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Review

The major parameters on biomass pyrolysis for hyperaccumulative plants – A review

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HIGHLIGHTS

- The use of hyperaccumulative plant species as feedstock for fast pyrolysis is feasible.
- The selection of a phytoextractor must be process-oriented.
- The parameters of pyrolysis should be adjusted to the input and to the desired products.
- The hazards related to the biochar must be assessed properly in future experiments.

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ABSTRACT

Phytoextraction is one of the main phytoremediation techniques and it has often been described as a potentially feasible *in situ* soil decontamination method of large amounts of heavy metals, organic pollutants and explosive compounds. As this remediation technique is approaching extensive on-field experimentation and commercialization, research focus is on investigating new ways to achieve the valorisation of its by-products. Biomass pyrolysis represents a key step to numerous valorisation options and it is characterized by differential output products that are determined by the operating conditions of the process and the characteristics of the input. However, when used to valorise plants that have undergone significant metal uptake, this strategy involves some new aspects related to harvest, procedure and final product reutilization. This paper reviews the studies made on biomass pyrolysis of plants with emphasis on the differential quality and distribution of pyrolysis products in relation with the variables of the process and the metal-rich phytoextraction feedstock properties. By investigating these parameters, this survey provides indications on ways to optimize the valorisation of phytoremediation by-products through biomass pyrolysis.

Contents

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1. Introduction

Contamination of soils by toxic metals and metalloids represents a serious hazard for ecosystems along with public health, and has consequently been a general concern for more than 25 years (Nriagu et al., 1998). To provide solutions to this environmental issue, several methods that rely on the physiological and metabolic mechanisms of plants have been developed and studied, as seen in Fig. 1 (Cunningham et al., 1995; Salt et al., 1995; Chaney et al., 1997; Pauwels et al., 2008). These biotechnological methods are broadly termed phytoremediation and one of them, phytoextraction, is based on the particular property of some plant species that allow them to achieve the bioaccumulation of these pollutants in their aerial parts, which are then harvested to be later discarded or valorised (Kumar et al., 1995; McGrath and Brooks, 1998; Angle et al., 2001). Phytoextraction is a superficially-contaminated soil remediation technique that targets pollutants such as heavy metals, metalloids, organic compounds, explosives and other hazardous elements. It functions by (i) reaching and absorbing pollutants through their roots and/or their symbiotic mycorrhizae hyphal network, (ii) promoting their translocation from roots to shoots and (iii) segregating pollutants in specific tissues, thus obliterating their diffusion potential and reducing their deleterious environmental effects (Garbisu and Alkorta, 2001; Göhre and Paszkowski, 2006). Such plants are qualified as hyperaccumulative and they induce, naturally or with addition of chelating agents, the pollutants absorption and bottom-up translocation instead of avoiding growth on contaminated grounds or using biochemical strategies to bypass assimilation of the contaminants as their non cumulative counterparts do (Baker, 1981). While the yields of contaminated biomass are continuously removed, treatments are developed to address the problem of pollutants diffusion control during its valorisation and pyrolysis has been regularly described as an effective and environmentally responsible technique.

Biomass pyrolysis is a residual biomass treatment operation that successfully responds to the challenges of volume reduction and metal pollutant risk control. This procedure is central to plant residues' valorisation processes like carbonization, combustion, liquefaction and gasification, which explains why it is being explored with increasing interest (Bridgwater, 2012). The basic principle of this process consists in heating biological matter at narrowly controlled temperatures and in anoxic conditions, which inhibits any flame ignition during the reaction (Czernik and Bridgwater, 2004). The products of this pyrolysis are a solid fraction (char and ash), a liquid fraction (bio-oil and tar) and a gas fraction (condensable and non-condensable vapour gas). The product quantity and composition of every fraction is affected by the characteristics of the original feedstock and the conditions in place during the process (Chan et al., 1988). Controlled variables such as temperature, heating rate and vapour residence time that are inherent to the pyrolysis process should ideally be adjusted accordingly to the feedstock initial characteristics (moisture content, chemical composition and content in inorganic elements).

When treating a metal-rich plant feedstock, the objective is to maximise the metal content in the char and minimise it in the liquid and gaseous phases, thus preserving the high value of the newly generated products. However, it must be taken into account that the choices of plant species, targeted metal or metalloid pollutants and pyrolysis procedure will impact the operation and the performance of a feedstock-sensitive valorisation process like biomass pyrolysis. The objective of this paper is to review and discuss the recent developments made on the subject of biomass pyrolysis of plants with emphasis on the differential quality and distribution of pyrolysis final products in relation with the major operational parameters of the process and the metal-rich phytoextraction feedstock content.

2. Phytoextraction

When proceeding phytoextraction, the main objective is to extensively cultivate *in situ* hyperaccumulative plants that can raise their intern concentration of pollutant essential trace metals (Cu, Ni, Fe, Se and Zn), non-essential metals (Cd, Co, Cr, Pb and Hg) or metalloids (As). To be commercially relevant, the bioaccumulation should reach a shoots/roots metal concentration threshold ratio conventionally set above 1, while pursuing significant and

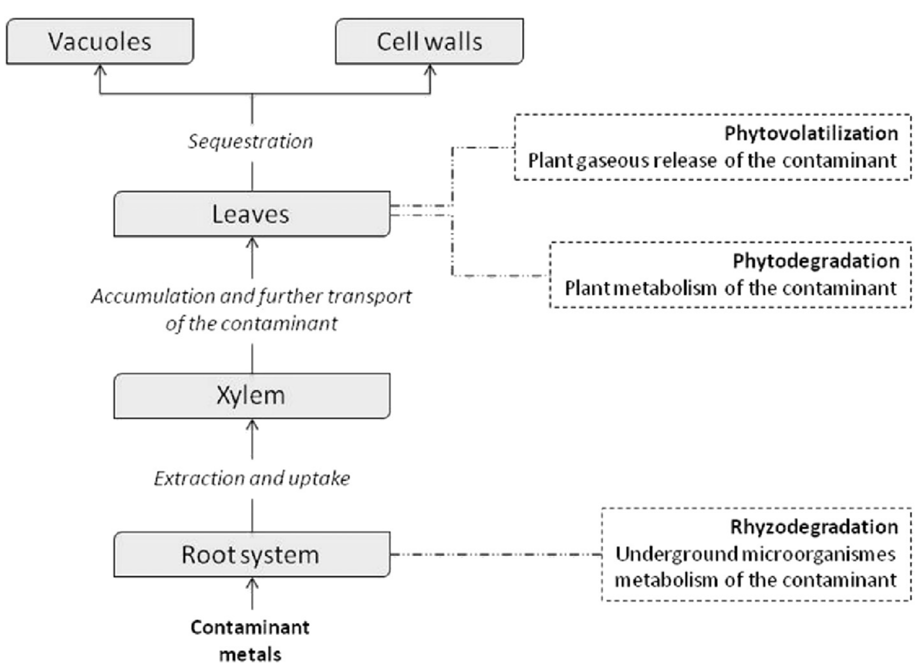

Fig. 1. Graphic representation of the main phytoremediation methods.