

Common reeds (*Phragmites australis*) as sustainable energy source: experimental and modelling analysis of torrefaction and pyrolysis processes

FRANCESCO PATUZZI*, TANJA MIMMO*, STEFANO CESCO*, ANDREA GASPARELLA* and MARCO BARATIERI*

*Faculty of Science and Technology, Free University of Bolzano, Piazza Università 5, Bolzano, 39100, Italy

Abstract

The aim of this study is to apply advanced analytical techniques and kinetic modelling to common reeds (*Phragmites australis*) to characterize its pyrolysis and torrefaction as possible environmental friendly and sustainable pathways of fuel upgrading. Simultaneous thermogravimetric and differential scanning calorimetry analysis have been carried out on common reeds. The evolved gases during the decomposition process have been analysed by a coupled infrared gas analyser and gas chromatograph/mass spectrometer. Different reed origins (China and Italy) and plant parts (stem and leaves) have been compared. The results have been used to calibrate a torrefaction kinetic model. The model has also been tested simulating a reed torrefaction run occurring in a bench-scale apparatus, supplementing the chemical analysis with a thermal simulation of the reactor carried out through a finite elements approach. The results show that the proposed modelling approach allows the prediction of the reaction products with a satisfying degree of accuracy. Besides its phytodepuration potential, *P. australis* has proven to be an interesting natural biomass resource for thermochemical conversion processes and energy production both for its suitability and availability.

Keywords: biomass, modelling, *Phragmites australis*, reeds, thermal analysis, torrefaction

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Introduction

Most of the solid biomass traditionally used as fuel for heating purposes (e.g. woodchips, wood pellets, cordwood) were products or by-products of forest management and timber industry. However, in the last years, growing crops (both herbaceous and woody) has gained widespread appeal for energy production (Strezov *et al.*, 2008). In particular, perennial grasses such as Switchgrass (*Panicum virgatum*), Miscanthus (*Miscanthus × giganteus*) and Reed canarygrass (*Phalaris arundinacea*) open new renewable energy scenarios. Perennial grasses are now being used as solid fuel in cofired coal power plants as well as targeted as a choice feedstock for such advanced biofuels as cellulosic ethanol. Furthermore, perennial grasses can also be pressed into pellets, briquettes and cubes and used as a heating fuel to replace or complement fuels made from wood fibre. Grasses can grow on marginal lands suited for continuous row crop production or in open rural land currently not in agricultural production. They usually have a high productivity and once established, require far fewer

inputs in comparison to annual crops in terms of diesel, fertilizer and pesticides needs.

Besides terrestrial grass plants, also the emergent aquatic macrophyte can play an important role as local energy source in places where they are naturally present in great amounts. In addition, wetland plants have a high macronutrients accumulation capability because of their generally fast growth and high biomass production (Bragato *et al.*, 2006). As a consequence, their utilization for energy production could have, as additional advantage, the disposal of such kind of elements from the ecosystem. In particular, *Phragmites australis*, known as common reed, is one of the most common plants living in wet ecosystems (Bonanno & Lo Giudice, 2010). Although this species has been widely studied for its phytodepuration potential (Weis & Weis, 2004), few experiences can be found in international literature concerning the energy utilization of *P. australis*. The interest for this topic starts in the 1980s, in particular for the application of reeds in direct combustion (Granéli, 1984). In the last years similar solutions have been proposed, as well as the application for biogas production through fermentation (Barz *et al.*, 2006; Kask *et al.*, 2007; Komulainen *et al.*, 2008). Besides this, a promising but not yet completely characterized application of common reeds seems its thermochemical conversion through

