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Mitigating Corrosion in Activated Carbon Purified Biogas: A Case Study of Copper and Aluminum Metals

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ABSTRACT

The objective of this study is to investigate the potential reduction in corrosion of aluminum and copper metals when exposed to biogas purified by activated carbon derived from cashew branches. Both aluminum and copper metals were subjected to raw and purified biogas, and their corrosion rates were analyzed using the gravimetric method. The results revealed that the corrosion rate of both metals increased over time when exposed to unfiltered biogas. However, a notable reduction in corrosion rate was observed when the metals were exposed to biogas filtered with activated carbon. This suggests that activated carbon derived from cashew branches could effectively mitigate the corrosive effects of hydrogen sulfide in biogas. Additionally, the study found that aluminum exhibited greater resistance to corrosion compared to copper when exposed to filtered biogas. This research on green inhibitors introduces novel approaches, particularly in utilizing activated carbon from cashew branches for biogas purification, offering a promising strategy to mitigate its corrosive nature. Furthermore, the evaluation of this filtration method's efficacy in protecting aluminum and copper metals underscores its potential significance in corrosion prevention within biogas systems.

Keywords: Biogas, Corrosion, Copper, Aluminum, Activated carbon.

INTRODUCTION

The Ministry of Petroleum, Energy, and Renewable Energy Development in Côte d'Ivoire has set ambitious goals to position the country as a leading energy market in West Africa by 2030. With a population exceeding 26 million, Côte d'Ivoire aims to reduce its greenhouse gas emissions by 28% by 2030 by integrating more renewable energy sources into its energy portfolio[1,2]. As part of this initiative, the country targets sourcing 42% of its energy from renewable sources by 2030. In line with these objectives, various initiatives have been launched to implement projects focused on biogas production from organic waste[3-6].

Biogas, a promising renewable energy source, is typically produced through the anaerobic fermentation of organic materials such as agricultural waste, food residues, and sewage sludge[3-6]. However, despite its environmental and economic benefits, biogas can pose challenges related to corrosion due to the presence of hydrogen sulfide (H_2S), a corrosive gas that can induce corrosion phenomena upon condensation[7,8]. When H_2S dissolves in water, it renders the condensate acidic, accelerating the corrosion of metallic materials in contact with biogas or its condensate, such as pipes and storage equipment[7,8].

To address these challenges and ensure the longevity of biogas production infrastructure, it is crucial to implement protective measures. Strategies such as using corrosion-resistant coatings, regular equipment monitoring, and controlling H_2S content in biogas can help mitigate corrosion's adverse effects[9]. Additionally, further research into the specific corrosion mechanisms associated with biogas is needed to develop more effective protection solutions[9-11].

Biogas comprises methane (CH_4), carbon dioxide (CO_2), and trace elements such as water (H_2O) and hydrogen sulfide (H_2S). H_2S is highly odorous, toxic, and corrosive, making it a significant concern for biogas processing facilities[7]. The pH level of biogas is influenced by various factors within the installation infrastructure, including low points where condensation accumulates, water stagnation, and H_2S concentration[9-17]. These factors contribute to corrosion of steel, copper, and aluminum equipment, highlighting the importance of corrosion management in industrial processes[11-20].

As energy prices continue to rise, the demand for cost-effective design solutions for biogas production is increasing. Aluminum and copper are preferred choices for use in biogas plants due to their advantageous properties[16]. Furthermore, there have been no studies specifically examining the use of activated carbon derived from cashew branches for biogas purification, nor has there been an assessment of the effectiveness of this filtration method in protecting aluminum and copper metals from biogas-induced corrosion. Therefore, our research aims to fill this gap by exploring these innovative and crucial aspects for the field of biogas production and corrosion management. The objective of our study is to assess the corrosive effect of biogas purified by activated carbon from cashew branches on aluminum and copper metals. Specifically, we aim to study the corrosion rate of copper and aluminum in filtered and unfiltered biogas and evaluate the protective effect of filtration on activated carbon on copper and aluminum metals.

