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DESIGN AND FABRICATION OF ATMOSPHERIC WATER HARVESTER

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Abstract:

Although science has made great strides in recent years, access to fresh water remains a major challenge for humanity due to water shortage for two-thirds of the world's population. Limited access to fresh water becomes more difficult due to the lack of natural resources of water. Many of these resources are also contaminated by human activities. Many attempts have been made to harvest water from the atmosphere, and condensation systems have received much attention. One of the challenges in generation systems is the high consumption energy of the cooling feed, despite the generation of large amounts of water from the atmosphere. Atmospheric harvesting is the best alternative for producing fresh water for everyday life. Atmospheric Water Harvester (AWH) is a device that can convert atmospheric moisture directly into usable and drinkable water. The global demand for sustainable and efficient water harvesting technologies has intensified in response to increasing water scarcity challenges. This abstract introduces a novel approach to atmospheric water harvesting (AWH) through the integration of advanced adsorbent materials and the Peltier effect. This hybrid system aims to enhance water capture efficiency and energy sustainability. The synergy between the adsorbent and Peltier components optimizes the overall efficiency of the atmospheric water harvesting system. By harnessing the Peltier effect, the system reduces the energy requirements for the desorption process, making the water harvesting process more sustainable and economically viable. Additionally, the hybrid system enhances the overall water capture capacity, pro- viding a reliable and continuous source of water. The highlights the potential of the pro- posed hybrid atmospheric water harvesting system to address water scarcity challenges in a sustainable manner. The integration of advanced adsorbents and the Peltier effect opens new avenues for the development of innovative and energy-efficient solutions in the field of atmospheric water harvesting.

Keywords: Peltier effect, Adsorbption system, Hydrogel, Hybrid AWH system,

1. INTRODUCTION

Water scarcity is a critical issue affecting communities worldwide, exacerbated by factors such as climate change, population growth, and inadequate water management practices. In regions where traditional freshwater sources are limited or unreliable, innovative solutions are urgently needed to ensure access to safe and sustainable water supplies. Atmospheric Water Harvesting (AWH) presents a promising approach to address this challenge by harnessing the abundant moisture present in the air.AWH systems are designed to extract water directly from the atmosphere by lever- aging natural processes of condensation and adsorption. These systems operate on the principle of collecting water vapor from the air and converting it into liquid water suit- able for various uses, including drinking, agriculture, and sanitation. By tapping into this overlooked water resource, AWH offers a decentralized and environmentally friendly solution to supplement traditional water sources. The technology behind AWH varies, but most systems consist of key components such as condensation surfaces, cooling mechanisms, and water collection and purification systems. Peltier devices play a crucial role in many AWH systems, serving as the cooling mechanism responsible for lowering the temperature of the air below its dew point. This cooling process enables water vapor to condense into liquid water, which is then collected and treated to meet quality standards. In addition to Peltier cooling, adsorption-based AWH techniques utilize adsorbent materials, such as hydrogels or zeolites, to capture water vapor from the air. These materials have a high affinity for water molecules, allowing them to absorb and retain moisture even in low humidity conditions. By combining various technologies and materials, AWH systems can maximize water capture efficiency and adapt to different environmental conditions.

The potential impact of AWH extends beyond addressing immediate water needs. By providing a sustainable source of water, AWH can enhance resilience to droughts, mitigate the effects of climate change, and improve livelihoods in water-scarce regions. Moreover, AWH has the versatility to be deployed in diverse settings, from rural com- munities lacking access to centralized water infrastructure to urban areas grappling with water shortages. As research and development in AWH continue to advance, there is a growing recognition of its role in sustainable water management strategies. By harnessing the power of the atmosphere to produce clean water, AWH offers hope for a future where water scarcity is no longer a barrier to human well-being and development.

