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Review article

An overview of the composition and application of biomass ash. Part 2. Potential utilisation, technological and ecological advantages and challenges

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ABSTRACT

An extended overview of the complex phase-mineral and chemical composition and properties of biomass ash (BA) was conducted in Part 1 of the present work. Then, the identified systematic associations, namely (1) Si–Al–Fe–Na–Ti (mostly glass, silicates and oxyhydroxides); (2) Ca–Mg–Mn (commonly carbonates, oxyhydroxides, glass, silicates and some phosphates and sulphates); and (3) K–P–S–Cl (normally phosphates, sulphates, chlorides, glass and some silicates and carbonates); connected with the occurrence, content and origin of elements and phases in the BA system were used for classification of BAs into four types and six sub-types in Part 1. The potential application of BA using the above classification approach is described in the present Part 2. It is demonstrated that such new BA classification has not only fundamental importance, but also has potential applications in prediction of properties and utilisation connected with the innovative and sustainable utilisation of BAs specified in different types and sub-types. The potential advantages and challenges related to utilisation of BA are described. Different aspects connected with BAs such as: (1) bulk utilisation (for soil amendment and fertilisation; production of construction materials, adsorbents, ceramics and other materials; plus synthesis of minerals); (2) recovery of valuable components and their utilisation (char, water-soluble, cenosphere–plerosphere, magnetic and heavy fractions; and elements); and (3) multicomponent utilisation; are described based on the reference investigations, present data and above classification. Subsequently, additional issues related to BAs, namely: (1) technological advantages and challenges (slagging, fouling and corrosion; low ash-fusion temperatures; erosion and abrasion; co-combustion and co-gasification; prediction of phase composition; and others); and (2) some environmental risks and health concerns (air, water, soil and plant contamination; acidity, alkalinity and leaching; volatilisation, retention, capture and immobilisation of hazardous elements and compounds; ash inhalation and disposal); during biomass and BA processing are also discussed. Finally, it is emphasised that the definitive utilisation, technological and environmental advantages and challenges related to BAs associate preferentially with specific BA types and sub-types and they could be predictable to some extent by using the above combined chemical and phase-mineral classification approaches.

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1. Introduction

The present overview contains two parts and describes the composition and application of biomass ash (BA), namely: (1) phase-mineral and chemical composition and classification of BA; and (2) potential utilisation, technological and ecological advantages and challenges of BA, respectively. This is the second part of the above overview, while Part 1 [1] has been reported recently.

It was estimated in Part 1 that approximately 480 million tonnes of biomass ash could be generated worldwide annually. This quantity is comparable to that of coal ash, namely 780 million tonnes produced per year at present [2]. The perspective of increasing large-scale combustion of natural biomass and its co-combustion with semi-biomass (contaminated biomass such as municipal solid waste, refuse-derived fuel, sewage sludge, demolition wood and other industrial organic wastes) and solid fossil fuels (coal, peat, petroleum coke) seems to be one of the main drivers for biofuel promotion by many countries worldwide in the near future. Therefore, some of the major open questions related to extensive biomass combustion are what we are going to do with this huge amount of BA and if there are any environmental risks related to BA.

Two fundamental aspects connected with the use of BA are to: (1) extend and improve the basic knowledge on composition and properties; and (2) apply this knowledge for the most innovative and sustainable utilisation and/or an environmentally safe disposal. The identification, quantification and characterisation of chemical and phase composition of BAs are initial and important steps for their utilisation. For that reason an extended overview of the phase-mineral and chemical composition and classification of BA was conducted in Part 1 of the present work. Some general considerations related to the composition of BA and particularly problems associated with this issue were discussed initially in Part 1. Then, reference peer-reviewed data including phase-mineral composition and properties of BAs plus own investigations were used to describe and organise the BA system. It was found that BA is a complex inorganic-organic mixture with polycomponent, heterogeneous and variable composition. The phase-mineral composition of BA includes:

(1) Mostly inorganic matter composed of non-crystalline (amorphous) and crystalline to semi-crystalline (mineral) constituents.
(2) Subordinately organic matter consisting of char and organic minerals.
(3) Some fluid matter comprising moisture and gas and gas–liquid inclusions associated with both inorganic and organic matter.

Approximately 229 forming, major, minor and accessory phases or minerals were identified in BAs. These species have primary, secondary or tertiary origin in the combustion residue and they are generated from natural (authigenic and detrital) and technogenic phases or minerals originally present in biomass. Common topics related to BA such as: terminology clarification; chemical composition; contents and concentration trends; correlations and associations; formation and behaviour; fusion temperatures; and leaching; were discussed and compared to coal ash. A general characterisation of the phase-mineral composition and description of the occurrence and origin for common constituents in BA, namely: (1) silicates; (2) oxides and hydroxides; (3) sulphates (plus sulphides, sulphosalts, sulphites and thiosulphates); (4) phosphates; (5) carbonates (plus bicarbonates); (6) chlorides (plus chlorites and chlorates); (7) nitrates; (8) glass; (9) other inorganic phases; (10) organic phases; and (11) organic minerals; were also conducted and compared to coal ash. Finally, certain major associations among the elements and their respective phases in the BA system were identified (see also Section 3.1). It was found that these systematic associations in BA have a key importance in both fundamental and applied aspects, namely their potential applications for classifications and indicator purposes connected with advanced processing of BA.

The main purpose of the present Part 2 is to describe the potential utilisation, technological and ecological advantages and challenges related to innovative and sustainable application of BA.

2. Materials, methods and data used

The present overview includes a combination of reference peer-reviewed data and own key studies on BAs, as well as data for ashes from other solid fuels. Comparisons for BAs are made dominantly with coal ashes since the latter combustion products are much better known and currently extensively utilised. The materials, methods and most of the data used were presented in Part 1. For better differentiation, the results in Part 2 are associated with: (1) peer-reviewed investigations; and (2) peer-reviewed data including our own new data and studies with novel interpretation ([3,4]; Part 1 and present data); and referred to as "reference investigations" and "present study" throughout the text, respectively.

3. Results and discussion

3.1. Chemical and phase-mineral classification of biomass ashes and its potential applications

It was demonstrated in Part 1 that the inorganic composition of biomass and BA is highly variable and the assignment of various biomass varieties to different inorganic types and sub-types could