In the context of research on green inhibitors, this work presents several innovative and significant elements. Firstly, it specifically focuses on the use of activated carbon derived from cashew branches as a filtration material to purify biogas. This approach represents a new method to reduce the corrosiveness of biogas, which could have a significant impact on the sustainability of biogas production installations. Additionally, this study aims to evaluate the effectiveness of activated carbon filtration in protecting aluminum and copper metals against biogas-induced corrosion. By highlighting the potential benefits of this protection method, this research helps address a gap in the literature on green inhibitors and provides promising prospects for the future of biogas production.

MATERIAL AND METHODS

Material

Before being transported to the experimental biogas site, the copper and aluminum samples underwent pre-treatment, which involved drying them in an oven at 40°C for 5 minutes. The Fig. 1 illustrates the copper and aluminum specimens.

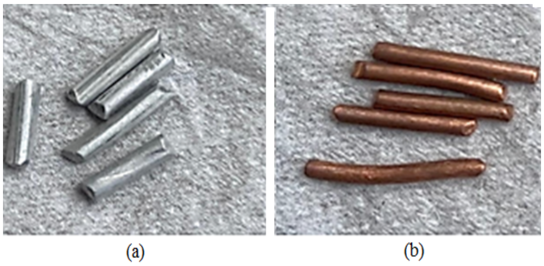

Fig. 1. Aluminum (a) and copper (b) samples

The masses of the copper and aluminum samples were measured using the balance (see Figure 2 below).

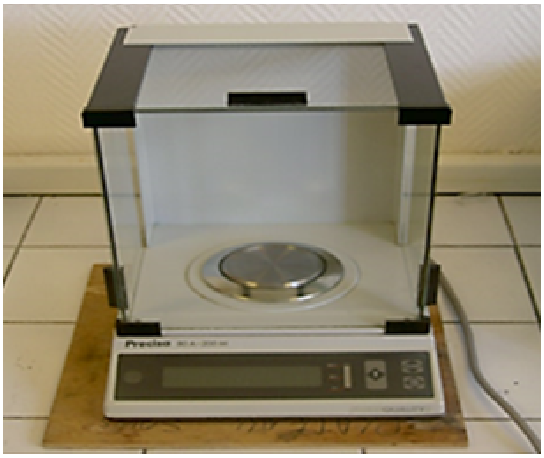

Fig. 2. OHAUS precision balance

Gravimetric analysis

Method

The gravimetric method was utilized to evaluate the corrosion of aluminum (Al) and copper (Cu) metals exposed to both raw and filtered biogas. This method revolves around calculating the corrosion rate by immersing the sample surface (S) into the corrosive environment for a specified duration (t) after initial weighing. Subsequently, after cleaning, the sample is re-weighed to ascertain the mass loss (Δm). Δm represents the loss of mass (in grams), calculated as the difference between the initial sample mass (m_0) and the final sample mass (m_1)[11].

EXPERIMENTAL

The aluminum (Al) and copper (Cu) metal samples were placed in contact with biogas in an air chamber after their initial weighing (m_1). After exposure durations of 5, 24, 48, and 72 h, the samples were removed. They were then washed with distilled water and cleaned with a brush before being dried in an oven. Subsequently, the samples were re-weighed to determine their new mass (m_2)[11].

Fig. 3. The chambers filled with biogas and samples

Corrosion rate

The corrosion rate value is determined as the average of three tests conducted under consistent conditions. Various samples of each metal, with different masses, were exposed to biogas in an air chamber for durations of 5, 24, 48, and 72 hours. The average corrosion rate of samples of each metal (W) was assessed by measuring the mass loss[11].

$$W = \frac{\Delta m}{S.t}\,[mg.cm^{-2}\,h^{-1}]$$

Where:
Δm: denotes the mass loss (in grams);
S: represents the total surface area of the sample (in square centimeters);
t: signifies the immersion time (in hours)[11].

