DESIGN AND DEVELOPMENT OF ATMOSPHERIC WATER HARVESTER

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Certification

This is to certify that [**Muhammad Adeel]**, **[20373]** have successfully completed the final project **[Design and Development of Atmospheric Water Harvester],** at the **[CAE]**, to fulfill the partial requirement of the degree **[BE AEROSPACE].**

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Abstract

In regions facing water shortages like arid areas, the concept of atmospheric water harvesting (AWH) has emerged as a potential solution, utilizing the moisture present in the air to provide a sustainable water source. This survey paper explores the role of numerical modelling in enhancing our understanding of AWH systems and improving their performance. It outlines how computer models simulate the complex processes involved, such as heat and fluid dynamics, aiding in optimizing design and operational choices. By examining factors like climate conditions and system design, the paper sheds light on how AWH can be made more effective. With its relevance to waterscarce regions, this paper underscores the importance of AWH and its potential to address water scarcity challenges It is important for countries like Pakistan, where water is hard to find. This means we can choose smarter ways to get enough water, even in places where it’s tough to find a liter of pure drinking water.

Undertaking

I certify that the project **[Design and Development of Atmospheric Water Harvester]** is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

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Chapter 1 INTRODUCTION 1.1 Project Title “Design and Development of Atmospheric Water Harvester”. 1.2 Project Description An apparatus will be designed such that it utilizes the Peltier effect, a phenomenon where a temperature difference is created across a semiconductor device, known as a Peltier module. One side of each circuit is heated, causing the air around it to warm up, while the other side becomes cold, reaching temperatures below the dew point. As ambient air passes over the cold side, moisture in the air condenses into water droplets. Fans positioned above the cold sides facilitate the collection of these droplets on a collection surface. The AWH essentially leverages the temperature gradient created by the Peltier effect to extract water from the air through condensation, offering a sustainable solution for water procurement. 1.3 Motivation Designing an atmospheric water harvester (AWH) project, especially considering the water scarcity issues in Pakistan, particularly in regions like the Thar Desert, is deeply rooted in addressing a critical need. In areas like Thar, where access to clean water is a severe challenge, this AWH project serves as a potential life-changing solution. The motivation stems from the desire to provide a sustainable and innovative technology that can harness water from the air, offering a reliable source in arid regions where 1 traditional water sources are scarce. The project has the potential to contribute to improved living conditions, health, and overall well-being of communities facing water shortages. By addressing the specific water scarcity issues in Pakistan, it becomes a commitment to making a positive impact and enhancing the quality of life for those affected by the

challenging conditions in regions like Thar. 1.4 Project Scope Water harvesting and collecting through an ambient air is a discovery inspired by the study of condensation phenomenon. This method is found to be very effective in recent years and different techniques are applied to optimize the results. This project involves development and fabrication of such an apparatus that will be used to harvest water from air. 1.5 Project Overview Chapter 1 deals with the introduction and project description. It explains the need for the project and a brief introduction to project. Chapter 2 presents a detailed literature review of terminologies related to atmospheric water harvesting. Chapter 3 explains in detail the project methodology followed in fabrication of the apparatus. Chapter 4 talks about the experiments and the results obtained from those experiments. Chapter 5 explains the challenges faced during the course of this project. Chapter 6 concludes the project report and defines the scope for future work. 2 Chapter 2 LITERATURE REVIEW 2.1 Background and Overview Water is essential for everything we do, but not everyone has enough of it. More than 2.2 billion people don't have safe drinking water, and about 4.2 billion experience serious water shortages at least once a year. Some places don't have enough water, and others suffer from not having water when they need it most. Things like farming, industries, and nature all need water, so when there's not enough to go around, it's a big challenge. [1] The usual sources of water, like rivers and underground wells, are getting used up too quickly. Climate change makes things worse by changing rain patterns and causing extreme weather. So, finding new ways to get water is

