Co-gasification of E-waste with Sewage Sludge for Hydrogen Production

Sameer Khan, Haider Khan, and Isam Janajreh*

Department of Mechanical Engineering, Khalifa University of Science and Technology, Abu Dhabi, United Arab Emirates

*Corresponding author. Tel: +971-2-312-3286; Email: Isam.Janajreh@ku.ac.ae

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1. Introduction

The circular economy, endorsed by the European Union (EU), focuses on recycling, reusing, and waste reduction to lessen environmental impact and enhance sustainability (Yang et al., 2023). This approach is crucial for managing electronic waste (E-waste) and Waste Electrical and Electronic Equipment (WEEE), which are challenging due to their mix of metals, plastics, glass, ceramics, and toxic chemicals such as flame retardants and polychlorinated biphenyls (Ghulam and Abushammala, 2023). E-waste's non-biodegradability and the toxic emissions from incineration (Ankit et al., 2021) further complicate disposal. This study suggests co-gasifying printed circuit board (PCB), a type of E-waste, and sewage sludge, leveraging entrained flow gasifier technology (near 1,000°C and high pressure near 30 bars) for E-waste management. This novel approach, particularly using regionally abundant sewage sludge in the UAE, aligns with circular economy principles by promoting waste-to-energy conversion (Abd-Elaty et al., 2007), addressing the literature gap in PCB and sewage sludge gasification.

2. Methodology

2.1. Material Characterization

The PCB, featuring brominated epoxy resin on glass fiber support with a copper circuit, had its metal content removed and was then processed into powder form (140-180 µm mesh size) for Thermogravimetric analysis (TGA) (see Fig. 1). Sewage sludge, a wastewater treatment byproduct containing organic and inorganic matter, was mixed with the PCB powder in various ratios (e.g., 25% sludge to 75% PCB) for proximate analysis. The TGA measurements, using Thermo-scientific STA TA (model- Q600, USA) were conducted out at room temperature with air flowing at a 100 ml/min flow rate, comparable to (Shabbar and Janajreh, 2013). Elemental compositions and calorific values of the samples were determined using a Thermoscientific flash CHNS-O (model 2000, USA) analyzer and a Parr bomb calorimeter (model 6100, USA), respectively.

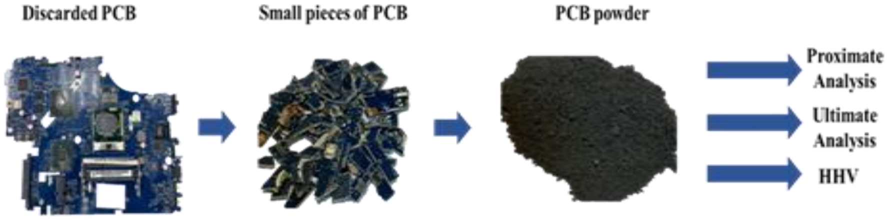

Fig 1: Steps taken to process the E-waste used in this study

2.2. Gasification Equilibrium Modelling

After conducting proximate, ultimate, and calorific analyses on feedstocks, a gasification equilibrium model is established, incorporating stoichiometric and non-stoichiometric methods to handle 12 to over 40 species. This model optimizes gasifier parameters and aims for minimal Gibbs energy, crucial for achieving high gasification efficiencies (98% to 99.5%) in an entrained flow gasifier. The model, which calculates gasification products (mole fractions) and cold gas efficiency (CGE) for PCB, sewage sludge, and their combinations, utilizes temperature sweeps from 750 K to 1,550 K and pressures of 30 bar to optimize yield. CGE is determined by the energy content of syngas components relative to the feedstock's energy input, providing insights into the gasifier's performance.

3. Results and Discussion

3.1. Material Characterization

Fig. 2 shows the TGA curve for PCB, sewage sludge and their mixture combinations. Table 1 lists the proximate, ultimate, and calorific analyses values for PCB, sewage sludge and mixtures.