Overview:

In the quest for sustainable solutions to water scarcity, innovative technologies like Atmospheric Water Harvesting (AWH) have emerged as promising approaches. Among the critical components driving the efficiency of AWH systems is the integration of Peltier devices. Peltier systems, based on the Peltier effect, offer a sophisticated cooling mechanism essential for condensing water vapor from the air, thereby transforming it into usable liquid water. Peltier devices, also known as thermoelectric coolers, operate by leveraging the thermoelectric effect, which occurs when an electric current is passed through two dissimilar conductors. This process creates a temperature difference across the junction of the con- ductors, enabling one side to cool while the other heats up. In the context of AWH, Peltier systems serve as the core cooling mechanism, enabling the extraction of water vapor from the air through condensation. The role of Peltier devices in AWH systems is fundamental. By lowering the temperature of the air below its dew point, Peltier systems facilitate the condensation of water vapor, transforming it into liquid water. This condensed water can then be collected and purified for various purposes, including drinking, agriculture, and sanitation. The efficiency and reliability of AWH systems heavily rely on the effectiveness of the cooling mechanism provided by Peltier devices.

In the quest to address water scarcity and provide sustainable solutions for water access, Atmospheric Water Harvesting (AWH) has emerged as a promising technology. A fundamental aspect of AWH involves the utilization of adsorption systems, which play a vital role in capturing water vapor from the air and converting it into usable liquid water. Adsorption, in the context of AWH, refers to the process by which adsorbent mate- rials selectively trap water molecules from the atmosphere. These materials, which can range from natural substances like zeolites to advanced synthetic polymers such as hydrogels, possess unique properties that enable them to attract and retain water molecules effectively. The principle underlying adsorption-based AWH is straightforward yet powerful: as humid air passes through the adsorption unit, water vapor adheres to the surface of the adsorbent material, forming a thin film of liquid water. This captured moisture is then harvested and collected for purification and distribution. Hydrogel-based adsorption systems have garnered significant attention in the realm of AWH due to their remarkable water-absorbing capabilities. Hydrogels are polymers with a three-dimensional network structure capable of absorbing large volumes of water relative to their weight. This property makes them particularly well-suited for atmospheric water capture, as they can efficiently extract moisture from the air even in arid or low-humidity environments.

Hybrid AWH systems combine the strengths of different water harvesting techniques, such as condensation and adsorption, to capitalize on diverse environmental conditions and optimize water yield. By leveraging complementary technologies, these systems can overcome individual limitations and achieve greater reliability and scalability. At the heart of hybrid AWH systems lies the synergy between Peltier cooling technology and adsorption-based water capture methods. Peltier devices, renowned for their ability to create temperature differentials, play a pivotal role in cooling the air to facilitate condensation, while adsorbent materials, such as hydrogels or zeolites, capture water vapor from the atmosphere with high efficiency. The integration of Peltier cooling and adsorption-based water capture offers several advantages. Firstly, it enhances water capture efficiency by leveraging both the condensation and adsorption processes, thereby maximizing water yield even in diverse climatic conditions. Secondly, it improves system reliability by providing redundancy in water harvesting mechanisms, ensuring consistent performance over time. Additionally, the hybrid approach enhances system scalability, allowing for adaptation to varying water demand and environmental factors.

2. WORKING PRINCIPLE

1. Peltier Effect

The Peltier effect is a thermoelectric phenomenon that occurs at the junction of two dis- similar conductive materials when an electric current passes through them. This effect is based on the principles of thermoelectricity, which involve the conversion of temperature differences into electrical voltage and vice versa. The working principle of the Peltier effect can be explained as follows: When a direct current (DC) is applied to the junction of two different conductive materials, one side of the junction absorbs heat while the other side releases heat. This phenomenon occurs due to the movement of charge carriers (electrons or holes) across the junction, driven by the electric current. At the junction where electrons move from the cold side to the hot side, energy is absorbed, causing cooling of the cold side. Conversely, at the junction where electrons move from the hot side to the cold side, energy is released, resulting in heating of the hot side. This creates a temperature gradient across the junction, with one side becoming cooler and the other side becoming warmer. The efficiency of the Peltier effect depends on the material properties of the conductive materials used in the junction, such as their Seebeck coefficient (which determines the amount of voltage generated per unit temperature difference) and electrical conductivity. Peltier devices utilize this effect in various applications such as refrigeration, temperature control, and cooling in atmospheric water harvesting systems, where they facilitate the condensation of water vapor from the air by creating a localized cooling effect within the condensation chamber.

