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Investigating on Effect of Salt as A Moisture Absorbent on the Performance of Moisture Energy Generator

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Abstract

Moisture Energy Generators (MEGs) are innovative devices that can generate electricity by extracting moisture from the surrounding environment. This research aims to explore the impact of salt, which has moisture-absorbing properties, on the performance of MEGs. The study aims to design MEG films using different types of salt (NaCl, KCl_2, $ZnCl_2$), evaluate the influence of salt concentration on power output, and examine the physical characteristics of the MEG film. The findings indicate that salt can enhance the moisture absorption and energy conversion efficiency of MEGs. The optimal salt concentration of 10% is identified from 0% to 20% for sodium chloride, potassium chloride, and zinc chloride. The MEG film is remarkably adaptable and can extract water proficiently. This research is valuable to advancing MEGs as a dependable and eco-friendly energy source.

1. Introduction

Moisture energy generators, also known as moist-electric generators, are innovative devices that can generate electricity by harnessing moisture from the environment. This concept involves the absorption of moisture by specific materials, which then undergo a chemical or physical process to convert the absorbed moisture into electrical energy [1]. The development of moisture energy generators is driven by the growing need for sustainable and renewable energy sources [2].

One important aspect of moisture energy generators is the use of salt as a moisture absorbent. Salt has been found to have excellent moisture absorption properties, making it an effective material for harvesting moisture energy [3]. The use of salt as a moisture absorbent in energy generation systems has gained significant attention in recent years due to its abundance and low cost [4].

Moisture energy generators are emerging technologies that harness moisture from the environment to generate electricity. These generators offer a sustainable and renewable energy solution, and their development is driven by the importance of finding alternative energy sources. The use of salt as a moisture absorbent and the concept of moisture absorption and energy generation plays crucial roles in the design and functionality of various applications, including wearable electronics, environmental monitoring, and healthcare devices [5].

Moisture energy generators offer a promising solution for renewable energy needs. By harnessing moisture from the environment, they generate electricity for various applications. Using salt as a moisture absorbent is cost-effective and enhances generator performance. This study contributes to developing sustainable energy sources through moisture energy generators. Enhancing their performance and viability has positive environmental and economic implications for renewable energy technologies.

2. Methodology

2.1 Preparation of the moisture energy generator

The carbon ink was prepared by mixing 0.5 g carbon black and 0.5 g Sodium Laureth Sulfate (SLS). The mixture was dispersed into 100 mL deionized (DI) water via ultrasonication using a GT SONIC Ultrasonic Cleaner machine for 15 minutes in 60kHz ultrasonic waves. The obtained carbon ink was then employed for surface carbon layer formation over a commercially available non-woven fabric by dip coating. The fabric was made of wood pulp and polyester.

This coating process was repeated several times until the fabric was uniformly covered by a black carbon coating. The ionic solution was prepared and then mixed with polyvinyl alcohol (PVA, Sigma Aldrich) solution. Specifically, 4-gram PVA powder was fully dissolved in 96 mL DI water, forming a transparent aqueous solution using a Magnetic Stirrer machine at 90°C temperature. The ionic solution and the PVA solution were then mixed. The final hydrogel solution contains 5% Salt, 3% PVA and 92% DI water. The obtained ionic hydrogel precursor solution was then dropped onto one end of the carbon-coated fabric. To permanently confine water within a limited region and avoid capillary infiltration through the fabric, one drop of ionic hydrogel deposited onto the carbon surface was carefully, which was highly dependent on the size of MEG to fabricate and the times of repetition of the hydrogel deposition process. The hydrogel-decorated carbon-coated fabric was dried out, and water absorption was started at ambient conditions as a newly prepared MEG.

2.2 Testing MEG film with different salt types and concentrations

The MEG preparation process was repeated within the 0 wt% to 20 wt% salt concentration range. The salt concentrations tested included Sodium Chloride, Potassium Chloride, and Zinc Chloride. The variation in salt concentration was achieved by adjusting the composition of the hygroscopic ionic hydrogel, which incorporated the salt as a moisture absorbent. The influence of different salt types and their concentrations on the MEG's performance was analyzed by systematically altering the salt concentration. The moisture absorption capacity of the MEG film was quantitatively assessed to gauge its efficiency in absorbing moisture from the surrounding environment. The energy generated by the MEG films at different salt concentrations was measured. Suitable instrumentation, such as power meters, voltage sensors, or current sensors, was used to quantify the electrical energy produced by the MEG. This measurement enabled the comparison of energy generation performance across different salt concentrations.