Activated Carbon Synthesis and Biogas Filtration

Activated Carbon Synthesis

Pre-treatment: Cashew tree branches, chosen as precursors for activated carbon production, were sun-dried to sufficient dryness, then crushed to obtain diameters ranging from 800 μm to 3 mm.

Chemical Impregnation: The crushed material was chemically activated using a 500 ppm potassium hydroxide (KOH) solution prepared with distilled water. The impregnation ratio was set at 0.3 $g.mL^{-1}$. This impregnation, carried out for 12 h at room temperature in tightly closed jars and stirred for thorough homogenization, optimized the process.

Carbonization: After the 12 h impregnation period, the material was filtered, then dried at 105°C for 24 h to remove interstitial and surface water content. Once dried, the material was carbonized for 3 h at a temperature of 500°C in a SNOL furnace, under a limited oxygen atmosphere. This phase was crucial for creating pores in the material, thus enhancing its efficiency.

Biogas Filtration

For biogas filtration, a cylindrical filter made of polyvinyl chloride, 0.25 m in height and 50 cm in diameter, was used. It contained a volume of 0.1 m^3 of activated carbon derived from cashew tree branches. Filtration was conducted at room temperature (approximately 25-30°C), a temperature often recommended for this process.

RESULTS AND DISCUSSION

Evaluation of the mass loss of the metals Al and Cu in relation to time

Figures 4 and 5 demonstrate the changes in mass loss relative to the initial mass of aluminum (Al) and copper (Cu) samples over time in both unfiltered and filtered biogas environments, respectively. Upon examination, it's evident that both metals experience increased mass loss with prolonged exposure (72 h) to direct contact with unfiltered biogas. Similarly, there is a noticeable upward trend in mass loss with longer exposure time for filtered biogas as well. This heightened propensity for mass loss in both scenarios may be attributed to aluminum's susceptibility to corrosion induced by hydrogen sulfide (H_2S) present in the biogas[9]. The concentrations of H_2S are 92 ppm and 7.5 ppm for unfiltered and filtered biogas, respectively. A comparison of aluminum and copper mass loss over time in unfiltered and filtered biogas suggests that both metals are highly sensitive to mass loss, particularly when directly exposed to unfiltered biogas. In unfiltered biogas, materials are exposed to elevated H_2S levels (92 ppm) and high humidity content, potentially accelerating the corrosion process and resulting in significant mass loss[9-16]. The observed reduction in corrosion rate upon contact with filtered biogas could be attributed not only to lower H_2S levels (7.5 ppm) and reduced humidity resulting from water molecule adsorption by activated carbon during filtration but also to the formation of a protective layer preventing corrosion progression[11-13].

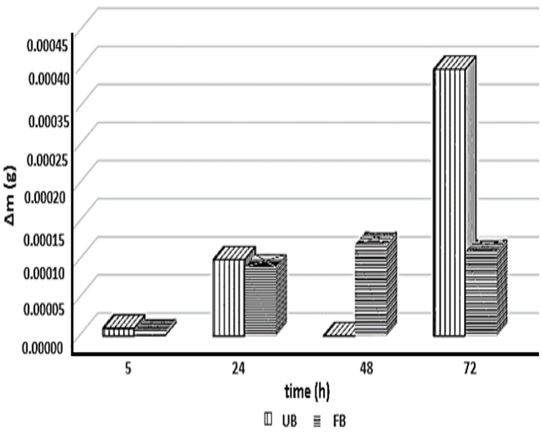

Fig. 4. Variation in aluminum mass loss over time in both unfiltered biogas (UB) and filtered biogas (FB)

