ISSN 1848-0071
620.92(436)=111
Recieved: 2015-12-01
Accepted: 2016-04-04
Professional paper

PROPERTIES OF BIOMASS AND BIOMASS WASTE FUELS FOR FLUIDIZED BED CONVERSION

MARKUS BŐSENHOFER, FRANZ WINTER

Institute of Chemical Engineering, Vienna University of Technology, Austria
e-mail: markus.boesenhofer@tuwien.ac.at

The energetic recovery of biomass and biomass waste has a long history in Austria. The available infrastructure consists of 17 fluidized bed combustors (FBC) with a total thermal capacity of 700 MW and three fluidized bed gasifiers with a total thermal capacity of 33 MW. Eight FBC plants have circulating beds while the other three have bubbling beds. In Austria, FBCs for biomass are employed in the heat and electricity producing industry, in the pulp and paper industry, and in the sewage sludge treatment. Additionally, the heat and electricity industry employs the three fluidized bed gasifiers. The applied fuel can be related to the respected industries: the heat and power industry usually utilizes biomass in form of wood chips, whereas the pulp and paper industry utilizes biomass waste like bark, waste wood and fibrous rejects. In this work the properties of biomass and biomass waste fuels of Austrian FBCs as well as the fuel impact on pre-processing and flue gas treatment are evaluated. In this context an overview of the utilized fuels is created and fuel properties like calorific value, content of impurities, availability, etc. are compared. The influences of the employed fuel on the flue gas treatment system are discussed. Thus, an additional overview of selected flue gas treatment system configurations is given. The main focus of this work is the comparison of fuels based on biomass and biomass waste and the investigation of their benefits and limitations. In order to do this, a prior characterization of selected biomass waste fuels based on literature is necessary.
Key words: fluidized bed conversion, biomass, biomass waste, fuel properties, fuel pre-processing, flue gas treatment.

Svojstva goriva od biomase i otpadne biomase pri pretvorbi u fluidiziranom sloju. Energetska oporaba biomase i otpada biomase ima dugu povijest u Austriji. Raspoloživa infrastruktura sastoji se od 17 komora izgaranja s fluidiziranim slojem (FBC) s ukupnom toplinskom snagom od 700 MW i tri rasplinjača s fluidiziranim slojem ukupne toplinske snage od 33 MW. Osam FBC postrojenja u izvedbi su cirkulirajućeg tipa, dok su ostala tri u mjehurastoj izvedbi. U Austriji su FBC na biomasu korišteni u proizvodnji toplinske i električne industrije, u industriji celuloze i papira, te u tretiranju kanalizacijskog mulja. Osim toga, industrija toplinske i električne energije koristi tri rasplinjača s fluidiziranim slojem. Primijenjena goriva može biti povezana s odgovarajućim industrijama: industrija za proizvodnju topline i energije obično koristi biomasu u obliku drvne sječke, dok industrija celuloze i papira koristi otpadnu biomasu poput kore, otpadnog drva i vlaknastih otpatka. U ovom radu se ocjenjuju svojstva goriva od biomase i otpada biomase austrijskog FBC kao i utjecaj goriva na pred-obradu i obradu dimnih plinova. U tom kontekstu daje se pregled korištenih goriva i uspoređuju se svojstva goriva kao što su kalorična vrijednost, sadržaj nečistoća, dostupnost i sl. Opisani su utjecaji korištenih goriva na obradu dimnih plinova. Stoga, dan je dodatni pregled odabrane konfiguracije sustava obrade dimnih plinova. Glavni fokus ovog rada je usporedba goriva dobivenih iz biomase i otpada biomase te istraživanje njihovih prednosti i ograničenja. Kako bi to mogli napraviti, nužna je prethodna karakterizacija izabranog goriva iz otpada biomase bazirana na literaturi.
Ključne riječi: pretvorba u fluidiziranom sloju, biomasa, otpad biomase, svojstva goriva, pred-obrada goriva, obrada dimnih plinova.