Correspondence: Tanja Mimmo, tel. + 39 0471 017 161, fax + 39 0471 017 009, e-mail: tanja.mimmo@unibz.it

pyrolysis (Sutcu, 2008; Zhao, 2011; Park, 2012) or gasification (Kitzler *et al.*, 2011; Yang *et al.*, 2012). In fact, grass biomass could be processed for energy purposes by means of direct combustion, dealing with conventional stages of emissions clean-up and the critical issues related to the combustion of solid heterogeneous fuels. A recent vision looks at developing energy chains consisting of a sequence of treatments, converting the biomass into gaseous or liquid fuels that can be used in a more efficient way. In this frame, a possible biomass pretreatment is the torrefaction process. It can be considered as a slow pyrolysis carried out at low temperatures (max. 280–300 °C) that enhances physical and thermochemical properties of biomass (Pentananunt *et al.*, 1990; Lipinsky *et al.*, 2002; Bergman & Kiel, 2005; Arias *et al.*, 2008; Bridgeman *et al.*, 2008, 2010; Repellin *et al.*, 2010) – such as grindability, uniformity, hydrophobicity and heating value – and can be a suitable pretreatment to improve the gasification/pyrolysis of the feedstock (Prins *et al.*, 2006a).

The aim of this study is the characterization of torrefaction and pyrolysis carried out on common reeds (*P. australis*), using advanced analytical techniques and kinetic modelling.

Materials and methods

Feedstock characterization

In this work, samples of common reed (*P. australis*) are analysed. Different plant parts (stem and leaves) are compared, as well as different places of origin. The main sampling activity has been carried out in China: some samples have been collected during a research expedition in Inner Mongolia province, in September 2010, within the frame of an interdisciplinary and international project of the Free University of Bolzano (Italy), the University of Greifswald (Germany) and the Chinese Research Academy of Environmental Sciences (CRAES). In particular, the samples have been collected in the area of Wuliangshuai Lake (one of the two study sites of the project), the largest lake system in the Yellow River Basin, having an area of almost 300 km². The main recharge of the lake is from irrigation return of Hetao Irrigation District, municipal sewage and industrial wastewater (Ruihong *et al.*, 2004). As a result, Wuliangshuai Lake has been increasingly subjected to eutrophication and almost half of the lake is presently covered by emergent vegetation, mainly *P. australis* and some scattered stands of *Typha latifolia*, whereas the open-water area is covered by submerged vegetation (Duan *et al.*, 2005).

The sampling procedure has been designed to be significant from a statistical point of view, following the approach used by Thevs *et al.* (2007). Different sampling points (i.e. plots) have been selected. For each plot, four subplots (square areas, side length: 0.5 m) have been randomly placed, keeping the same distance from a central fixed point. For each subplot, the five stems closest to the diagonal have been cut. The choice of the plots cannot be considered really random because they have been chosen also taking into account their reachability by car or boat; in fact, the infrastructures in the area are not well

developed and this has represented a serious problem for the sampling activity. Nevertheless, the sampling procedure minimizes the possibility of a subjective choice of subplots and stems from the operator. Because of this, the sample can be considered with a good approximation a random sample. Stems and leaves samples have been prepared cutting randomly pieces of the two type of tissues from the plants of the different plots.

As control, some samples of common reed have also been collected with the same procedure in the area of Monticolo Lake (Bolzano, Italy), in October 2010.

The moisture content of the collected samples has been determined according to the UNI CEN/TS 14774-2. Subsamples were dried at 45 °C for 48 h and ground with a Retsch Mill MM400 (Retsch, Düsseldorf, Germany). Ash content (UNI CEN/TS 14775), elemental composition (UNI CEN/TS 15104), sulphur and chlorine content (UNI CEN/TS 15289) and Lower Heating Value (UNI CEN/TS 14918) have been determined. Due to the high ash content, a more detailed analysis of the reed ash melting behaviour has been performed, according to UNI CEN/TS 15370-1.

Reeds can withstand extreme environmental conditions, including the presence of toxic contaminants such as heavy metals (Ye *et al.*, 1997; Baldantoni *et al.*, 2004; Quan, 2007; Bonanno & Lo Giudice, 2010). There are many cases in which, as other wetland plants, reed is utilized for the removal of pollutants, including metals (Chiu *et al.*, 2006; Calheiros *et al.*, 2009). For this reason, the metals content in the samples has been determined according to the UNI CEN/TS 15297.