2. Adsorption Technique

The principle of adsorption technique in atmospheric water harvesting (AWH) involves the selective capture of water vapor molecules from the air by adsorbent materials. Ad- sorption is a process where molecules of a substance adhere to the surface of another material, known as the adsorbent. In the context of AWH, adsorption techniques rely on the high affinity of certain materials for water molecules. Adsorbent materials used in AWH, such as hydro gels, silica gel, zeolites, or activated carbon, have a porous structure with a large surface area. This structure allows them to attract and retain water vapor from the surrounding air. When humid air passes through or contacts the adsorbent material, water molecules are adsorbed onto the surface of the material due to physical or chemical interactions. The adsorption process is influenced by factors such as humidity levels, temperature, and the properties of the adsorbent material, including its pore size, surface area, and affinity for water. Higher humidity levels and lower temperatures generally enhance the adsorption capacity of the material. Once the adsorbent becomes saturated with water vapor, it can undergo a regeneration process to release the captured water molecules. This regeneration can be achieved through various methods, such as heating, vacuum desorption, or using a desiccant to extract the water. The principle of adsorption in AWH is advantageous because it can operate effectively in high humidity environments and can be tailored to target specific contaminants or gases while capturing water vapor. This selective adsorption helps ensure that the harvested water is of high quality and free from impurities. Adsorption techniques play a vital role in AWH systems, providing a sustainable and decentralized source of clean water by harnessing the moisture present in the atmosphere.

3. METHODOLOGY

1. Peltier Method

In atmospheric water harvesting (AWH), Peltier modules play a crucial role in the cooling process necessary for condensation-based water harvesting systems. The working of a Peltier module in AWH can be explained as follows: When an electric current is applied to a Peltier module, it creates a temperature differential across its surfaces. One side of the module absorbs heat from its surroundings, while the other side releases heat. This phenomenon occurs due to the movement of charge carriers (electrons) across the junctions between the semiconductor materials within the Peltier module. In AWH systems, the cold side of the Peltier module is typically placed within the condensation chamber, where humid air is cooled to its dew point temperature. As the air cools, water vapor present in the atmosphere condenses into liquid water on the surfaces within the chamber. The Peltier module maintains the cold temperature necessary for condensation to occur efficiently. The hot side of the Peltier module dissipates the absorbed heat, ensuring a continuous cooling cycle within the condensation chamber. By regulating the electric current flowing through the Peltier module, the cooling effect can be controlled, allowing for precise temperature management to optimize water condensation rates. Overall, the working of a Peltier module in AWH systems enables the extraction of water vapor from the air through condensation, providing a sustainable and decentralized source of clean water. This technology is particularly effective in humid environments or during periods of high atmospheric moisture, contributing to water resilience and resource management in water-scarce regions.

