Waste fishing nets thermal decomposition and valuable products recovery

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Introduction

Over recent decades, rapid global population growth has substantially increased the demand for energy, leading to the rapid depletion of non-renewable energy sources and mismatches in energy production. A significant portion (approximately 68%) of these energy sources is derived from fossil fuels, specifically natural gas and oil. Despite their widespread industrial use, this has caused significant global environmental issues, including deteriorating water quality and heightened emissions of greenhouse gases. Consequently, this has spurred scientists and fuel industries to explore alternative methods of energy extraction and diverse raw materials.

Presently, numerous scientific and industrial institutions have been engaged in research aimed at discovering and advancing cutting-edge technologies for energy recovery from waste. A substantial fraction of waste derived from biological or plastic materials exhibits high levels of hydrocarbons. These hydrocarbons can be converted into higher value-added energy products, thereby contributing to the establishment of a circular economy. However, the diversity of potential waste sources with significant energy potential necessitates comprehensive research to expand the selection of prospective feedstocks.

Among potential feedstocks for pyrolysis processes are fishing nets. Material screening has revealed that marine plastic waste are pivotal sources of water pollution, significantly disrupting marine ecosystems. The substantial volume of floating plastic waste is linked to fishing activities, resulting in the annual loss or disposal of over 600,000 tons of fishing gear in oceans and water bodies. Furthermore, this plastic impedes the movement of aquatic organisms, entangling and leading to their mortality in nets. Plastic waste and fishing nets are interconnected due to their joint contribution to environmental pollution and the composition of synthetic materials. Fishing nets constitute a subset of plastic waste distinctly associated with fishing tools discarded, lost, or abandoned in aquatic environments. These tools are typically fabricated from synthetic polymer blends such as nylon, polypropylene (PP), and polyethylene (PE).

This research delves into the examination of the pyrolysis process of waste fishing nets and the influence of catalyst interactions at different temperatures on the resultant outputs, contributing to circular economy initiatives.

Materials and methods

Micro-scale thermal decomposition experiments were conducted using a thermogravimetric analyzer (Netzsch Jupiter F3, Germany) coupled with a Fourier Transform Infrared (FTIR) spectrometer (Bruker Tensor 27, Germany) in a TG-FTIR configuration. All tests were performed under inert, oxygen-free nitrogen atmosphere, maintaining sample masses of 15–20 mg per batch and a nitrogen flow rate of 60 mL/min. Catalytic pyrolysis trials utilized by using self prepared catalysts (bio-char impregnated with Cu and Fe), applying catalyst-to-feedstock mass ratio of 1:1, under identical experimental conditions. The studied temperature range spanned from 40 to 850 °C. DTG curves were produced by differentiating the TGA profiles, allowing identification of the temperature zone corresponding to the highest rate of thermal decomposition for each sample.

The pyrolysis experiments using end-of-life fishing net samples were performed in a laboratory-scale batch pyrolysis system. Based on the previous experiments, the catalytical bio-char impregnated test was performed at 700 °C followed by a 20-minute isothermal residence period to evaluate thermal stability and secondary reaction influence. The heating rate was maintained at ~20 °C/min, aligned with previously published experimental conditions. Every pyrolysis test was carried out using a 100 g polymer feedstock mass per run. The reactor operated under an inert nitrogen atmosphere, supplied at 1.5 L/min, ensuring oxygen-free conditions for volatile generation.

The experimental unit comprised a main pyrolysis reactor connected to a downstream condensation module, with 2–3 mm vent apertures that allowed continuous discharge of evolved gas and condensable vapors while ensuring solid char retention inside the reactor chamber. Condensed liquid products were collected in a dedicated vessel at the reactor outlet, whereas the non-condensable gaseous fraction was directed through a gas handling line for cooling, purification, compositional analysis, and final collection. Gas purification was achieved by sequential passage through five scrubbing bottles containing isopropanol, enabling removal of condensable and polar impurities. The cleaned gas stream was monitored continuously using a VISIT 03H gas analyzer for real-time determination of gas composition and process trends.