Thermal analysis

Thermal analysis of reeds (leaves and stems of *P. australis*) collected in China and Italy were performed using a simultaneous thermogravimetric analyser (STA 449F3, Netzsch). This technique combines both the heat flux differential scanning calorimetry (DSC) and thermogravimetry (TG). STA analysis was performed at a constant heating rate of 20 °C min⁻¹ under inert nitrogen atmosphere in a temperature range from 30 to 1000 °C. The evolved gas was further characterized by TG/STA coupled with a gas chromatography/mass spectrometry system and a Fourier Transform Infrared Spectrometer. Additional tests have been carried out on the stem samples, setting an intermediate temperature plateau at 250 °C to assess the effect of a possible torrefaction stage. All thermal analyses were performed in the applied laboratory of NETZSCH-Gerätebau in Selb, Germany.

Experimental apparatus

The experimental apparatus, set up at the Free University of Bolzano and schematically presented in Fig. 1, consists of a tubular electric furnace, a tubular reactor, a condenser, a series of impinger bottles for the collection of tars and a module for gas sampling and measurement. The furnace is able to reach the maximum temperature of 1050 °C. The reactor is placed inside the furnace; reactor and condenser are made out of quartz that is characterized by high resistance to temperature and chemicals, high purity and high stability.

The atmosphere inside the reactor is kept inert flowing nitrogen from a cylinder equipped with a pressure reducer. The gas produced inside the reactor flows through the condenser, where it is cooled. The tar collection is then performed in a series of six impinger bottles, according to the technical specification UNI

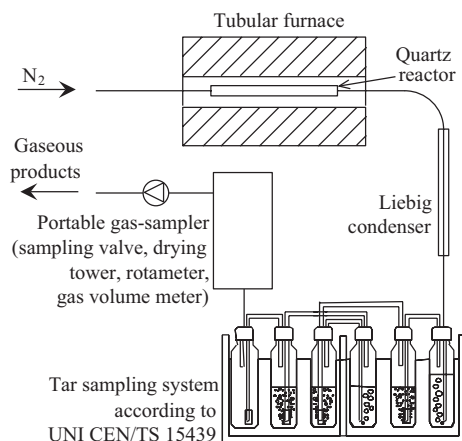
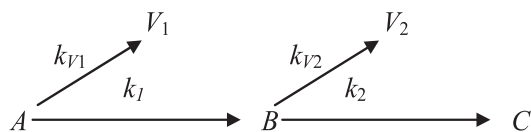


Fig. 1 Set-up of the bench-scale batch pyrolysis/torrefaction system.

CEN/TS 15439; the first impinger bottle acts as a moisture collector; all the bottles except the last one are filled with isopropanol, an organic solvent suitable for tars absorption. Except the first and the fourth, all the bottles are equipped with G2 frits; the first, the second and the fourth bottle are kept at 35/40 °C with water as cooling liquid, whereas the others are cooled at -15/-20 °C with a mixture of salt/ice/water. The gas suction device consists of a drying tower, a rotameter, a dry running rotary vane vacuum pump and a dry Gas Volume Meter.

Multiphase kinetic model for torrefaction

Investigating the thermal degradation of xylan, Di Blasi & Lanzetta (1997) have assumed a two-step mechanism involving the formation of an intermediate solid compound having a reduced degree of polymerization. This intermediate then reacts to give the final product. Prins (Prins, 2005; Prins *et al.*, 2006b) has proposed that the weight mass loss of willow wood during torrefaction treatment can be described by a similar two-step mechanism. This mechanism can be described by the following scheme:



The model assumes that the original biomass (compound A) forms first an intermediate product (compound B), whose degradation gives the final product (compound C) as char. In the proposed scheme, the formation of volatiles (V_1 and V_2) products is assumed to take place through reactions in parallel to those giving the compounds B and C respectively.

