.-2018: In this research paper, researchers investigated the efficiency of five different frost growth systems utilizing thermoelectric modules for cooling. These modules function by creating a temperature difference between their hot and cold sides. By applying electricity, one side gets hot while the other side gets cold. This project aimed to identify the most efficient method for achieving the desired frost growth conditions. The cold side heat exchangers, all identical and equipped with fins, were cooled by the thermoelectric modules to fall below freezing point. These surfaces acted as the base plates upon which frost would accumulate. The key area of investigation was the hot side heat exchangers, designed with five distinct cooling methods. Three of these methods employed active cooling techniques, likely involving fans, pumps, or fluid circulation to dissipate heat. The remaining two methods presumably relied on passive cooling strategies, such as heat sinks or natural convection, for heat removal. By comparing the performance of these various cooling approaches, the researchers hoped to determine the optimal balance between frost growth efficiency and energy consumption. This research has potential applications in diverse fields, such as refrigeration technology, air conditioning systems, and even frost-based dehumidification processes. Understanding how to efficiently achieve frost growth using thermoelectric modules could lead to more sustainable and energy-saving solutions in these areas.(4)

5. Sahar, Zolfagharkhani et al.-2018: In this study, researchers took a significant step forward in the development of gas compression refrigeration cycle technology for freshwater production. They tackled the challenge by creating a computer program that can simulate a flexible model of this cycle. This program isn't a one-size-fits-all solution; it can be adapted to account for the specific climatic conditions of any given location. This adaptability is crucial, as factors like temperature and humidity have a profound impact on the efficiency and output of such systems.

The program doesn't stop at simulating the cycle. It also delves into the key metrics of water production and energy intensity. By analyzing these outputs under various climatic scenarios, researchers gain valuable insights into how the system performs in real-world situations. This knowledge can be used to optimize the design and operation of the cycle for different environments, ensuring it remains effective in both dry and humid climates.(5)

6. Sajid, M. et al.-2017: This work delves into the critical role of cooling methods in maintaining the cold side temperature of thermoelectric generators (TEGs). As highlighted at the outset, TEG conversion efficiency hinges heavily on the temperature difference between its hot and cold sides. A larger temperature gap translates to more efficient electricity generation. Therefore, focusing on effective cooling strategies becomes paramount in optimizing TEG performance.

This exploration delves into the performance parameters of various heat rejection techniques employed for TEG cooling. Each method offers distinct advantages and drawbacks. For instance, air cooling boasts simplicity and affordability but may struggle to maintain sufficiently low temperatures, especially in hot environments. Conversely, water cooling offers superior heat transfer capabilities, leading to lower cold side temperatures. However, it introduces complexity through the need for pumps and plumbing, potentially increasing maintenance requirements and costs.

The overview provided here goes beyond simply listing cooling methods. It sheds light on the trade-offs associated with each approach. This insight is crucial for engineers and researchers seeking to integrate TEGs into real-world applications. By understanding the strengths and weaknesses of different cooling techniques, they can make informed decisions to optimize TEG performance and system efficiency for specific operating conditions.(6)

7. Joshi, V. et al.-2017: The researchers examined the influence of three key parameters on the amount of water generated: mass flow rate of moist air, ambient humidity, and the electric current supplied to the Peltier modules. Their findings indicate a direct proportional relationship between each of these factors and the water production. This implies that increasing the flow rate of moist air, operating in a more humid environment, or supplying a higher electric current to the Peltier modules will all lead to a greater yield of fresh water.

A significant observation was the impact of an internal heat sink placed on the cold side of the Peltier modules within the cooling channel. This modification resulted in an impressive 81% increase in water generation compared to the system without the heat sink. The enhanced heat transfer facilitated by the heat sink likely contributed to this improvement.

The experiment yielded a maximum water production of 240 ml over a 10-hour operation period. While this amount might seem modest, it represents a significant step forward in developing portable solutions for fresh water generation, particularly in coastal and humid regions with limited access to clean water sources. Further research and optimization could potentially lead to significant improvements in water production capacity, making this technology even more viable for practical applications.(7)

8. Dia, Milani et al.-2014: In this research paper, where advancements in solar energy offer a promising solution. By facilitating solar energy through rooftop flat-mounted photovoltaic thermal (PVT) arrays, AWG systems can be powered sustainably. PVT arrays not only generate electricity from sunlight (photovoltaic) but also capture heat (thermal) which can be used to drive the dehumidification process more efficiently.

This approach, particularly suited for scenarios like small field clinics in self-contained cabins, offers a completely self-sufficient solution. The PVT arrays on the cabin rooftops generate the electricity needed to power the AWG, while simultaneously producing heat to aid in water extraction. This eliminates dependence on external power grids, making AWGs a viable option even in remote locations with unreliable infrastructure.

In conclusion, atmospheric water generation with solar-powered AWG systems presents a sustainable and effective solution for emergency situations and remote locations. It offers the dual benefit of providing clean water and air conditioning, all while minimizing environmental impact.(8)

9. A.E., Kabeel-2007: The researcher meticulously designed, constructed, and then rigorously tested an integrated desiccant solar pyramid collector system. This pioneering system harnesses the power of the sun and the hygroscopic properties of a desiccant, like calcium chloride used in this experiment, to extract moisture from the surrounding air and produce fresh water. The cyclical operation of the system capitalizes on the contrasting conditions between day and night.

During night-time hours, the researcher strategically opened the four sides of the pyramid, allowing humid ambient air to flow freely into the collector. The meticulously placed desiccant within the pyramid readily absorbed water vapor from the incoming air due to its hygroscopic nature. As the night progressed, the researcher monitored the system, tracking the desiccant's moisture absorption rate and anticipating the need for regeneration come sunrise.