becoming important. The concept of collecting water from fog and dew can be traced back to ancient times. There are accounts and legends of using large stones or trees to artificially harvest dew, creating dew ”springs” and ”ponds.” This historical practice shows that humanity recognized the potential of dew as a source of fresh water since ancient times. [2] However, it wasn’t until the 20th century that these ancient accounts were translated into actual condensers. Atmospheric water harvesting is all about making water from the moisture in the air. It’s like when you see water droplets on a cold glass of water on a warm day. Modern systems use this idea in smart ways. They have surfaces that are cooler than the air around them. When the warm, moist air touches these surfaces, the water vapor turns back into liquid water, forming droplets. These droplets can then be collected and used. These systems use things like fans or natural breezes to bring moist air to the cool surfaces. And after the water is collected, it can be treated for different purposes, like drinking, farming, and industries. [3] 3 2.2 Introduction Atmospheric water harvesting has gained significant attention as a sustainable solution to address water scarcity. This section reviews the existing literature on atmospheric water harvesters, including the concepts of humidity, temperature, dew point, and the various mechanisms involved in the water harvesting cycle. Additionally, it explores different types of atmospheric water harvesters, with a focus on their working principles and the incorporation of thermoelectric effects, including the Peltier and Seebeck effects. [4] Scientists have looked at things like how humidity and water droplets form, how to make the surfaces that collect water work better, and how different weather affects these systems. They’ve also explored using fancy technology, like special effects that use temperature differences, to make these systems even better at getting water. By reading these studies, we can learn more about how these systems work, what challenges they have, and what they might do in the future to help us get more water in places where it’s hard to find. [5] Figure 2.1: AWH Types 2.2.1 Humidity Humidity refers to the amount of water vapor present in the air. It is often expressed as a percentage, indicating the ratio of the actual water vapor content to the maximum amount the air can hold at a specific temperature. Humidity plays a crucial role in 4 atmospheric water harvesting, as higher humidity levels mean there is more moisture available for condensation. [6] 2.2.2 Humid Temperature Humid temperature is a measure of how warm the air feels when both temperature and humidity are considered. It’s a way to understand how much moisture is in the air and how that affects our perception of heat. When humidity is high, sweat doesn’t evaporate from our skin as effectively, making us feel hotter than the regular temperature might suggest. On the other hand, when humidity is low, we might feel cooler because our sweat can evaporate more easily. [7] 2.2.3 Condensation Condensation refers to the process in which water vapor in the air transforms into liquid water. This happens when the air becomes cooler than a certain point known as the dew point temperature. As warm, humid air comes into contact with a cooler surface, such as the collection panels of an atmospheric water harvester, it loses some of its heat energy. This causes the water vapor within the air to slow

down and come together, forming tiny water droplets on the surface. These droplets then collect and accumulate, ultimately forming usable liquid water that can be collected and stored for various purposes. [8] 2.2.4 Dew Temperature Dew temperature refers to the temperature at which the air becomes saturated with moisture and starts to form dew on surfaces. It’s the point at which the air can’t hold any more water vapor, so the excess moisture begins to condense and turn into tiny water droplets on cooler surfaces. [9] 2.3 Classification based on Saturation In the context of AWH systems, understanding the dew temperature is important because it helps determine when and how condensation will occur. When the temperature of a collection surface in an AWH system drops below the dew temperature of the 5 surrounding air, water vapor in the air starts to turn into liquid water on that surface. This is a key process in harvesting water from the atmosphere. By creating conditions where the collection surface is cooler than the dew temperature, AWH systems can effectively collect water through condensation. [10] 2.3.1 Saturated Water Harvesting Saturated water harvesting refers to the process of collecting water from air that is already at its maximum humidity level, also known as 100cannot hold any more water vapor, and any additional cooling of the air will result in condensation of water vapor into liquid water. [10] 2.3.2 Unsaturated Water Harvesting Unsaturated water harvesting involves collecting water from air that is not at its maximum humidity level. The air still has the potential to hold more water vapor before reaching saturation. In this case, cooling the air below its current temperature will cause it to

become saturated, leading to condensation of water vapor. [11] 2.4 Classification based on Sources 2.4.1 Active Atmospheric Water Harvester Active AWH systems require an external energy source to facilitate the water harvesting process. This energy input can come from sources like electricity, solar power, or other forms of mechanical energy. [5] [12] Examples of active systems are vapor compression systems, solar-powered systems with mechanical components, and systems that use fans to direct air over condensing surfaces. [13] 2.4.2 Passive Atmospheric Water Harvester Passive AWH systems do not rely on external energy sources to drive the water harvesting process. Instead, they leverage natural environmental conditions and physical principles to collect and condense water vapor. [14] [15] Examples of passive AWH systems include dew collectors, radiative cooling systems, and certain types of fog collectors. 6 2.5 The Water Harvesting Cycle The atmospheric water harvesting cycle base on vapor compression refrigeration to extract water from air [16] 2.5.1 Collection Surface Cooling The first step is to create a surface that is cooler than the dew point temperature. This can be achieved through passive means, such as radiative cooling, or active methods involving cooling mechanisms. [17] 2.5.2 Air Moistening Fans or natural air movement are used to direct warm, humid air towards the cooled collection surface. As the air meets the surface, its temperature drops, and moisture begins to condense. [18] 2.5.3 Condensation When the air's temperature falls below the dew point, water vapor in the air turns into liquid water droplets on the collection surface. This process is essential for water harvesting [19] [20] 2.5.4 Water