All the involved reactions are assumed to be of first order and the kinetic parameters are described by the usual Arrhenius equation:

$$k_i = k_{0,i} \exp\left(-\frac{E_{a,i}}{RT}\right) \quad i = 1, 2, V_1, V_2 \quad (1)$$

where $k_{0,i}$ is the pre-exponential factor, $E_{a,i}$ the activation energy, R the universal gas constant and T the temperature in Kelvin degrees.

More details about the global kinetic reactions scheme and the calibration method – a least square optimization performed by means of a MatLab script – has been described elsewhere (Baratieri *et al.*, 2011; Patuzzi & Baratieri, 2011).

Model calibration and testing

The experimental TG data (on dry basis) at temperature lower than 300 °C (corresponding to the upper limit for torrefaction) have been used to calibrate the model in the solid-volatiles formulation (Scheme s1). The TG analysis performed with an intermediate temperature plateau has been necessary to maximize the number of experimental data within the torrefaction range of temperature. Each TG analysis has been repeated three times.

In the experimental apparatus some preliminary torrefaction tests have been performed on Italian reed stem samples, setting the oven temperature at 300 °C. A finite elements model of the reactor has been developed and tuned up to estimate the average temperature reached by the biomass inside the reactor (i.e. average torrefaction temperature). Thermal conductivity of reeds tissue has been estimated as the weighted average between the thermal conductivity of wood and air, considering the measured reed porosity of 60%. The numerical model integrates the heat equation within the oven and reactor domains. The convective effect due to the nitrogen flux inside the reactor and the radiative exchange between the oven and the reactor surfaces have been implemented. The model calibration has been carried out using the temperature measurements detected through K-type thermocouples.

Results

Feedstock characteristics and thermal analysis

The moisture content, the elemental composition, the metals content and the ash characteristic temperatures of *P. australis* tissues are reported in Table 1.

Stem and leave samples of *P. australis* both from China and Italy were analysed by STA to determine the different thermal stability. In addition, TG/FTIR and TG/GC/MS analyses were performed to get a better insight on the quality of the emitted gases during the thermal degradation. TG and DTG curves of stems and leaves are shown in Fig. 2a and b respectively. All the profiles show three main reactions. The first peak around 100 °C is due to water loss and can thus be attributed to the residual water content of the biomass. Water loss is followed by two reactions (B at around 280–300 °C and C at around 350–380 °C), which are also due to the main weight loss during thermal degradation. Figure 3 shows the Total Ion Current chromatogram evaluation at the temperatures corresponding to these two degradation steps.

The residual mass at 700 °C is 30.17% and 34.63% for Chinese stems and leaves respectively; 36.57% and 25.64% for Italian stems and leaves respectively. As a consequence, considering the average biomass distribution

