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MODERN AND RESOURCE-EFFICIENT APPROACHES TO PROCESSING ORGANIC SECONDARY RAW MATERIALS IN THE PRODUCTION OF SYNTHETIC FUELS

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Abstract. The article analyzes modern and resource-efficient approaches to processing organic secondary raw materials for the production of synthetic fuels. Organic secondary raw materials include agricultural residues, food waste, sewage sludge, wood-processing residues, livestock waste and the biodegradable fraction of municipal and industrial waste. These resources are traditionally treated as low-value waste, but under conditions of energy transition and circular economy they can become an important feedstock for producing syngas, bio-oil, biomethane, hydrogen, renewable methanol and synthetic liquid hydrocarbons.

Keywords: organic secondary raw materials, synthetic fuels, biomass, waste processing, pyrolysis, gasification.

INTRODUCTION

The production of synthetic fuels from organic secondary raw materials is becoming an important direction in modern energy, environmental and industrial policy. The growing demand for energy, the instability of fossil fuel markets, the accumulation of organic waste and the need to reduce greenhouse gas emissions require new technological approaches to waste utilization. Organic residues are no longer viewed only as a sanitation problem. They are increasingly interpreted as carbon-containing resources that can be transformed into fuels, chemicals and energy carriers. In this sense, the processing of organic secondary raw materials connects three strategic objectives: waste reduction, renewable energy development and industrial resource efficiency.

MATERIALS AND METHODS

A key modern approach is the transition from waste disposal to circular resource conversion. Traditional waste management often focuses on collection, transport, landfill disposal or simple incineration. Resource-efficient fuel production requires another logic: organic waste should be classified, pre-treated, converted and integrated into energy or industrial value chains. This approach reduces the loss of carbon resources and creates additional economic value. In circular economy terms, the objective is not merely to destroy waste, but to preserve its useful energy and material potential as far as possible.

Feedstock preparation is one of the most important stages of synthetic fuel production. Organic secondary raw materials are heterogeneous; they may contain water, soil, metals, plastics, stones or other contaminants. If these impurities are not removed, they can reduce reactor efficiency, increase ash formation, poison catalysts and complicate gas cleaning. Preparation may include sorting, drying, grinding, pelletizing, briquetting, torrefaction and homogenization. For gasification and pyrolysis, moisture reduction is especially important because excessive water content consumes energy and lowers thermal efficiency. For anaerobic digestion, however, high moisture may be acceptable, while the main requirement is biological degradability and stable microbial conditions.

RESULTS AND DISCUSSION

Pyrolysis is a modern thermochemical method for converting organic raw materials into bio-oil, gas and solid carbon-rich residue. It is carried out in the absence or near absence of oxygen. Fast pyrolysis is usually oriented toward the production of liquid bio-oil, while slow pyrolysis produces more biochar. Bridgwater's review of fast pyrolysis shows that bio-oil production depends strongly on reactor design, heating rate, temperature, vapour residence time and product upgrading [3]. This means that resource efficiency in pyrolysis cannot be achieved only by increasing temperature. It requires careful control of heat transfer, vapour cooling, secondary cracking and catalytic treatment of oxygen-rich compounds.

Bio-oil obtained through pyrolysis is not automatically equivalent to conventional liquid fuel. It contains water, oxygenated compounds and unstable fractions, which may cause corrosion, ageing and low heating value. Therefore, modern pyrolysis systems increasingly include upgrading technologies such as catalytic cracking, hydrodeoxygenation and emulsification with conventional fuels. Resource efficiency is improved when pyrolysis gas is recycled for process heating and biochar is used for soil improvement, carbon storage or activated carbon production. Such integrated use of all product streams reduces waste and increases total economic output.

Gasification is one of the most flexible routes for producing synthetic fuels from biomass and organic waste. In gasification, carbon-rich material reacts with a controlled amount of oxygen, air, steam or carbon dioxide to form synthesis gas, mainly composed of hydrogen, carbon monoxide, carbon dioxide, methane and light hydrocarbons. IEA Bioenergy Task 33 identifies gasification as a technically viable pathway for producing renewable fuels and chemicals, although wider commercial use still depends on investment, policy stability and successful first-of-a-kind plants [1].

The main advantage of gasification is that syngas can be converted into different products. It may be used for heat and power generation, hydrogen production, methanol synthesis or Fischer–Tropsch liquid fuels. However, gasification also requires strict control of feedstock quality, reactor conditions and gas cleaning. Tar formation is one of the main technological problems. Tar can condense, block pipelines, reduce efficiency and damage catalysts. Modern resource-efficient gasification therefore includes tar reforming, filtration, hot gas cleaning, catalytic conversion and heat recovery. The objective is to produce clean syngas with a composition suitable for downstream synthesis.

The conversion of syngas into renewable methanol is a particularly promising direction. Methanol can be used as a chemical feedstock, fuel component, hydrogen carrier and platform molecule for producing other chemicals. According to IRENA and the Methanol Institute, renewable methanol can be produced through bio-methanol routes based on biomass and waste, as well as e-methanol routes based on renewable hydrogen and captured carbon dioxide [2]. In waste-based methanol production, optimization requires stable syngas composition, effective CO_2 management, active catalysts and efficient product separation. The process becomes more resource-efficient when waste carbon is converted into a useful fuel instead of being emitted or landfilled.

Hydrogen production from organic secondary raw materials is another modern technological route. Biomass gasification followed by water-gas shift reaction and gas separation can produce hydrogen from renewable or waste-derived carbon sources. Spath and Mann’s NREL design study describes a biomass-to-hydrogen route that includes feed handling, drying, gasification, gas conditioning, shift conversion and hydrogen purification [4]. The importance of this route lies in its potential to connect waste processing with low-carbon hydrogen systems. However, its efficiency depends on gasifier performance, heat integration, gas cleaning, carbon management and scale of production.

Fischer–Tropsch synthesis is a more complex route that converts syngas into synthetic liquid hydrocarbons. These fuels may be used in transport, including sectors where direct electrification is difficult. The process requires syngas with an appropriate hydrogen-to-carbon monoxide ratio and very low levels of catalyst poisons. Hamelinck and Faaij analyzed biomass-based production of methanol and hydrogen and showed that technical and economic results depend on conversion concepts, process integration and future development of key components [5].

CONCLUSION

Modern and resource-efficient processing of organic secondary raw materials in synthetic fuel production is a complex technological and economic task. It includes feedstock classification, pre-treatment, thermochemical or biochemical conversion, gas cleaning, catalytic upgrading, energy integration, digital control and environmental assessment. Pyrolysis, gasification, anaerobic digestion, renewable methanol synthesis, hydrogen production and Fischer–Tropsch synthesis each have specific advantages and limitations. Their effectiveness depends on matching the technology with the feedstock and integrating the process into a broader circular economy system.

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