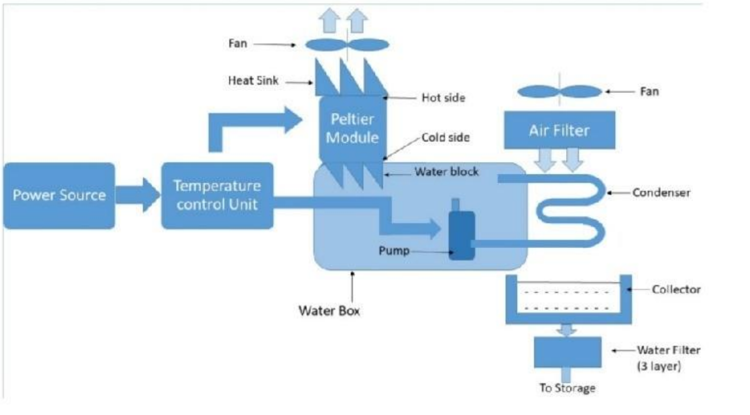

Fig 1: Working of Peltier method

2. Adsorption Method

The adsorbent method for generating water from the atmosphere relies on the principle of adsorption, where certain materials, often referred to as adsorbents or desiccants, attract and hold moisture from the surrounding air. Specialized materials with a high affinity for water molecules are chosen as adsorbents. These materials have porous structures or specific chemical properties that allow them to attract and retain moisture effectively. When exposed to humid air, the adsorbent material interacts with water vapor molecules present in the atmosphere. The material's surface or pores attract and capture these water molecules, adhering them to the surface or within the structure of the material through various mechanisms such as hydrogen bonding or van der Waals forces. Once the water molecules are adsorbed onto the surface or within the structure of the adsorbent material, they are held there until conditions favor their release. The adsorbent effectively"stores" the captured moisture within its structure. When subjected to specific conditions, such as changes in temperature, reduced pressure, or heating, the adsorbent material releases the captured moisture. This process involves desorption, where the adsorbed water molecules are released from the material, becoming liquid or vapor form, which can then be collected and utilized. Hydrophilicity refers to the property of a substance or material that exhibits an affinity or attraction to water. Substances that are hydrophilic tend to interact favorably with water molecules. This property arises from the molecular structure of the material, which allows it to form bonds or associations with water. The released water, whether in liquid or vapor form, is collected and channeled into a storage container for use. Depending on the setup, this collected water can be purified and made suitable for drinking, agricultural use, or other purposes.

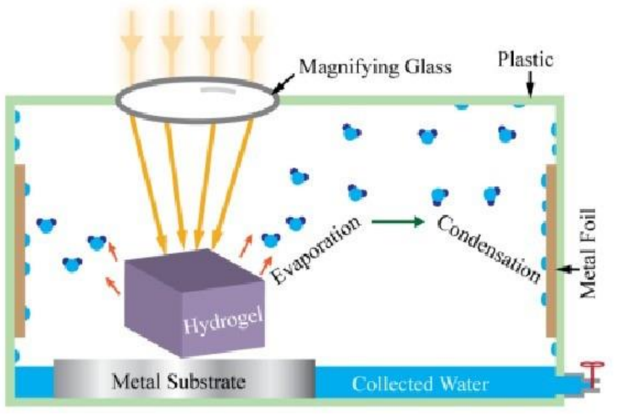

Fig 2: Adsorption principle

3. Hybridization

Hybridization methodology for atmospheric water harvesting (AWH) involves integrating multiple water capture technologies to enhance efficiency, reliability, and sustainability. The process begins with a comprehensive site assessment to understand local climatic conditions, water demand, and available resources. Based on this assessment, suitable AWH technologies are selected for hybridization. These may include condensation-based systems using Peltier devices for cooling and adsorption-based systems utilizing hydro- gel or other adsorbents for water vapor capture. The hybrid AWH system's design incorporates these technologies synergistically, optimizing their interactions and operational strategies. Components such as condensation chambers, adsorption units, cooling systems, and water storage tanks are procured and installed, ensuring seamless integration and functionality. Operational strategies are then developed to schedule water harvesting cycles, optimize cooling and regeneration processes, and implement automation for efficient operation. Water collected from both condensation and adsorption processes is purified to meet quality standards before storage. A monitoring and maintenance program is established to assess system performance regularly, identify areas for improvement, and ensure long-term reliability. Through continuous evaluation and optimization, hybrid AWH methodologies aim to maximize water yield, energy efficiency, and overall system effectiveness, contributing significantly to sustainable water management practices.

4. WORKING

The atmospheric air is entering to the system through air filter and fan. The Peltier module inside the system will attain that atmospheric air into dew point temperature and some of the air particle will condensed to water in the module and the remaining air will go through copper coil with the help of a pump. The fan is provided to cool the copper coil and the remaining air will condense to water. Water will collected with the help of a water tray and the water filter will help to remove impurities from the water. The waste heat from the Peltier system will go through a chimney to the absorption system. Adsorbent operating system contains a bed and it will heat with the help of sunlight and magnifying glass which is provided in the top of the system. Side opening will open according to the timer provided, the night time to increase the water absorption from the atmospheric air to the absorbed and in the day light the sunlight and waste heat will heat up the bed and it will remove the hydrophilicity of adsorbent. The absence of hydrophilicity will increase the desorption rate of water from adsorbent. The closing of doors will increase the partial pressure inside the operation system. Increasing the partial pressure will condense the atmosphere into water. Also copper coils are provided in the side surface which will condense atmospheric air into water. After condensation collecting tube is provided to collect the water cumulate water in the bottom to water collector. At last go through water filter and collect to collector.

