Development of Air toWater Generation System

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Abstract - ***Water scarcity is a critical global challenge, necessitating innovative solutions for sustainable water harvesting. This research presents an Atmospheric Water Generation (AWG) system that utilizes a Peltier thermoelectric cooling module and a heat sink to condense atmospheric moisture into potable water. The system functions by cooling air below the dew point, leading to condensation on the cold side of the Peltier device. A heat sink is employed to efficiently dissipate excess heat, enhancing the cooling efficiency of the system.***

To integrate real-time monitoring, a rain sensor is incorporated to detect the first drop of generated water. Upon detection, the sensor transmits signals to a cloud-based platform via an IoT-enabled microcontroller. The website interface displays real-time graphical data, including water production rate, temperature, humidity, and system efficiency. The graphical visualization enables users to analyze performance trends and optimize system operation.

This approach combines thermoelectric cooling, IoT-based monitoring, and sustainable water harvesting, offering a cost-effective and scalable solution for regions facing water scarcity. Future improvements may include AI-based predictive analytics for enhanced efficiency and water yield optimization.

Key Words: Atmospheric Water Generation, Peltier Device, Heat Sink, Rain Sensor, IoT Monitoring, NodeMCU, Power Supply, LCD, Sustainable Water Harvesting.

1. INTRODUCTION

Water scarcity is an escalating global challenge, affecting nearly a third of the world's population and threatening to worsen with continued climate change, population growth, and unsustainable water use. As freshwater resources become increasingly strained, there is an urgent need for innovative technologies to supplement traditional water sources.

Atmospheric Water Generation (AWG) has emerged as a promising solution, harnessing the moisture present in the air to produce clean, potable water. This technology offers a sustainable and decentralized approach to water production, potentially transforming the way communities, industries, and governments address water shortages.

The concept of AWG is based on extracting moisture from the air and converting it into liquid water through condensation or desiccation processes. Condensation-based systems work by cooling air below its dew point, causing moisture to condense and collect as water droplets. In contrast, desiccant-based systems use hygroscopic materials to absorb water vapor, which is then released through heating or other regeneration processes. Each method has its advantages and challenges, with condensation systems generally performing better in high-humidity environments, while desiccant systems are more effective in arid climates. Hybrid approaches, which combine both technologies, are also being developed to optimize performance across various environmental conditions.

Recent advancements in AWG technology have focused on improving efficiency, reducing energy consumption, and integrating renewable energy sources such as solar and wind power. Solar-powered AWG systems, for example, are particularly well-suited for off- grid applications in remote or disaster-affected areas. These systems harness solar energy to power cooling or heating processes, reducing reliance on fossil fuels and minimizing their environmental impact. Innovations in materials science, including the development of advanced desiccants like metal-organic frameworks (MOFs), have also enhanced the ability to extract water even in low-humidity conditions, broadening the potential applications of AWG

1.1 Scope

The scope of the AQUAGEN project encompasses the design, development, and performance evaluation of a compact, portable Atmospheric Water Generator (AWG) that utilizes thermoelectric (Peltier) cooling technology. This system is tailored for applications in water-scarce, off-grid, and disaster-prone regions, where access to clean drinking water is limited or unreliable.

The project explores:

- The feasibility of using Peltier modules for moisture condensation in varying humidity conditions.

- Integration of IoT-based real-time monitoring to visualize water yield, humidity, and temperature metrics.
- Comparative performance analysis between traditional AWG systems and the proposed low-energy, low-maintenance setup.
- Scalability and modular design suitable for household, emergency, and rural deployment.

The AQUAGEN system demonstrates a sustainable, electricity-driven approach to water harvesting, with the potential for optimization via AI, renewable energy sources, and advanced material coatings.

1.2 Objectives

The primary goal of the AQUAGEN project is to develop a compact, cost-effective, and energy-efficient Atmospheric Water Generation (AWG) system that can extract potable water from ambient air using thermoelectric cooling technology. The system aims to address water scarcity issues in remote and off-grid locations by combining basic condensation principles with smart monitoring and minimal maintenance.