INTRODUCTION

In Austria, the utilization of biomass and biomass waste in fluidized bed combustors (FBC) is common. Common kinds of biomass are wood chips, fibrous rejects, waste wood, sawdust, fibrous sludge, or sewage sludge. In 2015 eleven FBC plants utilized biomass and biomass waste. Five of them employ almost exclusively sewage sludge and, additionally, three fluidized bed gasifiers (FBG) excusively employing wood chips exits, but only two of them are in operation.

UTILIZED BIOMASS FUELS IN AUSTRIA

In this section, an overview of the FBC plants in Austria utilizing biomass fuels, of the utilized fuels and the contents of selected impurities is given.

FBC plants in Austria utilizing biomass fuels

The existing infrastructure of biomass utilizing fluidized bed plants in Austria is shown in Table 1. The table also shows the thermal plant capacities, the utilized fuels and the related industry, which is either heat and power (HP), pulp and paper industry (PP) or sewage sludge treatment (SST).

Table 1. Austrian fluidized bed combustors utilizing biomass fuels, based on [1]
Tablica 1. Komore izgaranja u Austriji s fluidiziranim slojem koje za gorivo koriste biomasu, na temelju [1]

location	commissioning	furnace type[a]	thermal capacity [MW]	utilized biomass fuels	related industry[b]
Gratkorn 1	1981	CFBC	25	bark, sludge, rejects	PP
Bruck	1984	BFBC	15	bark, sludge, rejects	PP
Frantschach	1984	CFBC	61	bark, sewage sludge, rejects	PP
Pitten	1984	BFBC	60	sewage sludge, rejects	PP
Gratkorn 2	1986	CFBC	133	bark, sludge, rejects	PP
Lenzing	1987	CFBC	108	bark, waste wood, sludge, rejects	PP
Simmering I-III	1992	BFBC	3 x 20	sewage sludge	SST
Steyrermühl	1994	CFBC	48	bark, waste wood, wood chips, sludge	PP
Güssing	2001	FBG	8	waste wood, wood chips	HP
Bad Vöslau	2003	BFBC	1	sewage sludge	SST
Timelkam	2006	BFBC	49	bark, waste wood, wood chips, sawdust	HP
Hallein	2006	BFBC	30	wood chips	PP
Simmering	2006	CFBC	66	residual forest wood	HP
Heiligenkreuz	2006	BFBC	43	residual forest wood	HP
Oberwart	2008	FBG	10	wood chips	HP
Villach	2010	FBG	15	wood chips	HP
Großwilfersdorf	2011	BFBC	2.3	sewage sludge	SST

[a] BFBC … bubbling fluidized bed combustor, CFBC … circulating fluidized bed combustor, FBG … fluidized bed gasifier
[b] HP … heat and power, PP … pulp and paper, SST … sewage sludge treatment

Employed fuels in Austria

The utilized fuels vary among the different industries. The HP industry generally utilizes fuels with the highest quality, while the PP industry emloys mainly their own wastes like bark, rejects and fiber sludge. The SST industry sometimes adds low-quality biomass fuels like waste wood to the sewage sludge in order to ensure a minimum lower heating value (LHV) [2].

BIOMASS FUEL EVALUATION

The fuel evaluation is based on two steps: the first includes an estimation of the flue gas concentrations of the selected pollutants sulfur dioxid (SO_2), nitrous gases represented by nitric oxide (NO) and chlorine compounds represented by hydrochloric acid (HCl). The estimated pollutant concentrations are compared with legal limits according to Austrian law in order to analyze the requirements for the flue gas cleaning systems. In the second step, the requirements for the fuel pre-processing systems are analyzed.

Fuel impact on flue gas pollutant concentrations

The flue gas concentrations of the selected pollutants are estimated by a combustion calculation employing the fuel compositions of Table 2. Total conversion of fuel sulfur to SO_2 and chlorine to HCl and a conversion degree of 0.3 for fuel nitrogen to NO, as reported by [5], was assumed for the calculation.