Results

Thermal analysis at micro scale

Figure 1 presents the results of the TGA-DTG analysis used to evaluate the pyrolysis behavior of the selected feedstock. The fishing net material displayed an initial, low-intensity mass loss event near 200 °C, which

is linked to the release of inorganic residues, adsorbed seawater salts, and other non-polymeric contaminants. This stage may also overlap with the early volatilization of secondary polymer fractions present in smaller amounts, such as PP and PE. The dominant degradation step was observed at approximately 440 °C, corresponding to the depolymerization, chain scission, and thermal decomposition of nylon-6, driven by the cleavage of repeating amide linkages (-NH-CO-). At this temperature region, most long polymer chains break down, generating a multi-phase product stream that includes volatile liquids (e.g., paraffinic and aromatic hydrocarbons), permanent and light gases (H_2, CH_4), monomeric species, and a carbon-rich char fraction. Reported degradation limits for these polymers vary in the literature, typically falling between 400 °C and 460 °C, depending largely on the applied heating rate.

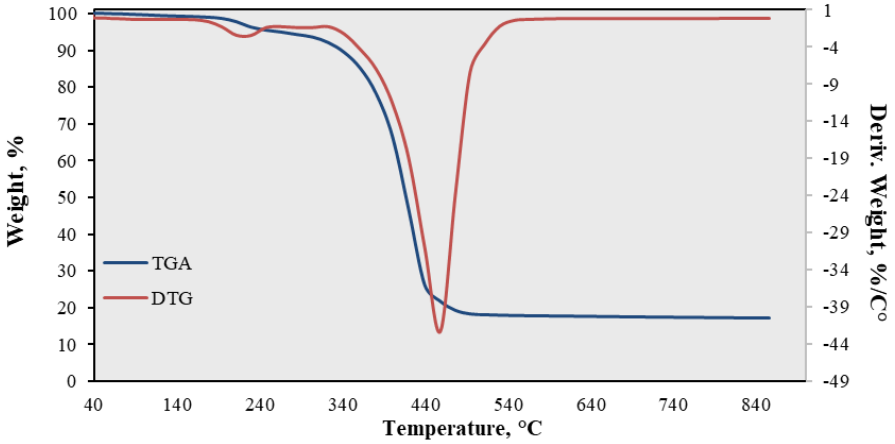

Fig. 1. Thermal decomposition of the Fishing nets

Pyrolysis products (liquid and gaseous) analysis

Gas and condensable liquid fractions from pyrolysis were analyzed using Agilent 7890 A gas chromatographs, configured with a TCD detector for permanent gases and GC/MS for liquid-phase chemical identification. The principal gas species detected in the non-condensable pyrolysis stream included CO, CO_2, CH_4, and H_2. Characterization of the condensed liquid fraction indicated a significant concentration of polycyclic aromatic compound derivatives. Evaluation of catalyst-assisted pyrolysis demonstrated positive industrially relevant trends, most notably a shift toward lighter aromatic hydrocarbons, reflecting an increased generation of low-molecular-weight aromatics. The experimental results suggest that the pyrolysis products possess strong potential for upgrading into energy-dense liquid hydrocarbons, including applications as drop-in transportation fuel components suitable for mobility and fuel blending systems.

Conclusions

This investigation shows the thermal decomposition of fishing nets and their main degradation peaks. As it was studied, the dominant degradation step was observed at approximately 440 °C, corresponding to the depolymerization, chain scission, and thermal decomposition of nylon-6, driven by the cleavage of repeating amide linkages (-NH-CO-). Initial assessment of the starting material involved TGA-DTG analysis showed that an 88 wt.% mass loss attributed to the thermal degradation of the primary polymer, Nylon-6.

Additional findings from this work will be detailed in the upcoming conference presentation. This study demonstrates the potential of waste fishing nets as a viable feedstock for pyrolysis-based energy recovery. The significant extraction of caprolactam further supports the opportunity to recover high-value chemical products, while also enabling its reintegration into Nylon-6 polymer synthesis. Overall, the results underline the material's promise as a secondary resource for both energy-rich product generation and monomer circularization, reinforcing its role in advancing circular economy strategies.

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