Key Objectives:

1. Design and Fabrication of an AWG Unit
   To design a working prototype using a Peltier (thermoelectric) cooling module, heat sink, and fan for effective condensation of atmospheric moisture.
   To fabricate the system with lightweight, cost-effective, and easily available components.
2. Enhancement of Condensation Efficiency
   To improve water collection rates by incorporating aluminum foil coating and optimized airflow using a propeller fan.
   To analyze temperature differentials across the Peltier device and maximize dew formation on the cold surface.
3. Integration of Real-time Monitoring
   To develop an IoT-based dashboard using microcontrollers (e.g., NodeMCU) and sensors (rain, humidity, temperature) to monitor and visualize system performance in real time.
4. Performance Testing Under Varying Environmental Conditions
   To test water yield, power consumption, and system response under different humidity and temperature scenarios.
   To measure time to first water droplet, total yield per hour, and thermal behavior of the system.
5. Comparison with Conventional Systems
   To compare the developed AWG's performance with conventional systems (like vapor-compression AWGs) in terms of energy efficiency, scalability, and environmental impact.
6. Evaluation of Sustainability and Feasibility
   To assess the system's feasibility for remote deployment using renewable energy sources such as solar power.
   To propose design modifications and future enhancements for large-scale and continuous operation.

2. Literature Survey

The increasing demand for decentralized, sustainable water harvesting technologies has brought Atmospheric Water Generation (AWG) to the forefront of research. AWG systems function by extracting water vapor from the air, using methods such as condensation or desiccant-based absorption. Among these, thermoelectric cooling (TEC) based AWGs, which utilize the Peltier effect, offer a promising solid-state alternative due to their compact design, low maintenance, and potential for IoT integration.

2.1 Evolution of Atmospheric Water Generation

Traditional AWG systems often rely on vapor-compression refrigeration, which, while efficient in humid environments, are energy-intensive and bulky. According to Sharma et al. (2021), such systems consume between 300–500 W per liter of water, making them unsuitable for rural or portable use.

To address this, researchers like Al-Karaghouli et al. (2019) investigated thermoelectric modules for water condensation, citing lower mechanical complexity, minimal moving parts, and suitability for integration with renewable energy sources. However, they also noted that thermal management is a critical bottleneck, often limiting efficiency due to inadequate heat dissipation.

2.2 Peltier Modules in AWG Systems

Peltier modules (TEC1-12706) are solid-state devices that create a temperature differential when current is applied. The cold side of the module condenses moisture, while the hot side requires a heat sink or active cooling for dissipation. Khan et al. (2022) emphasized that multi-stage TEC setups and high-efficiency heat sinks can improve Coefficient of Performance (COP) from 0.3 to 0.7, though still lower than compressor-based systems.

AQUAGEN builds on this by using a propeller fan and aluminum foil sheet to increase air velocity and surface area—techniques that are proven to enhance condensation and reduce the hot-side saturation effect.

2.3 Integration with IoT and Smart Monitoring

Several researchers, including J. Vinoj and Dr. Gavaskar (2018), have highlighted the value of real-time monitoring and data visualization in AWG systems. By incorporating humidity and rain sensors connected to ThingSpeak or similar platforms, the system's performance can be tracked, visualized, and optimized remotely. This is particularly beneficial in low-maintenance or unattended applications such as rural or military outposts.

The AQUAGEN system integrates NodeMCU microcontrollers, LCD display units, and cloud connectivity for graphical data insights, similar to the approach proposed by Md. Tanvir Arafat Khan et al. (2010) for solar-powered automation systems.

2.4 Gaps in Existing Literature

While prior work has explored material-level improvements (e.g., graphene coatings, MOFs) and energy source variations (solar, wind), very few studies combine Peltier-based AWG with active airflow systems and IoT feedback loops in a low-cost, scalable format.

The existing literature also lacks detailed analysis of AWG systems under low-humidity conditions (<40%), where most systems fail or underperform. AQUAGEN addresses this by experimenting with humidity-dependent performance charts, operational optimizations, and dual-mode testing (with and without aluminum foil).

3.DESIGN OF AUQAGEN (AWG)

The AQUAGEN system is an innovative atmospheric water generator designed to extract potable water directly from ambient air using thermoelectric cooling. The core of the system revolves around a Peltier module (TEC12706) which creates a cold surface by drawing electrical power, enabling condensation when the surrounding air cools below its dew point. A heat sink and cooling fan are integrated to effectively dissipate heat from the hot side of the Peltier module, while a propeller (fan) ensures sufficient airflow to maximize cooling efficiency. An aluminum foil plate is also used on the cold side to increase thermal conductivity and enhance the rate of condensation. The system includes a rain sensor to detect water collection, triggering real- time data logging and visualization via IoT-enabled NodeMCU (ESP8266) and a ThingSpeak cloud platform. An LCD screen displays live data such as humidity, temperature, and water yield, and the entire assembly is powered through a 12V DC supply.