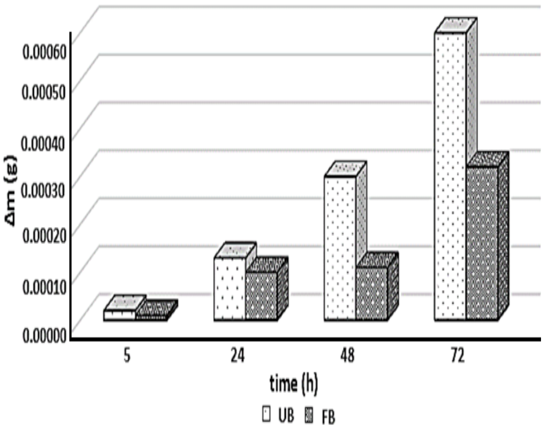

Fig. 5. Variation in copper mass loss over time in both unfiltered biogas (UB) and (FB)

Corrosion rate of aluminum and copper in biogas in relation to time

Figures 6 and 7 depict the calculated corrosion rates of aluminum and copper exposed to unfiltered and filtered biogas, respectively, over time.

In unfiltered biogas (UB), a noticeable increase in the corrosion rate of the metals occurred with prolonged contact time. Conversely, in filtered biogas (FB), the opposite trend was observed, indicating a decrease in the corrosion rate over time. The rise in the corrosion rate of metals exposed to unfiltered biogas could be explained by the continuous loss of metal elements and subsequent structural deterioration due to the acidic environment prevalent in unfiltered biogas, attributed to its high concentrations of hydrogen sulfide and moisture content[15,16].

The decline in the corrosion rate of

aluminum exposed to filtered biogas reflects minimal mass loss of the element. This reduced mass loss is attributed to the protective effect induced by activated carbon derived from cashew branches. The high levels of hydrogen sulfide and water, known to accelerate corrosion rates[9-16], were mitigated in filtered biogas through the adsorption of these molecules by activated carbon during filtration. This loss of mass significantly impacts the hardness of the metal's crystalline surface[9-11].

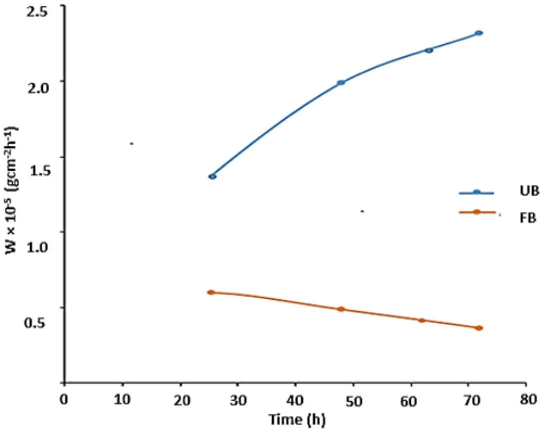

Fig. 6. Variation of the corrosion rate for aluminum

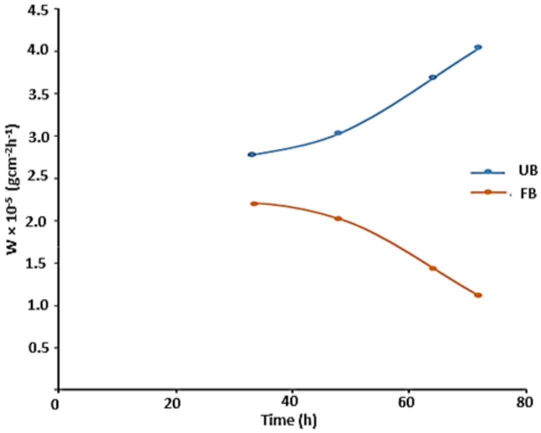

Fig. 7. Variation of the corrosion rate for copper

Comparative study of the corrosion rate of aluminum and copper in biogas

Figure 8 compares the corrosion rates of aluminum and copper in unfiltered biogas. The results show a gradual increase in corrosion rate over the duration of exposure to unfiltered biogas for both metals. Interestingly, this increase was more prominent for copper, indicating that the surface protected by the inhibiting copper complex (Cu-inh) provides less insulation against hydrogen sulfide compared to aluminum, which demonstrates superior protection[11].