Collection The condensed water droplets are collected through channels or surfaces designed to facilitate water flow. The collected water can then be stored, treated, and utilized for various purposes. [21] [22] 7 Figure 2.2: Schematic Diagram of AWH Cycle 2.6 Types of Atmospheric Water Harvester 2.6.1 Dew Collector Dew collectors use a cooled surface, often a metal or plastic material, to encourage the condensation of water vapor from the air. As the surface becomes cooler than the dew point temperature of the air, water droplets form on it and are collected for use. [23] Advantages of Dew Collector • Dew collectors are relatively simple devices that don't require complex machinery or power sources. This makes them suitable for remote areas with limited resources. [?] • Since dew collectors rely on natural temperature changes for condensation, they consume very little energy. This makes them energy-efficient and environmentally friendly. [24] • Dew collectors have few moving parts and don't require frequent maintenance. This can be advantageous in areas with limited access to technical expertise. [25] 8 • Dew collectors can work in various climates, especially in regions with high humidity levels during the night. Disadvantages of Dew Collector • Dew collectors typically produce smaller amounts of water compared to other AWH systems. The amount of water they can capture depends on factors like the size of the collection surface and local humidity levels. [26] • Dew collectors rely on temperature changes and humidity levels, which means they may not work effectively in areas with consistently high temperatures or low humidity. [27] • The process of dew formation and collection can be slow. This might not be ideal

for situations requiring larger quantities of water in a short time. • To capture significant amounts of water, dew collectors may need relatively large collection surfaces, which could be a limitation in areas with limited space 2.6.2 Fog Collector Fog collectors use a mesh or netting material to capture water droplets from fog. Fog particles get trapped on the mesh, where they coalesce into larger droplets and eventually drip down into a collection trough. These harvesters are commonly used in foggy areas. [28] Figure 2.3: Fog Collector 9 Advantages of Fog Collectors • Fog collectors are especially effective in regions with regular fog events, such as coastal areas or areas near mountains where moist air encounters cooler temperatures. [29] [30] • Fog collectors don't require a power source to function. They rely on natural air movement and the physical properties of fog droplets. • The design of fog collectors is relatively simple, consisting of mesh or netting materials that are easy to set up and maintain. [31] • Fog collectors have minimal impact on the environment and don't consume much energy, making them a sustainable water harvesting option. Disadvantages of Fog Collectors • Fog collectors are highly dependent on the presence of fog. If foggy conditions are rare or inconsistent, their water production can be limited. [32] • The amount of water that fog collectors can capture depends on the frequency and density of fog events. They might not be suitable for areas with low fog occurrence. • Fog droplets are tiny, and it takes time for them to accumulate and coalesce into usable water. This slow process might not meet immediate water needs. [17] • Over time, the mesh or netting material can get clogged with captured particles or

become damaged, requiring regular maintenance 2.6.3 Radiative Cooling Systems These systems use a combination of materials and designs to emit thermal radiation to the cold sky, allowing the collection surface to become cooler than the air. As a result, condensation occurs even in relatively dry environments. [33] Advantages of Radiative Cooling Systems – Radiative cooling systems operate without the need for mechanical components or energy input. They rely on natural cooling processes and the specific properties of materials. [34] – These systems consume very little energy, making them environmentally friendly and cost-effective in the long run. – Radiative cooling systems can work effectively in arid and dry environments where nighttime temperatures drop significantly, promoting efficient radiative heat emission. [35] – The design of radiative cooling systems can be relatively simple, involving specially designed materials and surfaces that emit heat effectively. 10 Disadvantages of Radiative Cooling Systems – The effectiveness of radiative cooling systems depends on clear nighttime skies that allow heat to radiate away. Cloud cover can reduce their efficiency. [36] – The process of radiative cooling and subsequent condensation can be relatively slow, which might not meet urgent water needs. – Radiative cooling systems heavily rely on temperature differences between the collection surface and the air. This effectiveness might vary with seasonal or geographic changes. [37] – The collection surface needs to be kept clean and well-maintained to ensure efficient heat emission and condensation. 2.6.4 Humidification-Dehumidification Systems Dry air is brought into contact with water or a wet surface. This adds moisture to the air until it becomes saturated, meaning it can’t hold any more water vapor without condensing. The saturated air is then cooled down using methods like cooling coils or heat exchange systems. As the air cools, it reaches its dew point temperature, causing the excess moisture to condense into liquid water droplets. [38] Advantages of Humidification-Dehumidification Systems – Humidification-dehumidification systems can be adjusted to work effectively in a range of humidity conditions, making them versatile in various environments. [39] – These systems can yield relatively higher amounts of water compared to some other AWH methods, depending on the design and operation. – Humidification-dehumidification systems can work well in dry climates where the humidity levels are low, provided that a source of water for humidification is available. [40] – By manipulating the processes of humidification and dehumidification, these systems offer more control over water production, allowing adjustments based on demand. Disadvantages of Humid. -Dehumidification Systems – The dehumidification step in these systems requires energy input for cooling, which can make them less energy-efficient compared to passive systems. [41] 11 – Humidification-dehumidification systems are more complex than some other AWH systems due to the need for mechanical components like fans, humidifiers, and cooling systems. – The mechanical components of these systems require regular maintenance to ensure efficient and reliable operation. – Setting up and maintaining these systems can involve higher initial costs compared to some passive AWH methods. 2.6.5 Adsorption Based System It refers to a method of water harvesting that