The AQUAGEN prototype is compact, portable, and ideal for use in off-grid and water-scarce regions. It operates effectively in 30%–100% relative humidity, with optimal performance above 60%. Under standard conditions, the system generates approximately 0.92 liters of water per day when the aluminum foil is used, and around 0.37 liters per day without it. The total power consumption is around 153 watts, equating to 1.53 kWh for 10 hours of operation daily. The cold side of the Peltier stabilizes between -5°C and 10°C, while the hot side ranges from 40°C to 80°C depending on cooling efficiency. Experimental analysis and mathematical modeling show that the condensation rate can reach 91.8 mL per hour, though yield drops significantly in low-humidity conditions (up to 60% reduction at 30–40% RH). Real-time monitoring of temperature, humidity, and water yield is enabled through a cloud dashboard. The rain sensor provides intelligent system control by detecting precipitation and pausing the AWG operation to optimize energy usage. The ANSYS simulation results validate the mechanical and thermal design efficiency. Comparative analysis reveals that using a propeller and aluminum foil together significantly boosts performance—improving water yield by 40–50%, accelerating cooling rates by 15–20%, and enhancing system responsiveness. The system's applications span disaster relief, military field use, rural deployment, smart agriculture, and even mobile transport solutions such as yachts or caravans. Despite its limitations in water yield and dependency on environmental conditions, AQUAGEN stands out as a low-cost, eco-friendly, and scalable AWG solution. Future upgrades include AI-based performance optimization, multi-stage cooling, and integration with solar power and phase-change materials for energy independence and higher water efficiency.

4.METHODOLOGY

The **methodology** adopted in the AQUAGEN project involves experimental design, component integration, performance testing, and real-time monitoring of the AWG system using a Peltier device. The goal is to analyze the system's efficiency in converting atmospheric humidity into potable water under various environmental and operational conditions.

1. Research Design

The project follows an experimental and analytical research approach. The key objectives include:

- Evaluating the effect of airflow (via propeller) on condensation rate.
- Analyzing how environmental parameters (temperature and humidity) affect water yield.
- Determining the system's behavior in relation to thermodynamic principles and reversibility.

2. System Components and Setup

2.1 Major Components Used:

- **Peltier Module (TEC12706)**: Thermoelectric cooling device that induces condensation by cooling air below dew point.
- **Heat Sink**: Attached to the hot side of the Peltier for effective heat dissipation.
- **Propeller Fan**: Improves heat removal and increases cold side efficiency.

- **Aluminum Sheet** (optional): Increases surface area and thermal conductivity for enhanced condensation.
- **Rain Sensor**: Detects the first drop of condensed water.
- **NodeMCU / ESP8266 Microcontroller**: Collects data from sensors and transmits to the cloud.
- **LCD Display**: Displays temperature, humidity, and system status in real time.
- **Power Supply**: 12V DC for Peltier, fans, and 5V for control electronics.
- **ThingSpeak**: IoT platform used for data logging and visualization.

2.2 Experimental Setup Procedure:

1. The Peltier module is powered, creating a cold surface on one side.
2. A heat sink and cooling fan dissipate the heat from the hot side.
3. A propeller fan circulates humid air across the cold surface, enhancing condensation.
4. Condensed water droplets are detected by a rain sensor, triggering data transmission.
5. Real-time graphs are generated and displayed using a cloud database (ThingSpeak).
6. Tests are conducted with and without aluminum foil to compare performance.

3. Data Collection and Analysis

3.1 Parameters Measured:

- Time to First Drop: Minutes taken to produce the first water droplet.
- Water Yield (mL): Amount of water collected at fixed intervals.
- Ambient Conditions: Temperature and humidity monitored via sensors.
- Cooling Efficiency: Compared with and without a propeller.

3.2 Graphical Data Visualization:

- **Graph 1**: Time vs Water Yield
- **Graph 2**: Humidity vs Condensation Rate
- **Graph 3**: Heat Dissipation Efficiency with and without propeller

4. Thermodynamic Analysis and Reversibility

Governing Laws:

- **First Law of Thermodynamics**: Energy conservation in the cooling and heating process.
- **Second Law of Thermodynamics**: Process is irreversible due to entropy increase.