Figure 9 illustrates the comparison of corrosion rates of aluminum and copper in filtered biogas. As shown, the corrosion rate for both metals initially decreases before stabilizing. These findings can be attributed to the protective effect induced by activated carbon on metal corrosion when exposed to filtered biogas. The slight difference observed in the corrosion rates of the two metals is believed to originate from variances in their crystalline structures[11].

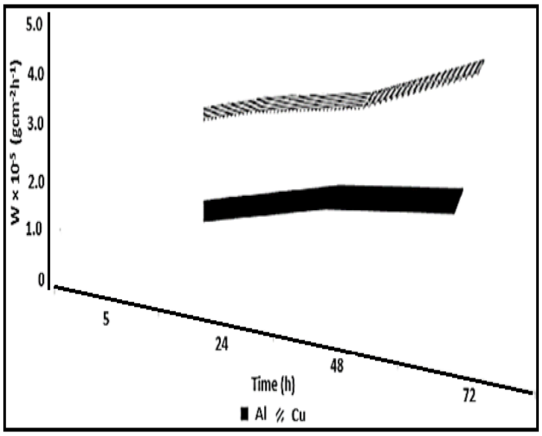

Fig. 8. Comparison of aluminum and copper corrosion rates in unfiltered biogas in this study

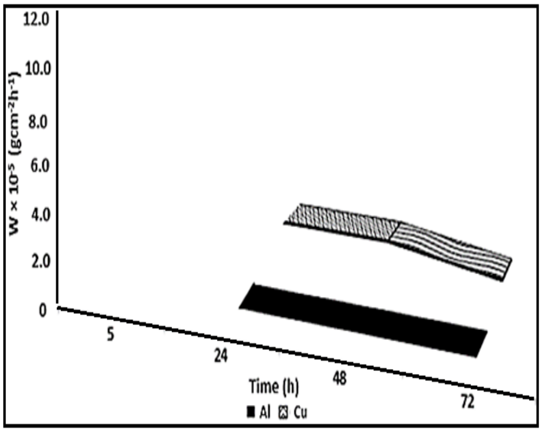

Fig. 9. Comparison of aluminum and copper corrosion rates in filtered biogas in this study

Analysis of the protective power induced (PPI)

The concept of Protective Power Induced (PPI) through biogas filtration with activated carbon derived from cashew branches assesses the long-term effectiveness of this filtration process in preserving the integrity of metals exposed to filtered biogas[11]. It evaluates the filtration system's ability to shield metals from the adverse effects of biogas over time, ensuring their prolonged durability and resistance to corrosion or other forms of damage[11].

Figure 10 illustrates the evolution of the protective capability induced by biogas filtration for aluminum metal. The analysis shows a gradual increase in protective capability over time, from 40% to 79.05%. This suggests the formation of a dense protective layer on the aluminum surface, providing enhanced protection against corrosive elements present in the biogas[11].

Similarly, Fig. 11 depicts the evolution of the protective capability induced by filtration for copper metal, which also increases over time, ranging from 45% to 72.5%. This indicates the effectiveness of biogas filtration with activated carbon derived from cashew branches in safeguarding copper against corrosion, thereby prolonging its durability and performance in biogas environments[11].

Figure 12 compares the protective capabilities induced by biogas filtration for aluminum and copper metals. The analysis reveals that aluminum exhibits higher protective power than copper, attributed to differences in their crystalline structures[11]. While aluminum forms a more effective barrier against corrosion in filtered biogas, copper also benefits from the filtration process, albeit to a lesser extent. Understanding these differences allows industries to make informed decisions regarding material selection for biogas-related applications, ensuring optimal performance and longevity in corrosive environments[9,11].

