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Review article

An overview of the behaviour of biomass during combustion: Part II. Ash fusion and ash formation mechanisms of biomass types

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ABSTRACT

An extended overview of the phase–mineral transformations of organic and inorganic matter during biomass combustion was conducted in Part I of the present work. The ash fusion and ash formation mechanisms of biomass types and sub-types during combustion are described in the present Part II. For that purpose the identified systematic associations based on the occurrence, content and origin of elements and phases in the biomass ash (BA) system, 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); were used as classification of BAs into four types (“S”, “C”, “K” and “CK”) and six sub-types with high, medium and low acid tendencies and their description was given. Then, topics related to ash fusion behaviour such as: some general considerations and observations about ash melting; ash fusion temperatures (AFTs) of biomass and their comparisons with coal; relationships between AFTs and inorganic composition of biomass and coal; and ash fusion mechanisms of biomass and coal are characterized. Further, issues connected with the ash formation mechanisms of BA types and sub-types are discussed. Subsequently, aspects related to potential applications of ash formation mechanisms for BA types and sub-types, namely some key technological problems (fusion, slagging and fouling predictions, low ash fusion temperatures, co-combustion and application of BA) and environmental risks (volatilization, capture and water leaching of hazardous elements) are described. Finally, it is emphasized that the application of this new classification approach based on combined phase–mineral and chemical composition of biomass and BA has not only fundamental importance, but also has potential applications in prediction of behaviour and properties connected with the innovative and sustainable utilization of biomass and BA. It is also demonstrated that the definitive utilization, technological and environmental advantages and challenges related to biomass and BA associate preferentially with their specific types and subtypes and they could be predictable to some extent by using the above or similar combined chemical and phase–mineral classification approaches.

Contents

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Nomenclature

A	ash yield	M	moisture
AFT	ash fusion temperature	MM	marine macroalgae
BA	biomass ash	MP	melting point
BC	beech wood chips	OM	organic matter
CC	corn cobs	PP	plum pits
daf	dry, ash-free basis	R^2	correlation coefficient
db	dry basis	RH	rice husks
DT	initial deformation temperature	SG	switchgrass
DTA	differential-thermal analysis	SS	sunflower shells
DWR	dry water-soluble residue	ST	spherical temperature
FC	fixed carbon	TGA	thermo-gravimetric analysis
FT	fluid temperature	VM	volatile matter
HAP	hazardous air pollutant elements	WS	walnut shells
HT	hemispherical temperature	XRD	X-ray powder diffraction
HTA	high-temperature ash (>500 °C)	%	weight %
IM	inorganic matter		

1. Introduction

Extensive reference peer-reviewed data plus own investigations for both biomass and biomass ash systems were used recently to perform several extended overviews related to: (1) chemical composition of biomass [1]; (2) organic and inorganic phase composition of biomass [2]; (3) phase–mineral and chemical composition of biomass ash (BA) [3]; and (4) potential utilization, technological and ecological advantages and challenges of BA [4]; respectively. New classifications based on data from proximate, ultimate, ash, structural and mineralogical analyses of biomass and BA have also been introduced therein [1–3].

The present work is an overview that contains two parts and describes the behaviour of biomass during combustion, namely: (1) phase–mineral transformations of organic matter (OM) and inorganic matter (IM); and (2) ash fusion and ash formation mechanisms, respectively. Part I [5] included major issues related to the composition, occurrence, transformation and origin of common constituents in biomass and BA such as: (1) OM, namely cellulose, hemicellulose, lignin, char and other organic phases plus organic minerals; and (2) IM such as silicates, oxides and hydroxides, phosphates, sulphates (plus sulphides, sulphosalts, sulphites and thiosulphates), carbonates (plus bicarbonates), chlorides (plus chlorites and chlorates), nitrates, glass, amorphous (non-glass) material and other inorganic phases; and they were described and compared to coal ash. A systematization of physico-chemical transformations during biomass combustion has also been given in Part I. This is the second part of the present overview and includes a critical review of publications and own investigations as an attempt will be undertaken to address the following objectives:

(1) Clarification of the ash fusion behaviour of biomass.
(2) Explanation of the ash formation mechanisms associated with biomass types and sub-types during combustion.
(3) Indication of some key technological and environmental challenges connected with combustion of biomass types and sub-types and application of their BAs.

2. Materials, methods and data used

The materials, methods and most of the data used were presented in Part I [5]. The data given in the former part include the chemical ash composition of biomass groups and sub-groups, the