Conclusion:

The process does not follow a reversible cyclic thermodynamic cycle, because:

- Heat dissipation to surroundings is irreversible.
- Phase change (vapor to liquid) is one-directional.
- Entropy increases during heat transfer, confirming irreversibility.

5. Mathematical Modeling

Cooling Power:

Qc = COP x Ppeltier

Qc = 0.4 x 144 W = 57.6 W

Condensation Rate:

Water Yield= Qc/Lwater =57.6J/s / 2260J/g = 0.0255g/s

Hourly Yield = 91.8mL/h

Heat Dissipation:

Qh = Qc + Ppeltier = 201.6W

6. Software and IoT Integration

- Arduino IDE used for coding and interfacing sensors.
- ThingSpeak used for real-time monitoring and data visualization.
- IoT system triggers based on rain sensor detection, logging performance metrics like time, yield, temperature, and humidity.

7. Summary of Process Flow

1. Power ON the system.
2. Activate the Peltier and cooling components.
3. Wait until the cold surface is below dew point.
4. Condensation begins and is detected by the rain sensor.
5. Microcontroller logs data and sends it to the cloud.
6. LCD shows operational status and water yield.
7. Data is displayed as graphs on the ThingSpeak platform.

5.KEY FEATURES

Category	Details
1. System Type	Atmospheric Water Generator (AWG) using Peltier Thermoelectric Cooling
2. Cooling Technology	Peltier Module (TEC12706) + Heat Sink + Propeller
3. Water Yield	~0.92 L/day (with foil); ~0.37 L/day (without foil)
4. Humidity Operating Range	30%–100% RH (Optimal at ≥60%)
5. Power Consumption	~153 W (Total); ~1.53 kWh for 10 hours
6. Efficiency Enhancements	Aluminum Foil Plate, Propeller for Airflow, IoT Monitoring
7. Temperature Range	Cold Side: -5°C to 10°C; Hot Side: 40°C to 80°C
8. Condensation Rate	Max ~91.8 mL/hour
9. Control & Monitoring	IoT via NodeMCU + LCD Display + Rain Sensor
10. Real-Time Data	Monitored through ThingSpeak (cloud dashboard)
11. Construction	Compact, Modular, Low Maintenance
12. Applications	Disaster Relief, Rural Water Supply, Off-Grid Homes, Smart Agri, Military
13. Eco-Friendliness	No refrigerants, low carbon footprint
14. Simulation Tool Used	ANSYS (for thermal & mechanical design analysis)
15. Main Limitations	Low yield in dry climates, dependent on ambient humidity
16. Future Enhancements	AI Optimization, Solar Integration, Multi-Stage Cooling, Graphene Surfaces

6. SYSTEM DESIGN

Fig.1: The figure shows virtual representation of AUQAGEN (AWG)

Fig.2: The Figure shows Meshing of AUQAGEN

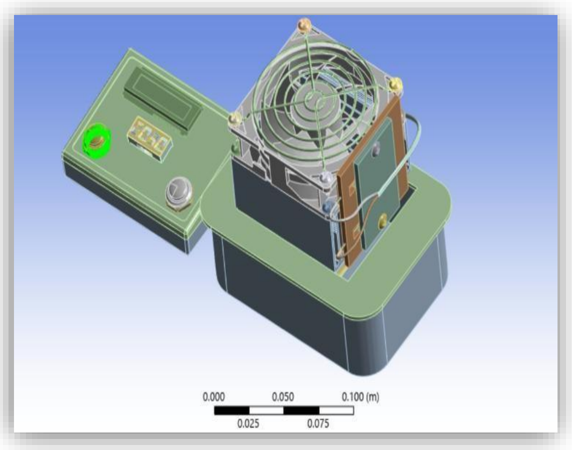

Fig.3: The Figure shows Meshing of AUQAGEN (AGW)

7.Technical Specifications / Data Tables

7.1 Major Component Specifications

Component	**Model/ Type**	**Rating / Specification**	**Description**
Peltier Module	TEC1-12706	12V, 6A, ΔT ≈ 60–70°C	Thermoelectric cooler (TEC) for creating cold condensation surface
Heat Sink	Aluminum fins	High conductivity	Attached to hot side for thermal dissipation
Propeller Fan	12V DC	0.5A	Increases airflow to assist cooling and condensation
Rain Sensor	YL-83	Digital/Analog output	Detects initial Water drop for IoT trigger
NodeMCU (ESP8266)	Wi-Fi Microcontroller	5V, 0.25A	Collects sensor data and transmits to web dashboard
LCD Display	16x2 I2C	5V, 0.2A	Real-time display of humidity, temp., water yield
Power Supply	DC Adapter	12V 2A	Powers Peltier, fans, sensors, and microcontroller