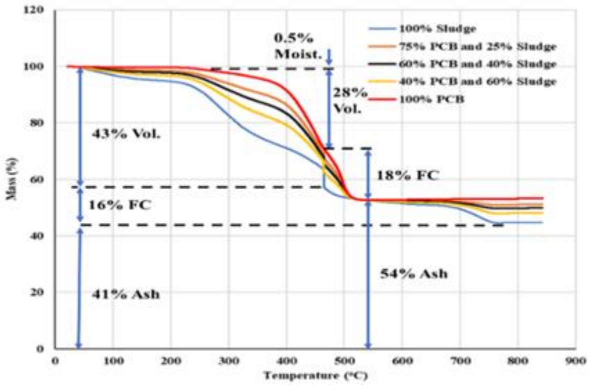

Fig 2: TGA curve for the sewage sludge, PCB, and their mixtures

Table 1: Proximate, ultimate, and calorific analyses values of PCB and sewage sludge

Species	**PCB** $CH_{1.2690}N_{0.0448}S_{0.0064}O_{0.1078}$	**Sewage sludge** $CH_{1.5229}N_{0.1181}S_{0.0143}O_{0.3086}$
Proximate analysis	**Mean**	**Mean**
Moisture (Wt%)	0.5 ± 0.01	0
Volatile (Wt%)	28 ± 0.01	43 ± 0.01
Fixed Carbon (Wt%)	18 ± 0.01	16 ± 0.01
Ash (Wt%)	54 ± 0.01	41 ± 0.05
Ultimate analysis	**Mean**	**Mean**
C (Wt%)	33.81 ± 0.01	34.79 ± 0.01
O (Wt%)	11.17 ± 0.01	14.32 ± 0.01
H (Wt%)	3.58 ± 0.01	4.42 ± 0.01
N (Wt%)	1.77 ± 0.01	4.80 ± 0.01
S (Wt%)	0.64 ± 0.01	1.33 ± 0.01
HHV (MJ/kg)	18.20 ± 0.2	12.75 ± 0.2

3.2. Gasification Equilibrium Modelling

Fig. 3 illustrates gasification yield and CGE for PCB and sewage sludge mixtures with increasing gasifier temperature at a constant 30 bars pressure. It can be observed that lower temperatures hinder full gasification, reducing CO and H_2. Raising the gasifier temperature externally or through enhanced feedstock combustion improves syngas production and CGE. The peak/optimal CGEs for PCB 40%, PCB 60%, and PCB 75%, are determined to be 47.98%, 50.78%, and 52.36%, at 1200°C, 1250°C, and 1250°C respectively, with 0.4294, 0.4244, and 0.4184 moles of hydrogen produced in the resulting syngas.

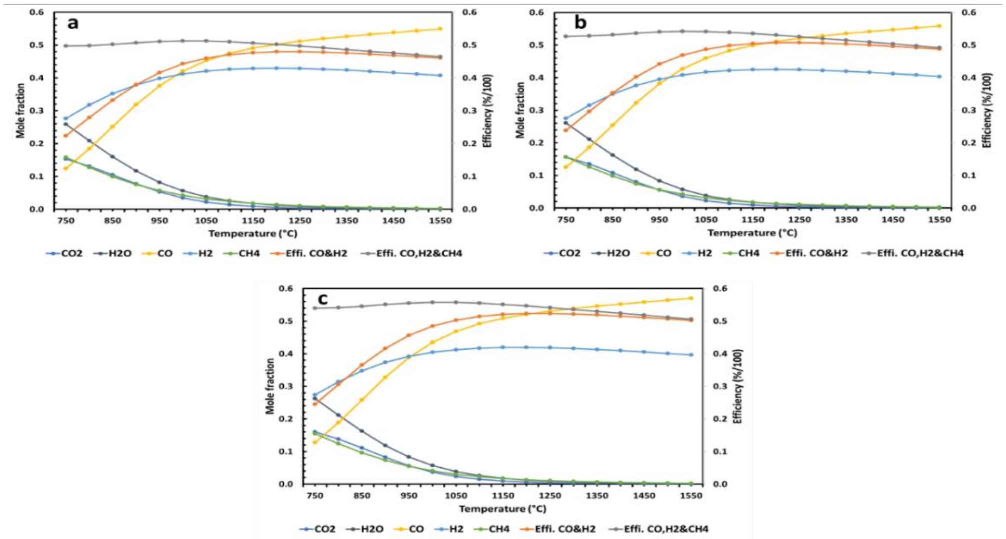

Fig. 3- Temperature influence on gasification products and CGE for (a) PCB 40% ; (b) PCB 60%; (c) PCB 75%

Conclusion

In conclusion, the growing E-waste issue, especially in high-generation areas like the UAE, necessitates efficient treatment methods due to its non-biodegradability and hazards. This study proposes thermochemical recovery through co-gasification of PCBs with sewage sludge as an effective solution. Material characterization reveal the complex interaction between PCB and sewage sludge properties. Equilibrium modeling suggests a 40% PCB to 60% sewage sludge blend is most feasible for hydrogen production. Future work includes high fidelity modeling to validate these findings. This research not only addresses E-waste challenges but also offers a method for hydrogen production, supporting global sustainable waste management and environmental goals.

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