Table 1 Chemical and physical characterization of *P. australis* tissues

Parameter	Unit	China		Italy	
		Stem	Leaves	Stem	Leaves
Moisture	%wt _{ar}	8.3 ± 0.2	8.7 ± 0.2	7.2 ± 0.1	7.5 ± 0.2
Ash	%wt _{dry}	6.5 ± 0.0	13.2 ± 0.0	8.0 ± 0.1	8.0 ± 0.0
LHV	MJ kg ⁻¹ _{dry}	16.86 ± 0.04	17.22 ± 0.06	16.83 ± 0.01	17.89 ± 0.04
C	%wt _{dry}	45.5 ± 0.4	44.6 ± 0.5	45.5 ± 0.4	50.0 ± 0.7
H	%wt _{dry}	6.0 ± 0.0	6.1 ± 0.0	6.3 ± 0.1	7.0 ± 0.2
N	%wt _{dry}	0.7 ± 0.0	2.7 ± 0.0	0.5 ± 0.0	1.5 ± 0.2
O	%wt _{dry}	40.3 ± 0.2	31.6 ± 0.5	39.5 ± 0.6	33.4 ± 1.0
S	%wt _{dry}	0.10 ± 0.01	0.40 ± 0.02	0.07 ± 0.00	0.11 ± 0.01
Cl	%wt _{dry}	0.90 ± 0.05	1.40 ± 0.03	0.14 ± 0.01	0.04 ± 0.00
Cd	mg kg ⁻¹ _{dry}	<0.1	<0.1	<0.1	<0.1
Cr	mg kg ⁻¹ _{dry}	1.2 ± 0.1	3.5 ± 0.2	0.3 ± 0.0	0.9 ± 0.0
Cu	mg kg ⁻¹ _{dry}	3.6 ± 0.2	6.2 ± 0.1	1.9 ± 0.1	2.9 ± 0.3
Hg	mg kg ⁻¹ _{dry}	< 0.2	<0.2	<0.2	<0.2
Mn	mg kg ⁻¹ _{dry}	127.3 ± 0.8	582.3 ± 0.9	180.0 ± 0.8	421.8 ± 1.0
Ni	mg kg ⁻¹ _{dry}	1.6 ± 0.1	2.2 ± 0.1	1.4 ± 0.2	1.5 ± 0.1
Pb	mg kg ⁻¹ _{dry}	<0.2	0.8 ± 0.0	<0.2	<0.2
Ash melting behaviour (characteristic temperatures)					
Sintering	°C	800 ± 1	1018 ± 2	911 ± 1	1012 ± 2
Softening	°C	1270 ± 2	1146 ± 2	>1500	>1500
Melting	°C	1318 ± 2	1242 ± 2	>1500	>1500
Flowing	°C	1363 ± 2	1277 ± 2	>1500	>1500

Mean ± standard deviation ($n = 3$).

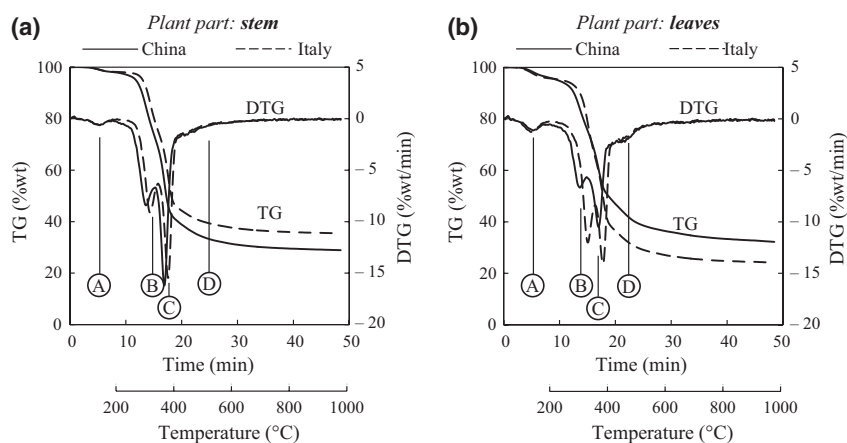


Fig. 2 Comparison between TG and DTG curves of (a) stems and (b) leaves of reed from different origins (continuous line: China; dashed line: Italy). Circles indicate the temperature at which IR spectra have been extracted.

in *P. australis* proposed by Shi *et al.* (2010), i.e. about 71% in stem and 29% in leaves, the weighted average conversion efficiency seems higher with the Italian reeds than with the Chinese ones: about 33.4% and 31.5% respectively.

In addition, for each sample, FTIR spectra have been recorded to better define the quality of the evolved gas

during thermal conversion. Spectra were recorded at four selected temperatures (Table 2), corresponding to three main reactions during thermal degradation (Rodrigues *et al.*, 2001). There are no qualitative differences between the IR spectra of the various reed samples; as an example the results for Chinese stem sample are reported in Fig. 4.

