Biogas Purification Technology Applied in Power Generation System: Use of Activated Carbon Impregnated with Iron Oxide Applied in Power Generation System

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ABSTRACT

This study developed and evaluated a biogas purification method using activated carbon impregnated with iron oxide (III). The biogas was studied before and after passing through the filter, focusing on the removal of ammonia and hydrogen sulfide, two highly corrosive compounds that affect engine performance and public health. The results indicated the effectiveness of the filter in eliminating these contaminants, which contributes to the safety and efficiency of the use of biogas as a renewable energy source. The main contributions of this work include the improvement in equipment durability and the reduction of toxic emissions, with potential for future optimizations and applicability in other industries that use polluting gases.

Keywords: Activated carbon; Biogas; Contaminant removal; Purification; Sustainability.

INTRODUCTION

The growing demand for alternative energy sources has encouraged the use of biogas as a sustainable solution for energy generation. Biogas is produced by the anaerobic decomposition of organic waste and has great energy potential. However, its composition contains contaminants, such as hydrogen sulfide (H_2S)

and ammonia (NH_3), which can cause corrosion in equipment, reduce combustion efficiency and release harmful emissions into the environment, such as nitrogen oxides (NO_X). Efficient removal of these contaminants is essential to ensure the viability of biogas as a clean energy source [1].

The efficiency of a biogas filter depends directly on its composition and the characteristics of the material used. Activated carbon filters impregnated with iron (III) oxide are effective in removing contaminants, such as H_2S, but over time, the adsorption sites saturate, reducing efficiency. The filter saturation time is influenced by the concentration of contaminants and the biogas flow. Iron (III) oxide acts as an oxidizing agent in biogas purification, reacting chemically with hydrogen sulfide (H_2S). In this reaction, H_2S is oxidized, forming solid sulfur compounds (such as elemental sulfur or iron sulfides), which are retained in the filter. Impregnation of activated carbon with iron (III) oxide extends the life of the filter, allowing it to adsorb larger amounts of H_2S before saturation [2,3]. In this context, this work aims to develop and evaluate the effectiveness of a biogas purification method using activated carbon impregnated with iron (III) oxide, aiming to improve the quality of biogas and reduce the negative impacts of its use.

MATERIALS AND METHODS

ANALYSIS

The gas detector used is the Instrutherm brand, model DG-550. This model was chosen to check for the presence of carbon sulfide, carbon monoxide, and ammonia, as the results allow us to evaluate the efficiency of the filter used for desulfurization of biogas, as well as the engine performance. The analysis is performed using six sensors that can detect up to seven gases simultaneously, using oxidation-reduction detectors.

PROTOTYPE OF ACTIVATED CARBON FILTER IMPREGNATED WITH IRON OXIDE III (AC-Fe_2O_3)

Activated carbon was chosen for its large surface area and porous structure, which makes it effective in adsorbing biogas impurities such as organic compounds and H_2S. In addition to being widely available and low cost, its impregnation with iron (III) oxide significantly increases the H_2S removal capacity by chemical redox reaction and anchoring of sulfur bacteria, improving filtration efficiency. The filter size was estimated taking into account the biogas flow rate and the H_2S concentration presented in its characterization [4]. The activated carbon used in the manufacture of the filter alone retains up to 20 mg of H_2S per gram of carbon; however, in the case of this prototype, activated carbon impregnated with 8% iron oxide will be used; this filter adsorbs 150 mg of H_2S per gram of activated carbon. To estimate the required amount of filter medium, the product of the biogas flow and the H_2S concentration is calculated, according to Equation (1).

$$Weight\ of\ filter\ media\ used\ per\ day\ =\ [((Bf \times [H_2S]) \div 150)\ \times\ 600 \quad \text{Eq. (1)}$$

Bf= Biogas flow (L/min)
$[H_2S]$= H_2S Concentration (mg/L)

With an estimated biogas flow of 45 L/min and a concentration of 5 ppmV (equivalent to 225 mg H_2S per minute), approximately 1.5 g of AC-Fe_2O_3 is required to adsorb the H_2S contaminant per minute of engine operation. Assuming that the engine runs for 10 hours per day, this results in a consumption of 900 g of AC-Fe_2O_3 per day. This design allows us to estimate the amount of energy required over time and plan filter replacement or maintenance, ensuring effective H_2S removal and system protection. On May 10, 2024, carbon was mixed with iron oxide (III) in the test environment, at a ratio of 8% by weight of iron oxide. The solids, activated carbon and iron oxide (III), were dry mixed in a rotary mixer for 45 min, ensuring complete homogenization. The dispersion of iron oxide (III) was visually confirmed by the uniform reddish coloration of the carbon. The porous structure of activated carbon facilitated the impregnation of iron oxide (III) without the need for solvents, due to interaction between the particles [5].

Considering the data used for the calculations, the filter produced shown in Fig. 1, with 200 kg of activated carbon impregnated with iron oxide (III), should take 222 days to saturate. This estimate may vary, increasing or decreasing the saturation time, depending on the composition of the biogas and the concentration of contaminants. The biogas used in the tests was produced from a CSTR (Continuous Stirred Tank Reactor) biodigester, which uses organic matter from vegetable and fruit waste, predominantly citrus, as a substrate. The bioprocess generated biogas with a high concentration of hydrogen and contaminants, which may indicate that the acidogenesis phase is occurring simultaneously with methanogenesis, or that there are specific conditions in the digester that favor the production of H_2 [6].

Figure 1. Biogas filter installed at test environment.

RESULTS AND DISCUSSION

On August 23, 2024, field tests revealed extremely high concentrations of ammonia (NH_3) and hydrogen sulfide (H_2S) in the analyzed biogas, with both compounds exceeding the detection limits of the equipment used (> 150 ppmV). These contaminants, nitrogen and sulfur compounds, are products of anaerobic digestion of the organic matter. After the biogas passing through the activated carbon filter impregnated with iron (III) oxide, measurements performed by the gas analyzer indicated concentrations of H_2S and NH_3 below the detection limit of 1 ppmV, accuracy limit of the equipment, after four measurements each 30 min during 3h. Based on these data, it is estimated that the filtration system achieved a removal of greater than 99.3% for both contaminants, demonstrating significant efficiency in the desulfurization and purification of biogas in the initial filtration conditions.

CONCLUSION

The biogas purification, using activated carbon impregnated with iron oxide (III), proved to be highly efficient in removing ammonia and hydrogen sulfide, two critical contaminants. The application of this filtration system not only improves the quality of the biogas, increasing the durability and performance of the equipment, but also significantly reduces the health risks associated with toxic emissions. The purified biogas can be used in a safer and more sustainable way in energy generation systems, promoting a transition to renewable sources. Future research can explore the optimization of the filter material and the reuse of captured residues, in addition to expanding the application of this technology to other industrial sectors that deal with polluting gases.

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