The potential of microalgae biomass from urban wastewater treatment for biofuel production by pyrolysis: flash versus conventional processes in the EU FLEXBY project

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Introduction

Microalgae have emerged as a highly promising solution in the quest for sustainable energy sources, due to their rapid growth rates, high photosynthetic efficiency, and capacity to utilize wastewater as a nutrient-rich cultivation medium. By thriving in municipal wastewater, microalgae offer a dual benefit: they contribute to wastewater treatment while simultaneously producing biomass that can be converted into bio-oil and biochar, which serve as a renewable biofuel source and a fertilizer, respectively. Their ability to capture significant amounts of CO_2 during growth further enhances their environmental impact by helping to mitigate carbon emissions (Hait et al., 2024).

Pyrolysis, particularly flash pyrolysis, is a key process in the conversion of microalgal biomass into valuable bio-oil. This thermochemical process offers the rapid decomposition of biomass and efficient recovery of energy-rich products such as bio-oil, bio-char, and gases. Flash pyrolysis, with its faster heating rates and shorter residence times, offers advantages such as higher bio-oil yields and improved energy efficiency compared to conventional pyrolysis methods (Ślęzak et al., 2022). Pyrolysis method could also influence the composition and characteristics of the bio-oil, highlighting the importance of selecting the appropriate pyrolysis method depending on the desired fuel properties

This integrated system not only addresses the need for cleaner energy but also reduces the environmental burden of wastewater management, presenting a circular approach that links resource recovery with renewable energy production. Consequently, microalgae-based biofuels, produced through advanced pyrolysis techniques, hold significant potential to contribute to the transition towards a low-carbon, sustainable energy future.

Methodology

Microalgae were cultivated in municipal wastewater after secondary treatment. Following harvesting, the microalgal biomass was dried and prepared for pyrolysis.

Two pyrolysis methods were employed: conventional pyrolysis (CP) and flash pyrolysis (FP). For the conventional pyrolysis, a specially designed cylindrical electric furnace, operating horizontally, was used. The dried microalgae biomass was loaded into the furnace at ambient temperature, and nitrogen gas was flowed at a rate of 100 ml/min to create an inert atmosphere. The heating protocol involved a ramp rate of 25°C per minute, reaching a final pyrolysis temperature of 500°C. Once the temperature was achieved, the sample was maintained at 500°C for one hour to ensure complete conversion. In the case of flash pyrolysis, the furnace was preheated to the operating temperature of 500°C. The microalgae biomass was then fed into the furnace once this temperature was reached. Following pyrolysis, three different fractions were collected from both processes: bio-char, bio-oil, and gases. These fractions were subsequently quantified and analyzed.

Results

Flash pyrolysis resulted in a notable shift in product distribution, favoring the liquid fraction (bio-oil) over the gaseous fraction (**Fig. 1**). Conventional pyrolysis produced a bio-oil yield of 27% and a gas yield of 24%. In contrast, flash pyrolysis increased the bio-oil yield to 34% while reducing the gas yield to 18%. This shift can be attributed to the rapid heating rates and shorter residence times in flash pyrolysis, which minimize secondary cracking reactions and allow more volatiles to condense into liquid bio-oil rather than forming gas (Marques et al., 2024). Both conventional and flash pyrolysis yielded comparable amounts of biochar, with biochar yields remaining consistently at 49%, clearly driven by the ash content, which for this biomass usually varies between 20-30%.

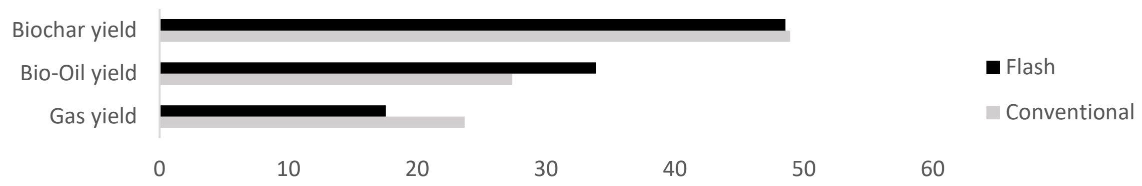

Fig. 1. Pyrolysis fractions yields (%)

Additionally, the biochar obtained could be of great interest due to its high mineral content (**Table 1**), including calcium (3.4%), phosphorus (1.34%), and magnesium (4.76%), making it suitable as a soil amendment or fertilizer. These minerals are essential for plant nutrition and can enhance soil fertility. Therefore, this material can provide the common benefits of biochar in soil, such as improving soil texture, water retention, increasing microbial activity, pollutant adsorption, and carbon fixation. Additionally, it can supply essential nutrients to plants, making this material particularly valuable (Marousek et al., 2024).

Table 1. Inorganic composition of microalgae cultivated in wastewater (%)

Mg	Ca	Si	P	Na	K	Al	Fe	Cl	S
4.8	3.4	1.4	1.3	0.7	0.4	0.2	0.1	0.1	0.1

Preliminary data also suggests that the composition and properties of the bio-oil obtained from flash pyrolysis differs from that produced through conventional pyrolysis. Further analysis is required to fully characterize these differences. These distinct characteristics could influence the potential applications of the bio-oil, making flash pyrolysis a promising technique for optimizing the quality and yield of biofuels from microalgal biomass.

Conclusions

The results of the pyrolysis experiments indicate that microalgae biomass cultivated in wastewater is a highly suitable feedstock for sustainable biofuels derived from bio-oil production. In particular, flash pyrolysis demonstrated a significant advantage by increasing the yield of bio-oil by 25%, making it a more efficient process for liquid fuel production. The consistent biochar yields (around 49%) in both pyrolysis methods highlight its potential as a source of solid carbon-rich materials, which have valuable applications in both agriculture and remediation. The high mineral content of the biochar makes it a valuable fertiliser, providing the common benefits of biochar in soil, as well as serving as a source of nutrients. This contributes to circular economy principles by integrating biofuel production with soil improvement and wastewater treatment.

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