With the arrival of daytime, the pyramid underwent a transformation orchestrated by the researcher. The four sides were meticulously closed, effectively sealing the collector and creating a controlled environment. Now bathed in sunlight, the pyramid's design, meticulously planned by the researcher, focused the solar energy onto the desiccant, initiating the regeneration process. This concentrated solar energy drove the release of the captured water vapor from the desiccant, allowing it to desorb and transition back to its dry state, ready for another night of moisture capture.

Simultaneously, the desorbed water vapor condensed on cooler surfaces within the sealed pyramid, typically on specially designed condenser plates implemented by the researcher. This condensed water vapor represented the system's output – clean, fresh water extracted directly from the ambient air. The collected water was then harvested, completing the cycle and showcasing the potential of this innovative technology for sustainable water production in even arid regions.(9)

10. Ahmed, Hamed -2001: The researcher meticulously assessed the performance of a desiccant/collector system designed to leverage solar energy for nighttime water vapor capture from the atmosphere. This innovative system employs a thick, corrugated layer of blackened cloth to maximize water vapor absorption during the quiet hours of the night. Following this absorption phase, a regeneration process takes place during the day, utilizing solar energy to desorb, or release, the captured moisture.

The evaluation yielded promising results, with actual recorded data demonstrating the system's capability to produce roughly 1.5 liters of fresh water per square meter, per day. The researcher meticulously documented the intricacies of system operation, including potential challenges encountered during its functionality. A crucial aspect of the assessment involved defining system efficiency, a metric that quantifies the system's ability to convert solar energy into usable fresh water. Remarkably, the evaluation recorded efficiency values exceeding 17%, highlighting the system's potential for sustainable water production.

Intrigued by these promising findings, the researcher delved further, exploring the applicability of this technology. Identifying potential applications broadens the scope of this technology's impact, particularly in regions facing water scarcity or limited access to reliable freshwater sources. The ability to generate clean water using readily available solar energy and nighttime air moisture presents a potentially transformative solution for these communities. Future research could focus on optimizing the system's design to enhance efficiency and production capacity, paving the way for a scalable and sustainable approach to water production in water-stressed regions.(10)

11. Ahmed, Hamed -2000: In this theoretical approach, the reviewer emphasizes the critical role of working desiccant concentration limits in desiccant-based dehumidification systems. These concentration limits significantly impact three key performance indicators: theoretical cycle efficiency, desiccant solution consumption, and regeneration temperature.

Theoretical Cycle Efficiency: The reviewer highlights that achieving a high difference between the strong solution (loaded with desiccant) and the weak solution (desiccant depleted) is paramount for optimal theoretical efficiency. A larger concentration gap signifies a more efficient system, capable of extracting more moisture from the air with less energy expenditure.

Desiccant Solution Consumption per Kg of Vapor Generated: The reviewer delves into the concept of desiccant solution consumption. They explain that the mass of solution required to remove a kilogram of water vapor is inversely proportional to the concentration difference. Essentially, a larger concentration difference allows the same amount of desiccant solution to capture more moisture, resulting in lower consumption per kilogram of vapor removed. This translates to both economic benefits and reduced environmental impact throughout the desiccant lifecycle.

Desiccant Regeneration Temperature: Regeneration, the process of revitalizing the desiccant solution by expelling captured water vapor, is another crucial factor analyzed by the reviewer. They point out that the regeneration temperature is directly linked to the concentration difference. Lower concentration differences necessitate higher regeneration temperatures, which can significantly increase energy consumption within the system. Conversely, a larger concentration difference allows for regeneration at lower temperatures, leading to improved overall system efficiency.

By emphasizing these interdependencies, the reviewer underscores the importance of optimizing desiccant concentration limits. This optimization ensures a well-balanced system that achieves high theoretical efficiency, minimizes desiccant consumption, and maintains low regeneration energy requirements for sustainable and cost-effective dehumidification.(11)

12. Yu.I, Aristov et al.-1999: The researchers at the Boreskov Institute of Catalysis have developed a new generation of selective water sorbents (SWSs) that hold immense promise for freshwater production from the atmosphere. These SWSs boast unique physicochemical properties that make them particularly well-suited for solar-driven sorption systems, a technology specifically designed to harness the sun's energy to extract water from the air.

Delving deeper, the SWSs' material properties exhibit a high degree of selectivity for water vapor, meaning they efficiently capture water molecules while minimizing the absorption of unwanted gases like nitrogen or oxygen. This selective nature translates to a more efficient freshwater production process. Additionally, the regeneration process, which is crucial for releasing the captured water molecules and making the SWSs reusable, is designed to be compatible with solar energy. This innovative approach reduces reliance on conventional energy sources, making the entire system more sustainable and environmentally friendly.

To validate this concept, researchers conducted lab-scale tests that yielded impressive results. The tests demonstrated the feasibility of freshwater production using these SWSs, with a potential output of 3-5 tonnes of freshwater for every 10 tonnes of processed air. While these are initial findings, they offer a compelling glimpse into the potential of this technology to address freshwater scarcity in regions with limited access to clean drinking water. Further research and development efforts are likely to optimize the SWSs' performance and refine the solar-driven sorption systems, paving the way for a scalable and sustainable solution for freshwater production.(12)

III. CONCLUSION

This review paper has provided a comprehensive overview of the current state of atmospheric water generation (AWG) technology. The reviewed studies demonstrate the potential of AWGs to extract water vapor from ambient air, offering a potential solution for water scarcity in various regions. However, a critical evaluation of the technology reveals limitations that require further exploration. Energy consumption remains a key concern, particularly for large-scale applications. Additionally, the effectiveness of AWGs in arid environments with low humidity needs further optimization.

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