relies on adsorption, a process where water molecules are attracted and held onto the surface of a material. An adsorbent material is selected based on its ability to attract and hold water molecules. Then, air is passed over or through the adsorbent material. Water vapor in the air stick to the surface of the adsorbent material due to its affinity for the material's surface. Once the adsorbent becomes saturated with water, a change in conditions, such as temperature or pressure, is introduced to release the water vapor from the adsorbent's surface. [42] Advantages of Adsorption-Based AWH – Adsorption-based systems can work effectively even in areas with relatively low humidity, making them suitable for arid regions. – Adsorption can lead to significant water accumulation on the adsorbent material, potentially resulting in higher water yields. – These systems can be designed to work in various climates and conditions, with passive or active operation. [?] Disadvantages of Adsorption-Based AWH – The desorption process often requires energy input, especially if it's driven by external sources like solar or thermal energy. – The choice of appropriate adsorbent materials is critical for efficient water capture and release. Developing or sourcing suitable materials can be a challenge. [43] – The cyclic nature of adsorption and desorption requires a more complex system design, including mechanisms for changing conditions and water collection. 12 2.6.6 Wind-Powered Systems Wind-powered AWH systems use fans or wind-catching structures to direct air towards the collection surface. Natural air movement or mechanical devices can be employed to achieve this, the collection surface is cooled below the dew point temperature of

the incoming air. As the warm, humid air comes into contact with the cooled surface, it loses heat, leading to condensation of water vapor into liquid water droplets. [44] Advantages of Wind-Powered Systems – Wind-powered systems use renewable wind energy, eliminating the need for conventional energy sources and reducing the environmental impact. – The active movement of air through the collection surface increases the chances of water vapor encountering the cooled surface, potentially leading to higher water yields. [45] – Wind-powered systems can work well in regions with consistent wind patterns, making them adaptable to different geographic locations. – Mechanical components like fans or wind-capturing devices allow for some control over the airflow and water collection, allowing adjustments based on needs and conditions. [46] Disadvantages of Wind-Powered Systems – Wind-powered systems require consistent wind to function effectively. In areas with low wind frequency or erratic wind patterns, their efficiency might be compromised. – Mechanical components, such as fans, require maintenance to ensure proper operation. Maintenance can be challenging in remote or inaccessible areas. – While wind energy is renewable, the energy conversion process (e.g., converting wind energy to mechanical energy for fans) may have energy losses, affecting overall efficiency. [47] – Setting up wind-powered systems may involve initial costs for equipment installation and maintenance, which could be a barrier in some cases. 2.6.7 Thermoelectric Effects Thermoelectric effects, such as the Peltier and Seebeck effects, play a role in enhancing atmospheric water harvesting efficiency. The Peltier effect involves passing an electric current through a junction of two different conductive materials. This creates a temperature difference across the junction, with one side 13 becoming cooler and the other side becoming warmer. [34] In a Peltier-enhanced system or electron hole theory, the cooler side of the Peltier junction is connected to the collection surface. As the electric current flows, it actively cools the surface, making it cooler than the surrounding air. When warm, humid air meets the cooled collection surface, water vapor in the air begins to condense into liquid water droplets on the surface. [48] [40] Figure 2.4: Thermoelectric Effect Advantages of Peltier-Enhanced Systems – Peltier-enhanced systems actively cool the collection surface, potentially leading to faster and more efficient condensation compared to passive cooling methods. [10] – The amount of electric current applied to the Peltier module can be adjusted, providing some control over the cooling process and water condensation rate. [17] – By utilizing active cooling, Peltier-enhanced systems can potentially achieve higher water yields compared to some passive systems. [12] 14 Disadvantages of Peltier-Enhanced Systems – Peltier-enhanced systems require electrical energy to operate the Peltier modules, making them less energy-efficient compared to passive systems. [49] – These systems involve electronic components and may require more technical expertise for installation and maintenance. [44] [1] – The addition of Peltier modules and associated components can increase the initial setup cost of the system. [50] – The electrical components, such as the Peltier modules, require regular maintenance to ensure proper functioning. [2] Figure 2.5: Peltier Effect 15 Chapter 3 METHODOLOGY 3.1 Design