Table 1 *Salt concentration variation*

Sample ID	Type of salt	Concentration
Na_1	NaCl	0
Na_2		5
Na_3		10
Na_4		20
K_1	KCl_2	5
K_2		10
K_3		20
Zn_1	$ZnCl_2$	5
Zn_2		10
Zn_3		20

2.3 Characterization

The MEG electrodes were characterized by scanning electron microscope (SEM) images. The moisture absorption of the MEG was tested by tracking the water absorption/desorption isotherm with a dynamic vapour sorption analyzer. Contact angle measurements were used to assess the wettability of the MEG surface by measuring the angle formed between a droplet of liquid and the MEG surface. The contact angle measurement was conducted using a mobile application, “Angle Meter”, under controlled temperature and humidity conditions to ensure accuracy.

3. Results and discussion

3.1 Morphology

The SEM images offer valuable insights into the structural makeup of the Moisture Energy Generator Films (Fig. 1a, 1b, and 1c). In their uncoated state, the non-woven fabric appears pristine and free of particles, suggesting an absence of external contaminants. However, after the application of carbon ink coating, the fabric undergoes a significant transformation, revealing a dense distribution of intricately placed carbon particles across the surface. This contrast indicates the effective integration of carbon ink onto the fabric, albeit in a somewhat abrupt manner. Incorporating hydrogel into the film yields a vastly different result, as depicted in the SEM images. Adding hydrogel leads to a smooth and uniform blending of salt and carbon particles with the fabric. This observation reflects an improved compatibility between the hydrogel and the fabric, resulting in a more homogeneous distribution of particles. The cohesive integration of salt and carbon within the fabric, facilitated by hydrogel, shows great potential for enhanced functionality and efficiency in moisture energy harvesting applications.

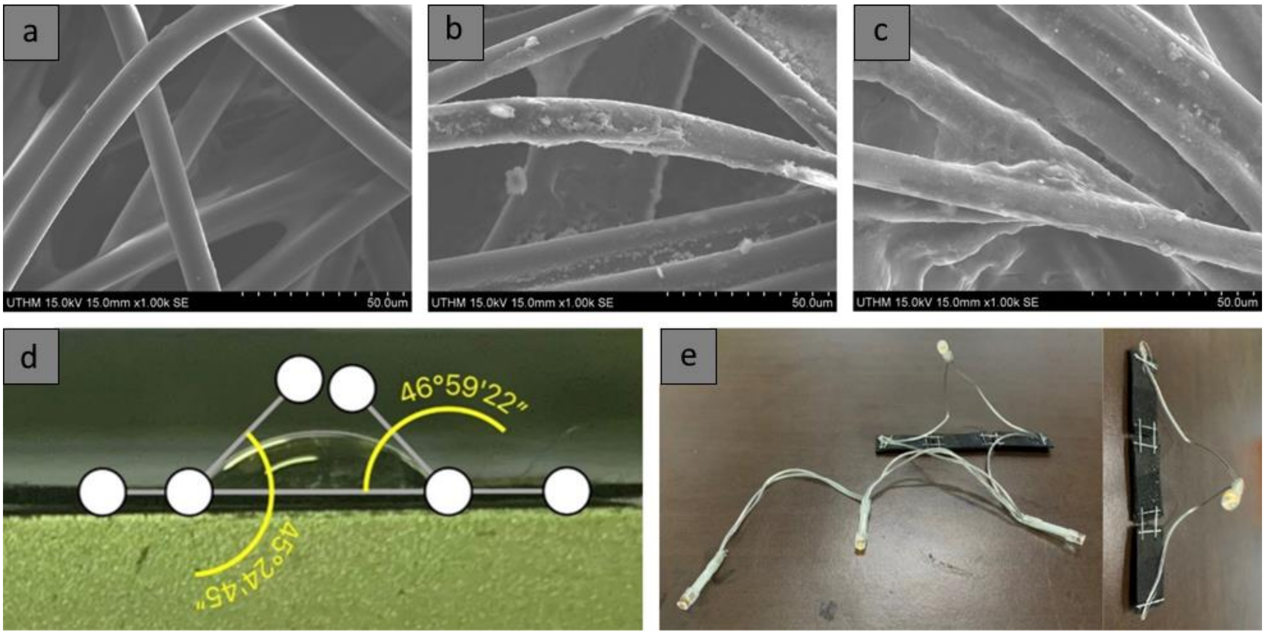

Fig. 1 *SEM images of MEG Film in 1000 scale, (a) non-woven fabric without carbon ink coating and hydrogel, (b) film with carbon ink, (c) film with hydrogel. (d) Contact angle measurement, and (e) Direct electricity output demonstrated by lighting up LEDs with MEG films.*