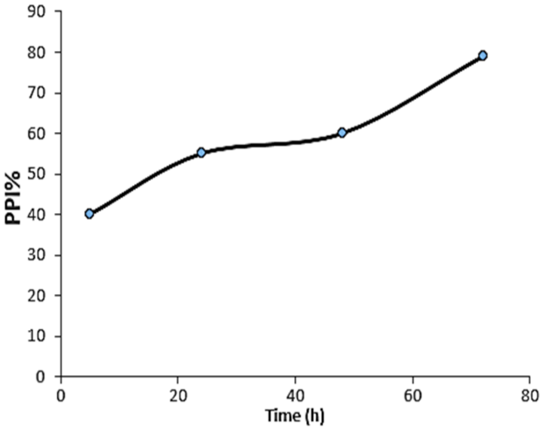

Fig. 10. Progression of the protective power induced in filtered biogas (aluminum case)

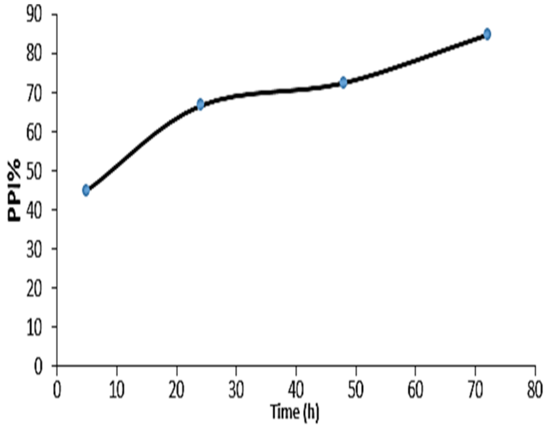

Fig. 11. Progression of the protective power induced in filtered biogas (copper case)

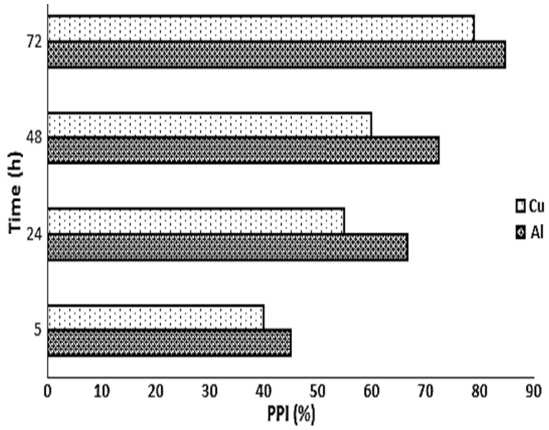

Fig. 12. Comparison of aluminum and copper corrosion rates in filtered biogas in this study

CONCLUSION

This research investigated the corrosive impact of biogas on copper and aluminum metals. The decline in corrosion rate observed over time in filtered biogas for both metals is attributed to the induced protective power of our activated carbon, effectively shielding a significant portion of the metals from the harsh environment.

The induced protective power values for aluminum and copper in filtered biogas are 79.5% and 72.5%, respectively. Consequently, aluminum demonstrates superior resistance to corrosion compared to copper in filtered biogas, highlighting the effectiveness of the studied activated carbon in corrosion protection.

These findings offer valuable insights for utilizing aluminum and copper in biogas-fueled setups. Given aluminum's heightened corrosion resistance in filtered biogas, prioritizing its use in critical components exposed to corrosive conditions may be advantageous. Moreover, the observed induced protective power values for activated carbon suggest its efficacy in corrosion mitigation. Therefore, employing activated carbon filters could be recommended to extend the longevity of metallic equipment in biogas installations. Additionally, ongoing assessment of the corrosion rate of copper and aluminum metals can aid in adjusting the minimum required thickness of these materials, ensuring enhanced durability and improved efficiency of boilers and steam generators fueled by biogas.

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Conflict of Interest

The authors declare no conflict of interest.

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