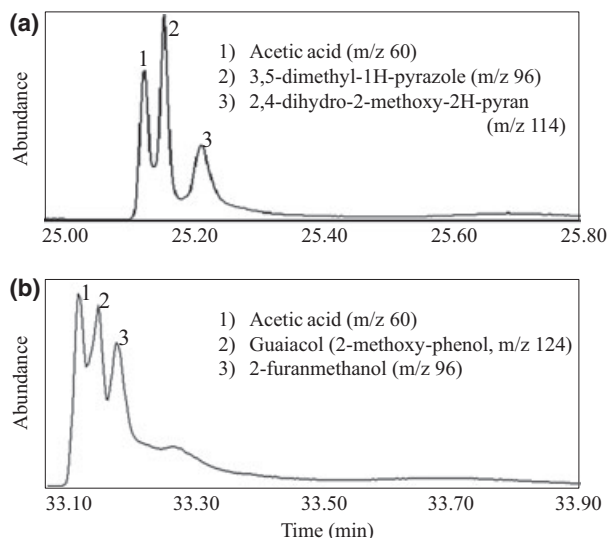


Fig. 3 Total ion current (TIC) chromatogram evaluation at (a) 2nd TG step (≈ 280 °C) and (b) 3rd TG step (≈ 350 °C).

Table 2 Temperatures at which FTIR spectra of the various samples have been recorded: A) moisture loss; B) first reaction; C) second reaction; D) almost completed reactions

Sample origin	Plant part	Temperature (°C)			
		A	B	C	D
China	Stem	102.4	281.7	353.7	429.8
China	Leaves	101.6	280.7	352.2	556.0
Italy	Stem	94.1	312.7	371.0	437.7
Italy	Leaves	102.6	296.7	366.3	483.0

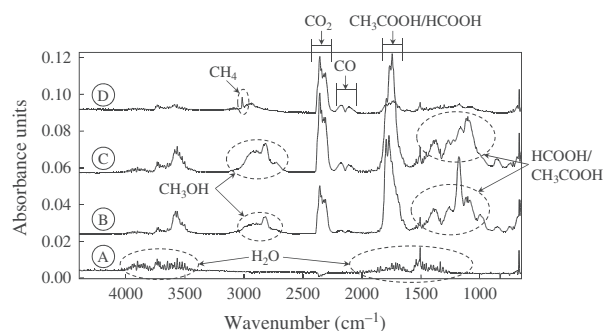


Fig. 4 FT IR spectra of the Chinese stem sample (A ≈ 105 °C, B ≈ 280 °C, C ≈ 350 °C, D ≈ 560 °C).

Torrefaction model calibration and testing

Results of the calibration are reported in Fig. 5. As can be observed, the model fits with satisfying accuracy the experimental TG data at temperatures lower than 300 °C.

The values of the model parameters that give the best fit of the experimental data are reported in Table 3.

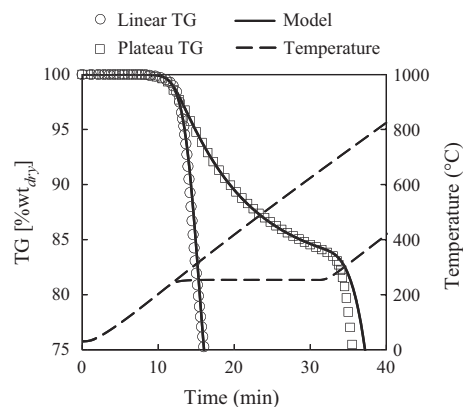


Fig. 5 Comparison between experimental TG data (linear and with temperature plateau at 250 °C) and values predicted by the torrefaction model.

Table 3 Value of the torrefaction model parameters that give the best fit of TG experimental data (referring to Italian stem sample)

	$k_{0,i}$	$E_{a,i}$
1	6.34E+04	76820
2	1.10E+10	145480
V_1	3.23E+07	110765
V_2	1.59E+10	155855
L_1	2.90E+07	110764
L_2	1.43E+10	159280
G_1	3.26E+06	110776
G_2	5.28E+09	153363

The two stages model previously described has been now extended to describe a complete kinetic mechanism for the prediction of the solid, liquid and gaseous phases amounts. The model in its extended formulation has been calibrated using experimental data about torrefied miscanthus (Zanzi *et al.*, 2004). In future, the calibration of the model applied to reed tissue will be refined using the liquid yields detected in the experimental apparatus previously described.