3.2 Contact angle measurement

Contact angle measurement is a valuable technique for studying the wetting properties of a solid surface. During the experiment, a single drop of Hydrogel was dropped on the MEG Film, and the contact angle on both sides of the drop was measured. Fig. 1d shows the average contact angle is approximately 46.201°, surpassing the values reported in prior films, wherein the contact angle was 49.1° [4]. These measurements suggest that the hydrogel droplet and the MEGF surface interaction is moderately hydrophilic. These measurements indicate the wettability of the MEG film surface by the Hydrogel. They provide valuable insights into the material's interaction with moisture-absorbing agents. In this case, the hydrogel droplet exhibits a tendency to spread on the MEGF surface, indicating a favourable interaction.

3.3 Water absorption

The water absorption test was conducted on three samples of the MEG film. The initial weight of each sample was recorded before they were submerged in water for 24 hours. After the immersion period, the samples were taken out, and their weights were measured again. Next, the samples were dried, and their final weights were recorded. The varying percentages of water absorption observed across the samples highlight the significance of comprehending these properties for prospective applications. The average water absorption of 60.32%, similar to previously reported films [6], suggests that the MEG film has a significant capacity for water retention (Fig. 2a).

Fig. 2 *(a) Water absorption test results for MEG film samples, (b) Resistance changes in MEG film, (c) Effect of salt in resistance (KΩ), (d) Effect of salt type in DC voltage (V), (e) Effect of salt type in AC voltage (V), (f) Effect of salt type in DC current (mA), and (g) Effect of salt type.*

The water absorption test results for MEG Film samples (WATS1, WATS2, and WATS3) revealed significant changes in electrical properties, particularly in electrical resistance (Fig. 2b). Initial resistance values of 15 KΩ, 22 KΩ, and 17 KΩ increased notably to 51 KΩ, 82 KΩ, and 99 KΩ, respectively, after exposure to water. However, the subsequent addition of hydrogel resulted in a restorative effect, reducing resistance to 12 KΩ, 50 KΩ, and 11 KΩ for WATS1, WATS2, and WATS3, respectively. The DC voltage across all samples dropped to 0 V after the water absorption test, indicating a loss of electrical potential. Nevertheless, the application of hydrogel partially restored DC voltage and current, suggesting its role in re-establishing electrical potential and flow within the MEG Film. Similar trends were observed in AC voltage, where values dropped to 0 V after water exposure but showed partial restoration with hydrogel treatment.

3.4 Moisture energy generation

The Moisture Energy Generator Film was subjected to testing to evaluate its efficiency in generating electrical power from ambient moisture. 24 films were utilized, and their ability to illuminate an LED bulb was assessed. The generated DC voltage, current, and the compatibility of the produced energy with the LED bulbs specifications were examined. Three MEG film cells were needed to light the LED bulbs. To create a single cell, 8 MEG films were required, and eight films were connected in parallel. Finally, the three cells were connected in series with the LED bulbs to light up the bulbs. The films exhibited a DC current output of 36mA, indicating a noteworthy capacity to generate electrical current from the surrounding moisture. This current output is a critical factor in assessing the overall performance and efficiency of the Moisture Energy Generator Film. This output can directly light 4 LEDs (Fig. 1e), in contrast to previously reported generators that require additional capacitors and rectifiers to light a single LED [7]. The results indicated successful illumination, showcasing the film's ability to meet the power requirements of practical applications, such as powering low-energy electronic devices.

