Turning Plastic Waste into Power: Pyrolysis for Sustainable Industrial Energy

Koumpakis D-A[1,*], Vlachokostas C.[1], Michailidou A.V.[1], Savva C.[1]

[1] Department of Mechanical Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

*corresponding author:
e-mail: amicha@meng.auth.gr

Abstract The research describes the creation of a basic pyrolysis system which industrial facilities can use to generate energy from their plastic waste. The system transforms 360 tons of plastic waste yearly into 160 tons of synthetic pyrolysis oil which powers a Combined Heat and Power (CHP) system. The annual production of this process reaches 500 MWh of electricity together with 60 MWh of heat. The transformation of waste into energy relies heavily on pyrolysis which functions as a thermochemical process that converts plastic waste into refined pyrolytic oil ready to use in diesel generators. The research describes an economic investment approach of a unit which works for Small and Medium-sized Enterprises (SMEs) with potential annual revenue of up to €45,000 yearly through net metering. The system operates as a self-sustained waste-to-energy system which promotes circular economy principles through material recycling into energy products. The study proves that industrial pyrolysis-based CHP systems are both environmentally sound and economically viable, which leads to energy sustainability and resource management.

Keywords: Pyrolysis, Energy Autonomy, Plastic Waste, Combined Heat and Power, Circular Economy

1. Introduction

The fast plastic production growth together with its rising consumption has caused severe environmental damage because of accumulating plastic waste at alarming rates. Most plastic debris that enter aquatic systems lead to severe water contamination as well as destroy biodiversity while blocking water infrastructure (Tibbetts, 2015).Microplastics represent the most enduring form of pollution since they can measure less than 5mm in diameter and thus enter marine food webs to disrupt ecological systems. The forecast shows that plastic pollution will increase threefold by 2040 annually and global plastic waste will exceed few billion tons by 2050 unless urgent action is taken (Haque and Fan, 2023).

The widespread practice of recycling mixed plastics faces economic challenges caused by the substantial resources process demands and energy which can create additional environmental issues. The thermochemical conversion method of pyrolysis serves as an efficient alternative to recycling for hydrocarbon-rich waste that cannot be recycled or lacs access to recycling infrastructure. This process is able to transform waste into useful fuel products and secondary materials. Pyrolysis has become more popular nowadays because it functions well in decentralized settings while it can handle various plastic waste without significant initial treatment needs(Yaqoob et al., 2024).

The operational parameters of pyrolysis systems remain moderate while their system configurations stay basic which makes them suitable for implementation in small to medium-sized enterprises (SMEs) (Cudjoe et al., 2023). The development of pyrolysis units as complementary side-industries can improve their scalability while reducing costs and environmental impact. Thus, it positions as a suitable solution for independent energy production and sustainable waste disposal.

This conceptual techno-economical analysis presents a decentralized pyrolysis-CHP (Combined Heat and Power) system engineered for small and medium-sized enterprises. The system processes 360 tons of plastic waste per year to generate 160 tons of synthetic pyrolysis oil which produces 500 MWh of electricity together with 60 MWh of thermal energy. The research provides operational and techno-economic inside of dimensioning and implication of such system showcasing its functionality potential at industrial facilities with significant plastic wastage.

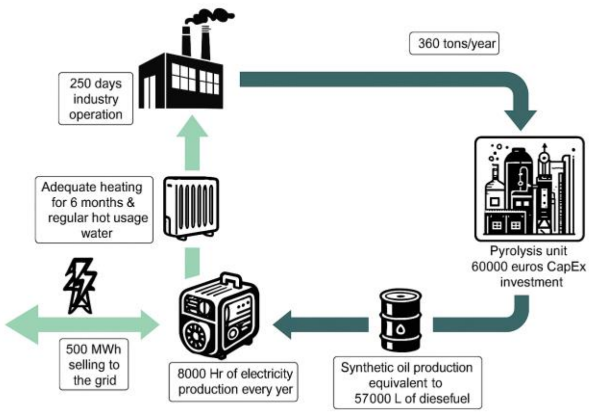

Figure 1. Proposed unit System Flow Diagram

2. Methodology

A multidisciplinary research design, evaluation and optimization of a decentralized pyrolysis-based system was developed that deals with plastic packaging waste generation. The methodology includes system design, material flow estimation, energy balance modeling, and a techno-economic assessment.

The system design was based on processing polyolefin-rich plastic waste and producing refined synthetic pyrolysis oil. Polyethylene (PE) and polypropylene (PP) were chosen as the main feedstock because of their high calorific values and good oil yields (Al-Salem et al., 2010)(Lopez, 2023).

The core unit consists of a continuous rotary pyrolysis reactor, operating at ~470°C in an oxygen-free environment, which thermochemically decomposes plastic into oil, gas, and char (Kabeyi and Olanrewaju, 2023). The oil produced is stored and refined for further use as fuel for a diesel generator. In addition to the electricity production, the generator's heat is recovered for onsite use through water circulators, improving total system efficiency.

Energy and mass balances were determined using stoichiometric equations, reactor specifications and literature conversion factors. A modular system architecture was adopted to facilitate scalability and integration into existing facilities.

A techno-economic assessment was conducted by using actual market prices for equipment and operations. Capital expenditure (CapEx) included shredders, reactors, pumps, heat exchangers, and generator set. Operational costs, including electricity consumption and plastic waste procurement, were evaluated alongside expected revenues from net metering at current mean of electricity prices.

The study also performed a sensitivity analysis to evaluate the effect of three key parameters (oil yield, plastic waste cost and electricity tariffs) on economic viability to determine the level of scalability and investment risk. The proposed system configuration was validated through benchmarking against existing small-scale waste-to-energy installations and refined based on best practices for decentralized energy production.

3. Conclusions

This research introduces an innovative method to handle plastic waste through industrial energy independence and environmental sustainability.

The system supports circular economy development by eliminating landfills while reducing emissions and recycling waste materials back into the energy system. The system features modular construction which enables seamless integration with current industrial facilities through minimal structural modifications and provides flexible expansion capabilities for growing waste amounts.

The decentralized pyrolysis-CHP system represents a functional answer to manage waste locally while producing energy from rich-hydrocarbon materials. The research adds to existing knowledge through its implementation-ready framework which unites industrial independence with environmental accountability. Future research needs to concentrate on deploying pilots at scale while developing a deeper understanding in policies that can enhance industrial sector adoption of such technologies.

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