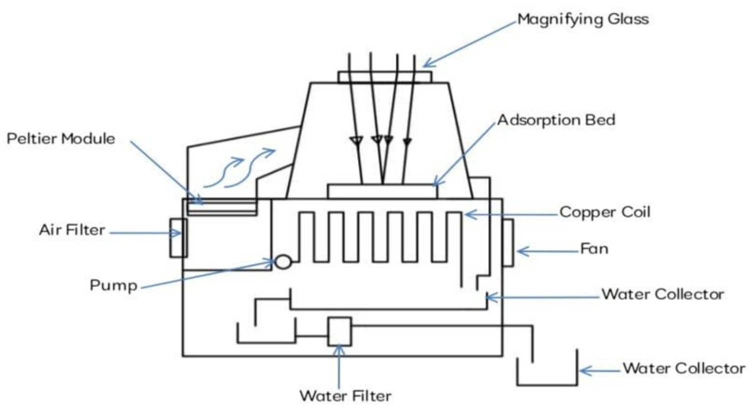

Fig 3: Design of the system

Fig 4: System setup

5. TESTING AND CALCULATION

1. Pelteir System:

To determine the quantity of water produced, we tested our system by operating it for three hours per day during different days. The temperature and humidity levels were different during different days. Our observations are shown in the following table.

Table 1: Quantity of water obtained in pelteir system

Date	Temperature (°C)	Humidity (%)	Work Hours (hr)	Water (mL)
17-4-2024	33	66	3	174
19-04-2024	34	68	3	178
21-04-2024	32	74	3	186
25-04-2024	30	68	3	182

2. Absorption Method:

The water quantity in this method was observed over a 24-hour period, taking into ac- count variations in humidity and temperature. The system underwent observation on different days, each day characterized by distinct temperature and humidity levels. Our recorded observations of water quantity in the absorption method are presented in the following table

Date	Temperature (°C)	Humidity (%)	Water (mL)
17-04-2024	35	60	1260
19-04-2024	34	63	1282
21-04-2024	30	70	1365
25-04-2024	32	65	1276

Table 2: Quantity of water obtained in absorption system for 24 hr

In the graph shown below the humidity range is plotted along y - axis and different days where plotted along x - axis of both the system.

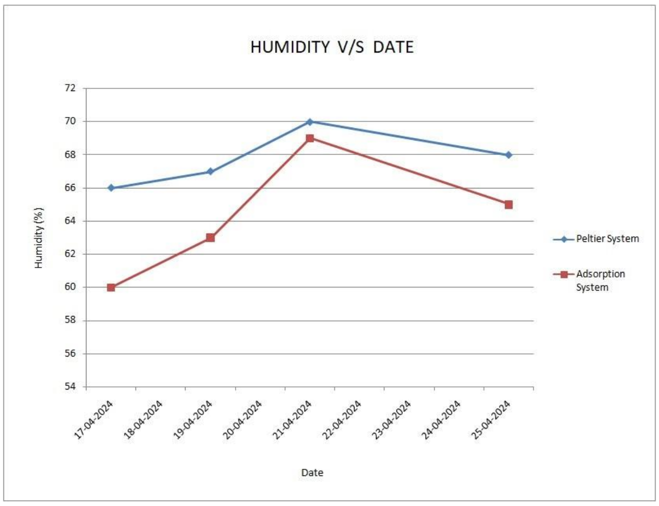

Fig 5: Humidity v/s Date

From the graph, we can observe that the humidity range falls between 60% and 70%, which is a narrower range than the required humidity range of 75% to 90%. This narrower humidity variation could potentially impact the system's performance significantly, particularly if the system is sensitive to precise humidity levels for optimal functionality. The deviation from the target humidity range might lead to fluctuations in system behavior, affecting its efficiency and reliability. Understanding and addressing this difference in humidity levels are crucial for ensuring the system operates within its desired parameters and achieves consistent results.

