Coffee processing by-products valorization: An overview of energy and environmental applications

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Introduction

Coffee is one of the most consumed beverages in the world and is the second largest traded commodity after petroleum. Due to the great demand of this product, large amounts of residues are generated in the coffee industry, which are toxic and represent serious environmental problems. Coffee husk (CH) and spent coffee grounds (SCG) are the main coffee industry residues [1]. 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 (in the range of 80% to 85%), organic load, and acidity. SCG are rich in sugars polymerized into cellulose and hemicellulose structures. They are composed by 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 [1].

Several attempts were performed for the coffee residues recovery. The first attempt was to use coffee residues as a fertilizer [2]. However, due to its low nitrogen content (approximately 2%) and its high acidity (approximate pH of 4.2), this use was considered uneconomic. The use of coffee residues as an animal feed for ruminants, pigs, chickens, and rabbits were examined [2]. 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 in order 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 could be directly subjected to combustion. A pretreatment technique such as drying and torrefaction could be applied in the case of high humidity content is order to remove water for the coffee processing by-products. In fact, moisture harms the performance of the thermochemical process and 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 for environmental applications. In particular, the use of raw and modified coffee residues for the removal of 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 for the removal of heavy metals and organic dyes from aqueous solution.. Furthermore, the chars can be transformed into activated carbons through different activation protocols. These activated carbons could be applied highly efficient for the removal of pollutants from aqueous and gaseous effluents. Moreover, These activated carbons can be used as a catalyst support for the elimination of several organic compounds.

The objective of this work is to present the state of the art on 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 researches corresponding to the direct valorisation of spent coffee grounds are mainly concentrated in Europe. This particularity can be explained by the fact that south-America is one of the most important coffee supplier in the world. It is also important to mention that the use of spent coffee grounds as alternative fuel was encouraged in Europe by the ECS (European Committee for Standardization), which has led to several research and development projects [3,4]. As mentioned previously, coffee husks and spent coffee grounds can be directly valorised through different combustion devices for domestic applications. In both cases, raw materials need to be densified in order 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 in order to optimize the densification process, adjust the quality of the solid fuel (formulation of agro-fuels) and/or the combustion efficiency. Among the different available biomasses to formulate solid fuels, wood sawdust was mainly used to prepare densified solid fuels (pellets, briquettes and logs). 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, fluidised bed). Then, the percentage of sawdust can range from few percents (5-10 wt%) to 80-90 wt% depending on the combustion process (furnace, stove, boiler).

Pyrolysis, gasification and hydrothermal conversion processes
The effect of defatting 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. To end, hydrothermal liquefaction was applied to the valorization of spent coffee grounds (SCG). Indeed, SCG contain 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 removal of pollutants from aqueous solution [5]. These adsorbents are available in large amounts and request low processing costs comparing to other adsorbents materials such as activated carbons and zeolites. Several investigations have examined the application of coffee processing residues in the removal of organic compounds, dyes, and heavy metals from aqueous effluent. These studies focused basically on the determination of the biosorbents adsorption capacities at laboratory scale using wastewater solution models. The experimental results were used to extract the kinetics, thermodynamic, and equilibrium parameters for pollutants adsorption.

Wastewater treatment by coffee by-products biochars
In order to improve the adsorption capacity of coffee processing residues, some researchers have carbonized these raw materials and used the obtained char for the removal of pollutants from wastewater. They have tested the effect of carbonization temperature of coffee residue on the adsorption capacity of copper ion in aqueous solution. Other works were carried out for the removal of dyes, pharmaceutical products [6] 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 for the removal of organic molecules (dyes, acids, pesticides, antibiotics…) and also of cationic and anionic species present in wastewater (lead, chromium, copper, fluoride…). Depending on the preparation routes but also on 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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