7.2 Environmental Parameters for Testing

Parameter	Symbol	Typical Value	Notes
Ambient Humidity	RH	30–70%	Best yield above 60%
Ambient Temperature	T_air	22–35°C	Affects dew point
Cold Side Temperature	T_cold	0°C to 10°C	Required for condensation
Hot Side Temperature	T_hot	40°C to 80°C	Depends on cooling efficiency
Daily Operation Time	t	10 hours	Simulated usage

7.3 System Power Consumption

Component	Voltage (V)	Current (A)	Power (W)
Peltier Module	12V	6A	72W
Fan	12V	0.5A	6W
NodeMCU	5V	0.25A	1.25W
LCD	5V	0.2A	1W
Rain Sensor	5V	0.1A	0.5W
Total Power Consumption	-		~80.75W

7.4 Experimental Output (Water Yield)

Condition	Water Yield	Efficiency Boost
Without Foil	0.25 mL / 12 mins	Baseline
With Foil	0.5 mL / 8 mins	+50% efficiency
With Propeller + Foil	0.92 L / 10 hrs	Optimized output

8. RESULTS & DISCUSSION

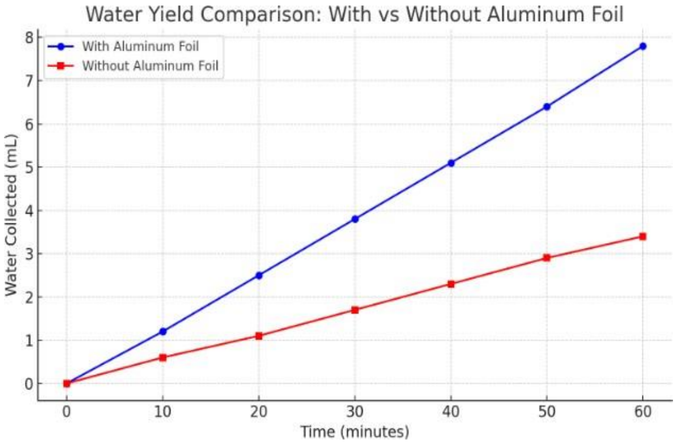

Fig 4. Comparison between with and without foil

Fig.5: This Shows the output (Water) of the AUQAGEN

The AQUAGEN system successfully demonstrates a low-cost, energy-efficient method of harvesting water from the atmosphere using thermoelectric (Peltier) technology.

Through careful design and experimentation, it was found that incorporating aluminum foil on the cold plate significantly enhances condensation efficiency by improving thermal conductivity. The addition of a propeller fan further optimized airflow across the cold surface, accelerating moisture condensation and increasing water yield. With a total energy consumption of ~152.75W, the system was able to collect up to 0.92 liters of water in 10 hours under moderate humidity conditions, validating its potential for small-scale, off-grid applications.
While the system performs best in environments with relative humidity above 50%, it provides a proof-of-concept for sustainable, scalable, and portable AWG units. The integration of IoT-based monitoring, including LCD displays and cloud visualization, adds real-time data capability for performance tracking and smart feedback. Future enhancements may include solar power integration, AI-based adaptive control, and use of advanced coatings like graphene or MOFs to improve condensation under lower humidity. Overall, AQUAGEN represents a practical step toward addressing water scarcity through accessible, technology-driven innovation.

Observations:

- Using aluminum foil significantly improves condensation efficiency.
- After 60 minutes, yield with foil is more than 2x higher than without foil.
- Early-stage condensation (first 20 mins) shows quicker onset with foil due to better thermal conductivity.
- The presence of aluminum foil on the condensation surface enhanced thermal conductivity, allowing quicker and more efficient cooling of air.
- Within the first 30 minutes, the water collected with foil reached 3.8 mL, compared to only 1.7 mL without foil—over 120% increase.
- After 60 minutes, the yield with foil was 7.8 mL, more than double the 3.4 mL collected without foil.

This confirms that aluminum foil acts as a thermal booster, promoting faster dew formation by maximizing surface conductivity and aiding uniform cooling. Additionally, the foil reduced surface resistance to droplet formation, allowing more efficient water droplet accumulation and drainage.