In the graph shown below, the quantity of water obtained is plotted along the y-axis, and different days are plotted along the x-axis of both systems.

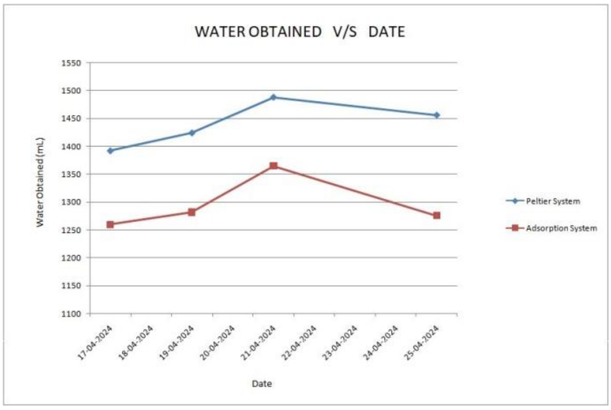

Fig 6: Water obtained v/s Date

From the above graph fig 8.2, we can observe that water quantity obtained in both peltier system and adsorption system on each different days where the obtained quantity of water in both system was lesser compared to the expected quantity due to the variation in humidity.

3. Running Cost Analysis

Conducting running cost analysis for the system based on electricity cost requires some factors such as power consumption, operating time, electricity cost and also the cost of hydrogel

1 unit of electricity = 1kWh
Cost for 1 unit of electricity = Rs 6.40
Electricity consumed by the system = 94.5W Operating time of the system = 24 hours
Electricity consumed for 24 hours = 94.5 x 24 = 2268Wh = 2.268kWh
Electricity cost for the system = 2.268 x 6.40 = Rs 14.5
Quantity of water obtained from the Peltier system = 1.44 L
Quantity of water obtained from the adsorption system = 1.30 L
Total quantity of water obtained = 1.44 + 1.30 = 2.74 L

1 kg of hydrogel could be reused for 8 cycles, so 1 kg for 8 days For 1 day hydrogel used will be 0.125 kg
Cost of 1 kg of hydrogel = Rs 133 Cost for 1 cycle = Rs 17
Total running cost for 1 day = Rs 14.5 + Rs 17 = Rs 31.50 Cost for 1 L of water = 31.50 / 2.74 = Rs 11.49

6. RESULT AND DISCUSSION

At the initiation of the project, we conducted a comprehensive review of journal papers and articles concerning both the Peltier cooling technique and the adsorption method. Our research revealed that both methods yield water at nearly identical humidity levels. This insight led us to propose a hybrid system combining the strengths of both approaches. Subsequently, we formulated the methodology and procedures for our project. Following this, we designed the structure of our hybrid system and proceeded with constructing the framework according to the dimensions outlined in our drawings. Upon completion of the framework construction, we assembled the components of our atmospheric water harvester. We rigorously tested the system's functionality and performance by observing humidity levels in various locations on different days. The Peltier system was operated for a duration of 3 hours, from which we extrapolated the water yield for a 24-hour period. Simultaneously, the adsorption method was operated continuously for an entire day. Throughout multiple testing sessions conducted on days with varying humidity levels within the range of 60% to 70%, we consistently obtained an average water quantity of 2.75 liters from our system. We noted that the amount of water collected varied in direct proportion to changes in humidity levels. Our observations indicated that the atmospheric water harvester could potentially produce up to 4 liters of water when optimal humidity conditions are met. Furthermore, through an analysis of operating costs, we determined that our system would be economically viable and beneficial for individuals experiencing water scarcity issues.

Table 3: Water Collection Data

Date	Water from Peltier system (mL)	Water from adsorption system (mL)	Total water collected (mL)
17-04-2024	1392	1260	2652
19-04-2024	1424	1289	2713
21-04-2024	1488	1365	2853
25-04-2024	1456	1276	2732
Average	**1440**	**1297.5**	**2862.5**

The table presents data on water collection from both a Peltier system and an adsorption system over a series of dates, along with the total water collected and average values. On April 17, 2024, the Peltier system yielded 1392 milliliters (mL) of water, while the adsorption system collected 1260 mL, resulting in a total of 2652 mL. Subsequent dates, April 19, 21, and 25, also saw water collection from both systems, with varying quantities. The highest total water collection occurred on April 21, with 2853 mL. The average values for water collection from the Peltier system, adsorption system, and total water collected across all dates were 1440 mL, 1297.5 mL, and 2862.5 mL, respectively. This data, presumably gathered from experiments or field observations, provides valuable in- sights into the performance of both systems over time, offering useful information for assessing their efficiency and effectiveness in water harvesting applications.