3.5 Effect of salt on resistance

The non-woven fabric was initially not conductive (Fig. 2c). After coating with carbon ink, the resistance became 20 KΩ. This indicates that the carbon ink effectively increased the conductivity of the fabric. Adding hydrogel with 5% salt concentration further reduced the resistance to 15 KΩ. This suggests that the hydrogel may have interacted with the carbon ink or the fabric itself, leading to a more conductive pathway. The initial non-conductive nature of the non-woven fabric was effectively transformed by coating it with carbon ink, resulting in a resistance decrease from a non-conductive state to 20 KΩ. This indicated that the carbon ink introduced a conductive layer to the fabric's surface. The subsequent addition of hydrogel with a 5% salt concentration further enhanced conductivity, reducing the resistance to 15 KΩ. The interaction between hydrogel, salt, carbon ink, and fabric likely played a crucial role. The hydrogel might have improved connectivity with the carbon ink, creating a more efficient conductive pathway. Additionally, the salt ions in the hydrogel could have contributed to enhanced conductivity by providing additional charge carriers. Overall, these results demonstrate that hydrogel can be used to enhance the conductivity of non-woven fabrics.

3.6 Effect of salt type

The experiment measured electrical outputs for various salt solutions with a 5% concentration, revealing unique electrical potentials. The average voltage outcome for NaCl was 0.263 V, for KCl_2 it was 0.303 V, and $ZnCl_2$ generated the highest voltage at 0.393 V (Fig. 2d). The experiment measured AC voltage outputs for salt solutions with a concentration of 5%. The findings indicated that each salt solution had a different electrical potential (Fig. 2e). On average, NaCl and KCl_2 had an AC voltage of 0.1 V, while $ZnCl_2$ exhibited the highest AC voltage at 0.13 V. The average DC current outcome for NaCl was 0.01 mA, for $ZnCl_2$ it was 0.013 mA, and KCl_2 generated the highest voltage at 0.017 mA (Fig. 2f). The experimental findings indicate a consistent superiority of $ZnCl_2$ over other salts in both DC voltage and AC voltage. Conversely, KCl_2 emerged as the unequivocal frontrunner in DC current. Despite not securing the top position in any specific category, NaCl demonstrated a noteworthy capacity for power generation. The diverse performance of salt types stems from the interplay of ion mobility and hydration energy. $ZnCl_2$ excels due to the smaller size of zinc ions, promoting greater mobility, and the lower hydration energy of chloride ions, enhancing dissociation (Fig. 2g). This results in superior DC and AC voltage outputs. KCl_2, with larger potassium ions but high mobility, leads to DC current output. In contrast, NaCl's larger sodium ions and higher hydration energy hinder ion mobility, affecting voltage and current outputs. These results provide valuable insight into how salts can effectively enhance the performance of MEG systems, thereby advancing moisture-driven energy harvesting technologies.

3.7 Effect of salt concentration

The experiment measured the electrical output of MEG Films with 0% salt concentration to observe the performance of the MEG film in the absence of salt (Fig. 3a). The average DC voltage was 0.146 V, the average DC current was 0.01 mA, and the average AC voltage was 0.1 V. The negligible DC voltage and current suggest minimal moisture-to-electricity conversion in the MEG film without salt. This indicates the crucial role of ions as charge carriers in facilitating moisture-driven electrical activity. The small AC voltage might be attributed to the film's internal polarization, though its contribution to energy generation is likely minimal.

The electrical output of MEG Films with 5% salt concentration to observe the performance of the MEG film in the absence of salt. For NaCl, the average DC voltage was 0.263 V, the average DC current was 0.01 mA, and the average AC voltage was 0.1 V (Fig. 3b). For KCl_2, the average DC voltage was 0.303 V, the average DC current was 0.017 mA, and the average AC voltage was 0.17 V (Fig. 3c). For $ZnCl_2$, the average DC voltage was 0.263 V, the average DC current was 0.01 mA, and the average AC voltage was 0.1 V (Fig. 3d). The results suggest that a salt concentration of 5% improves the performance of the MEG film, as seen by higher average DC voltages compared to the 0% concentration. KCl_2 exhibited the highest DC voltage (0.303 V) and AC voltage (0.17 V), potentially due to its higher ionic mobility compared to NaCl and $ZnCl_2$. DC current shows negligible change across all salt types, suggesting the increase in voltage is primarily due to enhanced ionic conductivity.