of an Atmospheric Water Generator The proposed solution is the design and assembly of an AWG prototype that employs the Peltier effect. This device incorporates thermoelectric coolers (TECs) that cool humid air that is sucked into the system by intake fans. The air is cooled by the cold side of the modules' plates to temperatures below the dew point of air, thus condensing the water content of the humid air. Extended surfaces are added to both sides of the TECs to increase the surface area, leading to an increase in the heat transfer and water generation rates. Another side of peltier circuit is attached to the hot side of the TECs serve as heat sinks. The system is contained in a depron and thermocol housing. The primary benefit of the proposed solution is its direct alleviation of the problem of water scarcity while avoiding the complexity of vapor compression refrigeration cycles. The proposed AWG system eliminates the need for bulky components and allows the device to be compact, light, portable, and durable at the cost of the coefficient of performance (COP) and cooling capacity. There is no compressor, decreasing the risk of failure, nor refrigerant, producing no pollution. The device also requires minimal maintenance, is low in cost, and silent in operation. The design of the AWG was initiated with the selection of the TECs. High surface area CPU cooler were selected to dissipate the heat from the hot side of the TECs. The behavior of the COP and cooling capacity of the TECs with increasing current was used to size the system. The cold side extended surfaces were analyzed considering maximum water generation rates and to prevent dry regions that have no contribution to water generation. The fabrication, sizing, and

assembly of the prototype were also carefully executed and are discussed. A TEC model is selected according to required power levels and the analysis of the prototype. Then, the heat sinks that effectively dissipate the heat of the TECs' hot sides are selected and the effect of varying currents on the cooling capacity and COP is studied, and the electrical configurations of the system are defined. The methodology used to select the extended surfaces of the TECs' cold side is explained. Then in the end, the design, fabrication and assembly of the prototype is presented. At last, experimental results, discussion, and comparison of AWGs are presented whereas key observations and conclusions are summarized. 16 3.1.1 Selection of Thermoelectric Cooler A typical TEC, also called a Peltier cooler module, is manufactured using two thin ceramic wafers with a series of p and n doped bismuth telluride (Bi2Te3) semiconductor materials sandwiched between the wafers. The ceramic material on both sides of the thermoelectric module adds rigidity and the necessary electrical insulation. The p-type semiconductor appears to have a deficit of electrons and the n-type semiconductor appears to have an excess. One p-type and one n-type semiconductor form a thermocouple. TECs consist of a larger number of couples that are arranged in rectangular form and are connected thermally in parallel and electrically in series. When DC current flows through the device, heat flows from one side of the junction to the other, resulting in one side becoming cooler and the other side warmer. At the cold junction, energy (heat) is absorbed by the electrons as they flow from a low energy level in the p-type semiconductor element to a higher energy level in the n-type semiconductor element. The power supply provides energy to move the electrons through the system. Continuing through the lattice of the material, at the hot junction, energy is expelled to a heat sink as the electrons drop from a high energy level element (n-type) to a lower energy level element (p-type). This is called the Peltier effect. Therefore, a TEC acts as a solid-state heat pump in this case. A commercial module was selected for the prototype. The selected TEC model is TEC1-12706, which uses Bi2Te3 as the thermoelectric material and is a one stage module with 127 couples and a maximum current rating of 6 A. This model was selected due to its wide availability, low cost, and low power. A more powerful TEC was not needed because the selected module was not meant to be operated at maximum capacity.This selection increases the number of TECs, while increasing the COP of each TEC, and augments water generation per unit of energy consumed. Figure 3.1: Peltier Circuit 17 3.1.2 Selection of Hot Heat sink High surface area commercial CPU heat sinks were selected for the prototype. CPU heat sinks were found to be compatible with TECs due to their small size. These large active heat sinks comprise of aluminum fins and copper heat pipes. High surface area heat sinks were selected for the design in order to allow the TECs to effectively dissipate heat. A specifically non-conductive and noncapacitive thermal adhesive was used to permanently attach the TECs to th