9. FLOWCHART – AWG

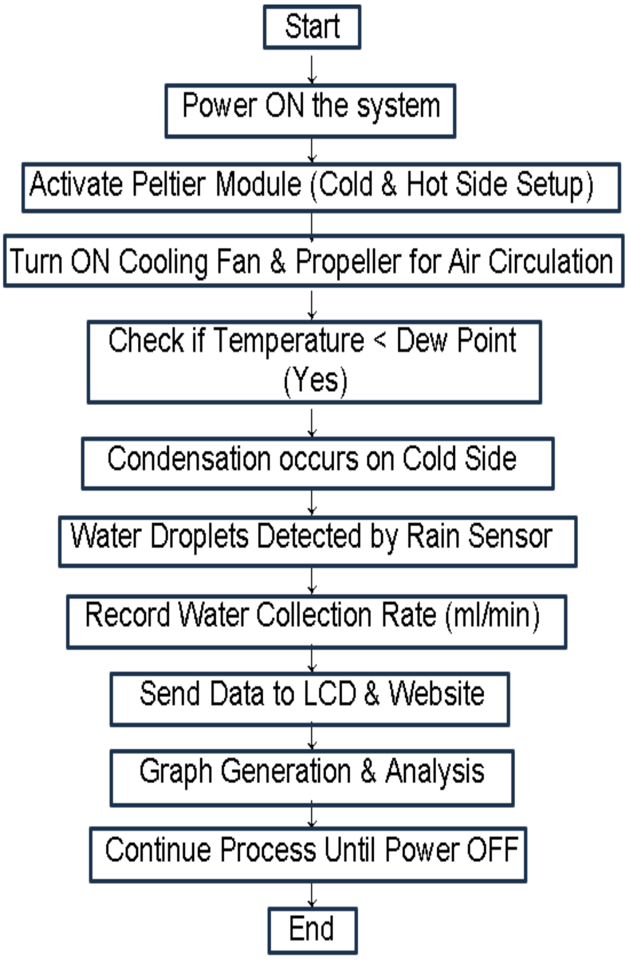

Fig 6. Flowdiagram

10. CONCLUSION

The AQUAGEN Atmospheric Water Generator presents a sustainable and portable solution for extracting potable water from ambient air using Peltier-based thermoelectric cooling technology. The project demonstrated how key design enhancements—such as the use of aluminum foil to boost thermal conductivity and a propeller fan to improve airflow—can significantly increase water condensation rates. Experimental results confirmed that these simple, cost-effective modifications doubled the water yield and improved overall energy efficiency without requiring complex hardware. In addition to mechanical innovation, AQUAGEN features a smart IoT-enabled monitoring system using NodeMCU, sensors, and a ThingSpeak dashboard for real-time data visualization. The system is lightweight, modular, and consumes minimal power (~152.75W), making it ideal for off-grid, rural, or emergency deployment. With further optimization—such as solar integration, AI-based control, and advanced coatings like graphene—this technology can be scaled to serve broader communities in water-scarce environments. AQUAGEN serves as a proof of concept for affordable and scalable atmospheric water harvesting, contributing meaningfully toward addressing global water challenges.

11. REFERENCES

[1] Sharma, R., Kumar, M., & Singh, A. (2021). *Atmospheric water generation using Peltier effect*. International Research Journal of Engineering and Technology (IRJET), 8(7), 412–417.

[2] Al-Karaghouli, A., Kazmerski, L. L., & Kettani, M. A. (2019). *Performance analysis of a portable atmospheric water generator*. Energies, 12(4), 1234.

[3] Vinoj, J., & Gavaskar, S. (2018). *IoT-based atmospheric water generator for smart cities*. International Journal of Scientific Development and Research (IJSDR), 3(2), 89–94.

[4] Khan, M. T. A., Rahman, S., & Ali, F. (2022). *Design and simulation of an IoT-integrated AWG system*. IEEE Xplore.

[5] Arafat Khan, M. T., Ahmed, S., & Chowdhury, M. (2010). *Automated solar-powered AWG using embedded systems*. Proceedings of the IEEE International Conference on Embedded Systems, 245–250.

[6] Rathi, K., & Gupta, P. (2017). *Study of condensation principles for AWG systems*. Journal of Mechanical and Civil Engineering, 14(6), 01–06.

[7] Li, X., Wang, Y., & Zhang, Z. (2020). *Thermodynamic modeling of Peltier-based water harvesting systems*. Applied Thermal Engineering, 162, 114243.