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RESEARCH ARTICLE

Coffee Processing By Products Valorization an Overview of Energy and Environmental Applications

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ABSTRACT:

This article examines the valorization of coffee processing by-products in energy and environmental applications. Coffee production generates significant waste, including pulp, husk, and wastewater, which poses environmental challenges if not managed properly. However, these by-products also present opportunities for sustainable utilization. Various methods such as anaerobic digestion, composting, and pyrolysis, have been explored to convert coffee waste into energy sources like biogas and biochar, as well as useful materials like compost. Additionally, using coffee by-products can mitigate environmental impacts by reducing greenhouse gas emissions and minimizing soil and water resource pollution. This review provides insights into the current state of research, challenges, and prospects in the valorization of coffee processing by-products for energy and environmental sustainability.

Keywords:Coffeeprocessing, Environmental applications, Waste management, Sustainability and Biogas

INTRODUCTION

Coffee is one the world's most consumed beverage, and the second-largest traded commodity after petroleum. Due to the great demand for this product, large amounts of residues are generated in the coffee industry, which are toxic environmental problems. Coffee husk (CH) and spent coffee grounds (SCG) are the main coffee industry residues (Mussatto et al.,2011). CH is a hull of coffee beans obtained as a by-product of the roasting process. Microscopic examination shows the presence of fibrous tissues from the surface layers of the CH. The main components of these fibrous tissues are cellulose (17.8% w/w) and hemicellulose (13.1% w/w). SCG are the solid residues obtained from the treatment of coffee powder with hot water to prepare instant coffee. SCG are a residue with fine particle size, high humidity (80% to 85%), organic load, and acidity. SCG are rich in sugars polymerized into cellulose and hemicellulose structures. They are composed of a majority of carbohydrates, being mannose (21.2% w/w), galactose (13.8% w/w) and arabinose (1.7% w/w) from hemicellulose, and glucose (8.6% w/w) from cellulose (Mussatto et al.,2011).

Several attempts were performed to recover the coffee residue. The first attempt was to use coffee residues as a fertilizer [2]. However, this use was considered uneconomic due to its low nitrogen content (approximately 2%) and high acidity (approximate pH of 4.2). The use of coffee residues as an animal feed for ruminants, pigs, chickens, and rabbits was examined (Bressani *et al*., 1979). However, the analysis of the amino acids contained in the protein of the coffee residues shows that half of the essential amino acids are absent. Therefore, a complement would be necessary for the coffee residues to be used as animal feed. For this reason, the idea was abandoned.

Coffee processing by-products can be converted through thermochemical or biochemical processes into biogas, biofuel, biodiesel, bioethanol, or directly subjected to combustion. A pretreatment technique such as drying and torrefaction could be applied in the case of high humidity content to remove water for the coffee processing by-products. Moisture harms the performance of the thermochemical process and

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influences the quality of gas produced. Removing moisture increases the energy value of the coffee by-product. The use of coffee processing by-products has also paid much attention to environmental applications. In particular, the use of raw and modified coffee residues to remove pollutants from aqueous and gaseous phases is addressed. The modification of coffee residues includes chars, activated carbon, and catalyst support production. Raw coffee processing residues and their corresponding chars can be used as biosorbents to remove heavy metals and organic dyes from aqueous solution. Different activation protocols can transform the chars into activated carbons. These activated carbons could be applied efficiently to remove pollutants from aqueous and gaseous effluents. Moreover, These activated carbons can be used as catalyst support for the elimination of catalyst support for the elimination of eliminate several organic compounds.

work's objective is to present the state of the art in the worldwide recovery of coffee processing residues for environmental and bioenergy applications.