The experimental torrefaction test performed on Italian reed stem has given a solid yield of 74.3% on dry basis. To compare it with the torrefaction model prediction, the finite elements model has been tuned up. The calibration has been carried out using a set of measured temperatures inside the reactor (i.e. nitrogen temperatures at the inlet, middle and outlet sections and temperature of the upper external surface of the reactor). After the calibration, the maximum deviation between the experimental temperatures (measured setting the oven at 300 °C) and the computed ones is of the order of magnitude of 1 °C. The integration of the temperature distribution inside the

biomass volume (divided by the biomass volume) gives an average biomass temperature of 275 °C when the oven is set at 300 °C. The average biomass temperature during the experimental torrefaction test has been then evaluated and imposed as input for the kinetic torrefaction model. The predicted solid yield is in good agreement with the measured one (Fig. 6). The finite elements model will be improved, implementing both the thermofluidynamics inside the reactor and the effects of the reagent media (i.e. biomass and syngas).

Discussion

Besides traditional woody biomasses, grass biomasses like *P. australis* are gaining widespread interest as potential energy sources. For this reason it is worth to characterize deeply the chemical and physical properties of such kind of feedstock, as well as its thermal behaviour.

Moisture content is one of the main parameters that have to be considered in the assessment of a feedstock as far as it concerns its applicability in thermochemical conversion processes. The collected reed samples, after being air dried for less than 20 days, have very low moisture content (Table 1). Thus, a first phase of on-site and inexpensive air drying before processing the biomass could be taken in consideration.

Focusing on Chinese samples, they present a high content of chlorine and sulphur. This could cause problems regarding emission and corrosion, thus it should be taken into consideration during the process design and impacts assessment.

Another aspect to be taken into account is the high ash content that can represent a problem in the management of the system, in particular if the melting temperature of the ash is low (formation of slag). Results suggest that reeds seem a suitable feedstock according to its ash melting behaviour. It is worth to point out that both the sintering and the softening temperatures are

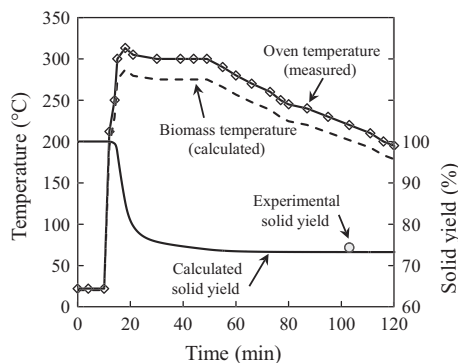


Fig. 6 Comparison between experimental and kinetic/finite elements modelling results for the reeds torrefaction test.

lower than the ash melting point (Table 1), 200–500 °C and 50–100 °C respectively.

Reeds are able to accumulate pollutants due to their phytodepuration potential (Weis & Weis, 2004). Thus, it is important to consider their heavy metals content. In fact, after thermochemical conversion processes most of the metals will be concentrated in the ashes. Metal concentrations are shown in Table 1, with particular high concentrations of manganese. Both in Chinese and Italian samples, the metals content in the leaves is generally higher than in the stem indicating the ability of *P. australis* to translocate metals to the shoots. However, as widely discussed in literature (Bonanno & Lo Giudice, 2010) most of the metals are accumulated within the roots. Therefore, by harvesting reeds for energy production metals might be again released into the environment. Reeds harvesting with the rootstock could thus be considered to enhance their phytoextraction capacities from the soil.

The calorimetric and ultimate analyses of torrefied reed denotes an increasing of the lower heating value and a decreasing of the H/C and O/C ratios (data not shown), in agreement with the literature (Bergman *et al.*, 2005; Prins *et al.*, 2006a). For example, Italian stem samples have been torrefied at 300 and 320 °C with a temperature programme characterized by a heating rate of 28 °C min⁻¹ until the process temperature is reached and then kept constant for 30 min. After the torrefaction treatment, these samples show a LHV increase of 5.2% and 11.4% respectively. The H/C ratio decreases by 17.4% and 19.1% respectively, whereas the O/C ratio by 4.1% and 11.3% respectively. Therefore, the higher the torrefaction temperature the higher the energy and carbon content of the residual biomass.