7. CONCLUSION

Hybrid atmospheric water harvesting (AWH) systems that integrate Peltier cooling with adsorption-based methods represent a promising approach to address water scarcity challenges and promote sustainable water resource management. The combination of these technologies has shown significant potential in enhancing water capture efficiency, im- proving energy utilization, ensuring water quality, and enhancing system reliability. The results from hybrid AWH projects highlight the synergistic benefits of combining Peltier cooling for targeted temperature control and adsorption-based methods for efficient wa- ter vapor capture. These systems have demonstrated increased water yield, reduced energy consumption, enhanced water quality standards, and scalability across various applications and environmental conditions. combining Peltier mechanisms with adsorption systems in atmospheric water harvesters can enhance their effectiveness in certain conditions. Peltier mechanisms utilize the temperature difference between two surfaces to generate electricity. By integrating Peltier modules into atmospheric water harvesters, excess heat from the adsorption process can be utilized to power the system, thereby increasing its efficiency and water yield. Adsorption systems typically require energy input to release the captured water vapor. By utilizing Peltier modules, the energy required for desorption can be reduced, making the overall process more energy-efficient. Atmospheric water harvesting is highly dependent on ambient temperature and humidity levels, which can vary greatly. The combination of Peltier and adsorption mechanisms allows for better adaptation to these variable conditions, optimizing water production across different environments. By utilizing waste heat from the peltier system to power the adsorption system, the hybrid setup reduces reliance on external energy sources, making it more environmentally friendly compared to traditional atmospheric water harvesters powered by fossil fuels or grid electricity. While hybrid AWH systems offer numerous advantages, they also come with challenges such as complexity, energy sustainability, and maintenance requirements. Addressing these challenges requires ongoing research, innovation, and collaboration across interdisciplinary fields to optimize system design, technology integration, and operational strategies. Looking ahead, the continued advancement of hybrid AWH technologies holds great promise for expanding access to clean water, particularly in water-stressed regions and communities facing water scarcity. By leveraging the strengths of Peltier cooling and adsorption-based methods, hybrid AWH systems can contribute significantly to sustainable water management practices, resilience against cli- mate change impacts, and equitable water access for present and future generations.

8. FUTURE SCOPE

The future scope of atmospheric water harvesting (AWH) holds tremendous potential for innovation, advancement, and widespread adoption. Several key areas offer exciting opportunities for development and expansion

- Technological Advancements: Continued research and development in AWH technologies are expected to lead to more efficient and cost-effective systems. This includes advancements in condensation methods, adsorption materials, cooling technologies and automation systems for optimized water capture and energy utilization.
- Integration with Renewable Energy Sources: Integration with renewable energy sources such as solar power, wind energy, and geothermal energy will enhance the sustainability of AWH systems. This includes developing hybrid systems that combine AWH with renewable energy generation and storage technologies for off- grid applications.
- Water Quality and Treatment: Future AWH systems will place greater emphasis on water quality assurance and treatment. Advanced filtration, purification, and disinfection techniques will be integrated into AWH systems to ensure the harvested water meets stringent quality standards for various applications, including drinking water.
- Smart Monitoring and Control: The incorporation of Internet of Things (IoT) technologies, sensors, and data analytics will enable smart monitoring and control of AWH systems. Real-time data collection, predictive maintenance, and remote monitoring capabilities will optimize system performance and resource management.
- Policy and Regulatory Frameworks: The development of supportive policy frame- works, incentives, and regulations will play a crucial role in promoting the adoption of AWH technologies. Government initiatives, subsidies for AWH projects, and water management policies will encourage investment and implementation

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