Energy applications

Combustion

The use of coffee husks to prepare fuels was mainly developed in south-America while research corresponding to the direct valorization of spent coffee grounds is mainly concentrated in Europe. This particularity can be explained by the fact that South America is one of the most important coffee suppliers in the world. It is also important to mention that the use of spent coffee grounds as an alternative fuel was encouraged in Europe by the ECS (European Committee for Standardization), which has led to several research and development projects (Jeguirim et al.,2014, Limousy et al., 2015]. As mentioned, coffee husks and spent coffee grounds can be directly valorized through different combustion devices for domestic applications. In both cases, raw materials need to be densified to improve storage (reduction of volume) and transportation (cost) conditions and also to obtain good combustion efficiencies, and. These by-products can be used directly (raw material) or blended with other biomasses to optimize the densification process and adjust the quality of the solid fuel (formulation of agrofuels) and/or the combustion efficiency. Wood sawdust was mainly used to prepare densified solid fuels (pellets, briquettes, and logs) among the different available biomasses to formulate solid fuels. It can be used to ensure the cohesion of the biomass particles to obtain good mechanical properties, but also to limit the slagging phenomenon when mineral content needs to be reduced (boilers, fluidized bed). Then, the percentage of sawdust can range from a few percent (5-10 wt%) to 80-90 wt% depending on the combustion process (furnace, stove, boiler).

Pyrolysis, gasification, and hydrothermal conversion processes

The defatting effect was investigated on the pyrolysis products of spent coffee grounds (SCG) to convert the lipids extracted into biodiesel. Some studies compared conventional, microwave, and catalytic pyrolysis. Different works showed that coffee by-products are more sensitive to torrefaction than many other biomasses (sawdust, rice husk), mainly because of their higher contents in lignocellulosic compounds, especially hemicellulose. Several authors reported that gasification is, among the conversion technologies, the most promising for generating heat, hydrogen, ethanol, and electricity. This technology was applied to coffee processing by-products to evaluate the potential of the different biomasses. Hydrothermal liquefaction was applied to the valorization of spent coffee grounds (SCG). Indeed, SCG contains high amounts of moisture (50-60 wt%), hence it is not energetically and technically feasible to be pyrolyzed. Moreover, the resulting oil is rich in oxygenated compounds (35-60 wt%) and has lower HHV (17-23 $MJ.kg^{-1}$) compared to petroleum fuel.

Environmental applications

Biosorbents

Numerous works have evaluated the performance of these cheap adsorbents for of removing pollutants from aqueous solution (Limousy et al., 2015). These adsorbents are available in large amounts and request low processing costs compared to other adsorbent materials such as activated carbons and zeolites. Several investigations have examined the application of coffee processing residues of removing organic compounds, dyes, and heavy metals from aqueous effluent. These studies focused on determining the biosorbent's adsorption capacities at the laboratory scale using wastewater solution models. The experimental results were used to extract pollutant adsorption kinetics, thermodynamic, and equilibrium parameters.

Wastewater treatment by coffee by-products biochars

Some researchers have carbonized coffee processing residues to improve their adsorption capacity and used the obtained char to remove pollutants from wastewater. They tested the effect of the carbonization temperature of coffee residue on the adsorption capacity of copper ions in an aqueous solution. Other works were carried out to remove dyes, pharmaceutical products [Chouchène et al., 2014], or other organic pollutants.

Wastewater and gas treatment with activated carbons prepared from coffee processing residues

Activated carbons obtained from coffee residues can be used to remove organic molecules (dyes, acids, pesticides, antibiotics…) and cationic and anionic species present in wastewater (lead, chromium, copper, fluoride…). Depending on the preparation routes and the experimental conditions, the performances can be strongly affected. These materials were also used to study the adsorption of different volatile organic compounds (VOCs) and other pollutants that could be eliminated by adsorption: ethylene, n-butane, formaldehyde, nitrogen dioxide (NO_2), hydrogen sulfide (H_2S) and CO_2.

CONCLUSION

Coffee processing by-products present interesting characteristics for energy and environmental applications. Depending on different parameters (moisture, origin, pretreatment conditions) these by-products can be oriented to the best valuable technologies to optimize the valorization process.

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