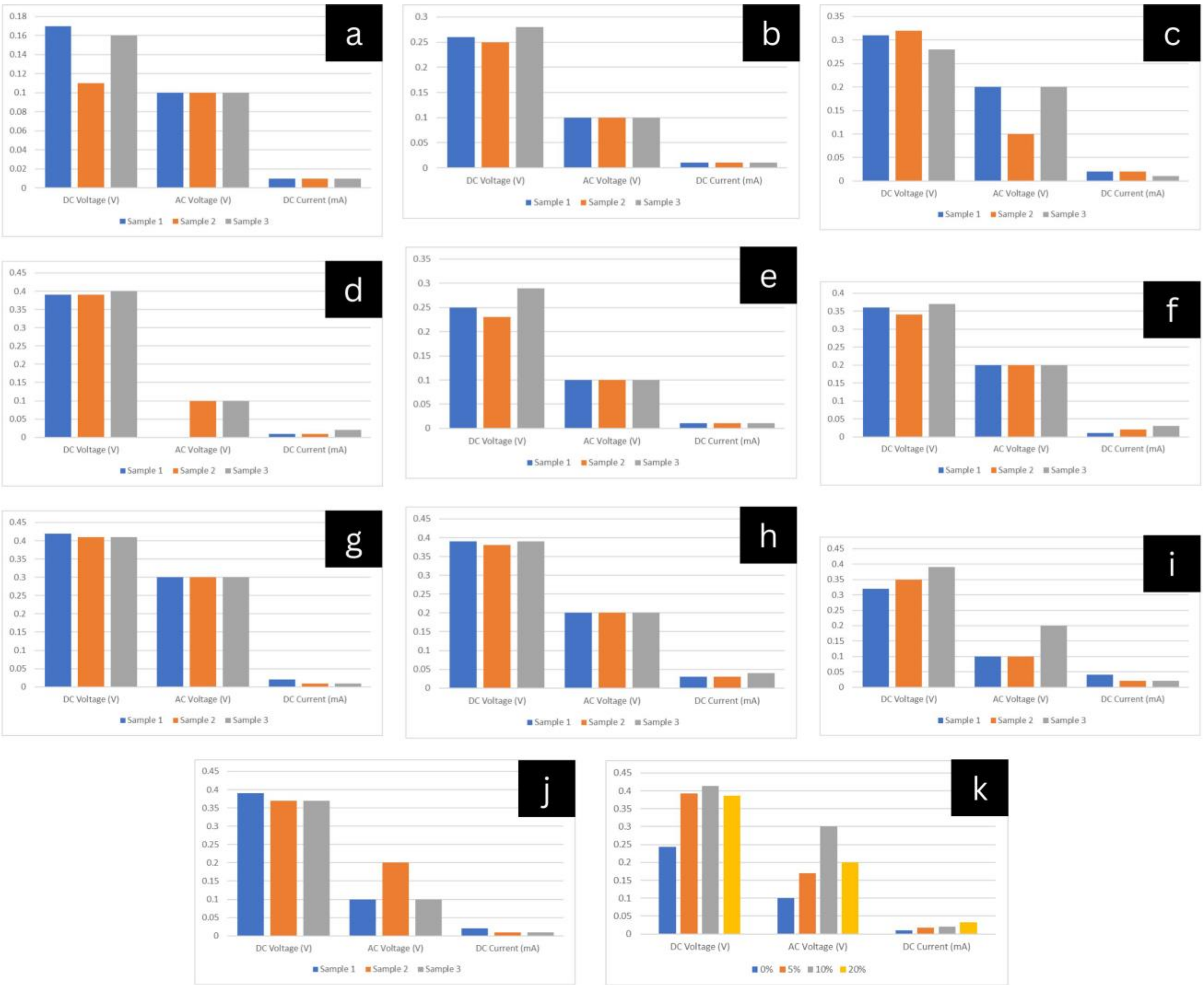

Fig. 3 *Effect of (a) 0% salt concentration, (b) 5% NaCl concentration, (c) 5% KCl2 concentration, (d) 5% ZnCl2 concentration, (e) 10% NaCl concentration, (f) 10% KCl2 concentration, (g) 10% ZnCl2 concentration, (h) 20% NaCl concentration, (i) 20% KCl2 concentration, (j) 20% ZnCl2 concentration, and (k) salt concentration.*