As far as it concerns reed thermal behaviour, as reed tissue can be considered as a lignocellulosic biomass, its thermal degradation profile might be compared with the one of lignin. In fact lignin degradation is known to start at relatively low temperatures, of 200–275 °C with the main process occurring around 400 °C (Rodrigues *et al.*, 2001), temperatures perfectly in accordance with the ones observed for reeds, both stems and leaves (Fig. 2).

Comparing the origin and the plant parts, the profiles do not change significantly their shape. However, the maximum peak temperatures of the two main reactions (B and C) differ according to the plant part and the origin. These temperature shifts of the thermal degradation reactions are most likely due to the higher lignin concentration of the stems.

For instance, thermal degradation of Chinese reed stems (Fig. 2a) starts at lower temperatures (280 °C) compared with Italian reed samples (290 °C). This temperature is even higher considering the third reaction

(C) showing a ΔT of 20 °C. Reed leaves show a similar trend (Fig. 2b), thermal degradation starts approximately 30 °C earlier in Italian leaves than in the Chinese ones. Degradative processes below 400 °C can be considered as primary decomposition involving single bond fragmentation as monomeric cleavage, whereas above 400 °C secondary thermolysis occurs with aromatization processes. In fact, the main reaction around 400 °C leads to the formation of aromatic compounds, namely phenolic, hydroxyl phenolic and guaiacyl-/syringyl-type compounds, most products having phenolic OH groups (Alén *et al.*, 1996). This is confirmed by the evolved gas analysis performed by means of TG/GC/MS (Fig. 3). Results of GC/MS analysis confirm that the second reaction around 280 °C releases acetic acid (m/z 60) and cyclic compounds as 3,5-dimethyl-1H-Pyrazole (m/z 96) and 2,4-dihydro-2-methoxy-2H-Pyran (m/z 114). The third reaction leads to the release of acetic acid (m/z 60), guaiacol (2-methoxy-Phenol, m/z 124), a known precursor of lignin and 2-Furanmethanol (m/z 96). Thermal degradation reactions are quite complex and involve several chain reactions and recombination radicals formed throughout the thermolysis. This might lead to ambiguous identification and interpretation of the evolved compounds. Further analysis will be necessary to better define and qualify the single compounds released during each reaction.

The moisture loss of biomass sample attributed to the first peak (A) was confirmed by the FTIR spectra recorded at 100 °C. At higher temperatures, i.e. around 300 °C, methanol (CH₃OH), acetic acid (CH₃COOH) and formic acid (HCOOH) could be detected. These three compounds are still present up to 350 °C but not at temperatures higher than 450–500 °C. In addition, carbon dioxide (CO₂) release increased from temperatures around 300 °C to temperatures around 350 °C and then decreased at around 450–500 °C. At this latter temperature methane (CH₄) could also be detected in the evolved gases. This is in accordance to thermodynamic equilibrium calculation, as well as the increasing trend of carbon monoxide (CO).

Final remarks

The application of advanced analytical techniques (TG/STA-IR-GC-MS) has given a useful insight into the thermal degradation process of common reeds (*P. australis*). In particular, the data collected through STA analysis have been used to tune up a kinetic/torrefaction model already developed, capable to predict the product yields.

The model has been tested simulating a reed torrefaction run occurring in a bench-scale apparatus, coupling the chemical analysis with a thermal simulation of the reactor carried out through a finite elements approach.

The resulting numerical tool seems to be suitable for the assessment of the torrefaction process performance.

Based on both modelling and experimental results, *P. australis* can be considered an interesting natural biomass resource both acting as a second-generation feedstock and as phytoextractant for its metal accumulation potential.

Further developments of this research will include the analysis of the liquid yield (obtained by means of the bench-scale apparatus), the subsequent refinement of the model calibration (in its solid–gas–liquid formulation) and the enhancement of the finite elements model through the implementation of the reagent media inside the reactor.

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