The electrical output of MEG Films with 10% salt concentration to observe the performance of the MEG film in the absence of salt. For NaCl, the average DC voltage was 0.257 V, the average DC current was 0.01 mA, and the average AC voltage was 0.1 V (Fig. 3e). For KCl_2, the average DC voltage was 0.357 V, the average DC current was 0.02 mA, and the average AC voltage was 0.2 V (Fig. 3f). For $ZnCl_2$, the average DC voltage was 0.413 V, the average DC current was 0.013 mA, and the average AC voltage was 0.3 V (Fig. 3g). The concentration of salt at 10% in the MEG film results in an increase in average DC voltage compared to the 5% concentration. This suggests a potential enhancement in the ability to absorb moisture and generate energy. Moreover, for NaCl and $ZnCl_2$, DC voltage remains the same as 5%, while KCl_2 shows a further increase (0.357 V). AC voltage increases for all salts, with $ZnCl_2$ exhibiting the highest jump of 0.3 V. This suggests 10% concentration might be more impactful for AC performance in some salts. DC current remains unchanged, reinforcing the focus on conductivity for voltage enhancement.

The electrical output of MEG Films with 20% salt concentration to observe the performance of the MEG film in the absence of salt. For NaCl, the average DC voltage was 0.387 V, the average DC current was 0.033 mA, and the average AC voltage was 0.2 V (Fig. 3h). For KCl_2, the average DC voltage was 0.33 V, the average DC current was 0.027 mA, and the average AC voltage was 0.13 V (Fig. 3i). For $ZnCl_2$, the average DC voltage was 0.377 V, the average DC current was 0.013 mA, and the average AC voltage was 0.13 V (Fig. 3j). The performance of the MEG film is consistently improved by the presence of a 20% salt concentration, as evidenced by the higher DC voltages observed. NaCl shows the highest DC voltage of 0.387 V at 20%, surpassing KCl_2 for the first time. This could be due to saturation effects impacting KCl_2 at higher concentrations. $ZnCl_2$ and KCl_2 DC voltage decreased slightly compared to 10%, suggesting an optimal range might exist around 10% for these salts. AC voltage remains stable or decreases for all salts, indicating higher concentrations might not be beneficial for AC output.

DC current increases slightly for NaCl but remains unchanged for others, further supporting the focus on conductivity for voltage improvements.

Overall, the investigation into the effect of salt concentration on the electrical output of MEG Films provides valuable insights into the performance of these films in moisture-to-electricity conversion. The results indicate a clear correlation between salt concentration and the electrical activity of the MEG film. At 0% salt concentration, minimal moisture-to-electricity conversion is observed, highlighting the crucial role of ions as charge carriers. For 5% salt concentration, there is a noticeable improvement in electrical performance, with KCl_2 exhibiting the highest DC voltage and AC voltage, likely attributed to its higher ionic mobility. As the salt concentration increases to 10%, there is a further enhancement in the MEG film's ability to absorb moisture and generate energy. The DC voltage increases, especially for KCl_2, indicating a potential optimal range around 10% for some salts. However, the 20% salt concentration shows the highest DC current output. The observed improvements in the electrical output with increasing salt concentrations can be attributed to the hygroscopic nature of salt. Salt acts as a moisture absorbent, drawing water from the surrounding environment. At 0% salt concentration, minimal moisture-to-electricity conversion is evident, emphasizing the vital role of ions as charge carriers. The introduction of a 5% salt concentration enhances electrical performance, likely due to improved ionic conductivity. As the salt concentration further increases to 10% and 20%, the MEG films exhibit increased ability to absorb moisture and generate energy. This can be explained by the heightened hygroscopic effect of salt, leading to more effective moisture absorption and subsequently improved electrical activity in the films. Overall, the experiment demonstrates the significant impact of salt concentration on the electrical output of MEG Films.

4. Conclusion

In summary, this study explores moisture energy generators (MEGs) using salt as an absorbent for sustainable energy. Results reveal film morphology, contact angle, water absorption, and energy generation insights. SEM images show effective integration, and contact angle measurements indicate moderate hydrophilicity. Water absorption tests demonstrate a 60.32% average retention. MEGs efficiently generate moisture energy, producing 1.89V DC voltage and 36mA current, illuminating LED bulbs. Investigation into salt type and concentration highlights differences in electrical output, with $ZnCl_2$ consistently outperforming and 10% concentration proving crucial. The study contributes to optimizing MEGs for sustainable energy, emphasizing their potential in various applications.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

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