Table 2. Properties of biomass fuels utilized by Austrian fluidized bed combustors, Source: [3,4]
Tablica 2. Svojstva biomase korištene kao gorivo u komorama izgaranja u Austriji s fluidiziranim slojem, izvor: [3,4]

fuel	LHV [MJ/kg daf[1]]		moisture content [wt-%]	ash content [wt-% dry]		sulfur [wt-% daf]		nitrogen [wt-% daf]		chlorine [mg/kg DM[2]]	
	min	max	max	min	max	min	max	min	max	min	max
bark	16.0	20.7	8	-	5	-	0.3	0.4	2.0	124	421
rejects	34.1	34.1	44	5	15	0.1	0.1	0.2	0.3	2709	8045
residual wood	18.2	23.5	43	-	27	-	0.3	0.1	1.2	34	1386
sawdust	17.2	20.4	8	-	2	-	0.0	0.1	0.2	336	336
sewage sludge	21.0	24.5	82	26	50	1.1	2.4	2.3	8.5	500	4000
fiber sludge	10.3	22.9	85	12	55	-	2.0	0.2	1.9	455	2326
waste wood	16.2	20.0	23	-	25	-	0.6	0.2	1.8	126	9800
wood chips	16.6	20.3	48	-	8	-	0.4	0.1	2.2	-	1100

[1] dry and ash free, [2] dry matter

In Austria the legal flue gas concentration limits for pollutants depend on the decision of approval. According to Austrian law there are several different possibilities for the approval depending on fuel and capacity. Thus, different legal emission limits exist. In this work the emission limits according to the Emission Protection Law for Boiler Installations [6] (Emissionsschutzgesetz für Kesselanlagen) and the EU directive 2010/75 [7] are employed, although emission limits according to other laws are lower than the limits according to the Emission Protection Law for Boiler Installations. The limits according to the Emission Protection Law for Boiler Installation are employed because they represent a kind of a minimum standard for flue gas quality. The legal limits for dry flue gas and a reference oxygen content of 6 vol-% for SO_2, NO_X (as NO_2) and hydrochloric acid (HCl) are at 200 mg/Nm³, 200 mg/Nm³ [8] and 10 mg/Nm³ [7], respectively. Since the legal limits are with reference to 6 vol-% oxygen, the calculated flue gas concentrations have to be converted for comparison (equation 1).

$$C_{i,ref\ state} = \frac{C_{O_2,air} - C_{O_2,ref\ state}}{C_{O_2,air} - C_{O_2,flue\ gas}} C_{i,flue\ gas} \quad (1)$$

$C_{i,ref\ state}$ and $C_{O2,ref\ state}$ are the concentration of component i in mg/Nm³ and O_2 in vol-%, respectively. $C_{O2,\ air}$ is the oxygen concentration in air and $C_{i,flue\ gas}$ and $C_{O2,\ flue\ gas}$ are the concentration of the componente i in mg/Nm³ and O_2 in vol-% in the flue gas.

Table 3. Calculated pollutant concentrations in flue gases of biomass fuels at the reference oxygen content

Tablica 3. Izračunate koncentracije onečišćujućih tvari u dimnim plinovima od biomase kao goriva na referentni sadržaj kisika

fuel	SO_2 [mg/Nm³]		NO_2 [mg/Nm³]		HCl [mg/Nm³]	
	min	max	min	max	min	max
bark	79	733	457	2275	17	51
rejects	137	151	203	246	273	625
residual wood	30	657	165	1504	0	188
sawdust	62	80	305	223	46	107
sewage sludge	2819	5167	2818	8982	65	443
fiber sludge	154	4640	322	2131	90	274
waste wood	0	1297	227	1827	15	1038
wood chips	0	1063	70	2587	0	137
legal limit	**200**		**200**		**10**	

Table 3. shows the calculated pollutant flue gas concentrations for the considered biomass fuels at the oxygen reference content. The results indicate that flue gas treatment is necessary in any case. Considering inclusion effects of flue gas components to ash or bed material [9] and other emission reduction effects emerging in plants, might results in polutant concentrations than presented in Table 3. Flue gas treatment is necessary even if these

effects would be considered in the calculation.

The SO_2 emissions of the utilized sludges and the NO_2 emissions of sewage sludge significantly exceed the legal emission limits. HCl emissions, Cl forms mainly HCl, are highly problematic in case of rejects, sewage sludge and waste wood.

The varying pollutant concentrations of the different fuels indicate that the flue gas treatment systems and especially the operating supplies vary depending on the utilized fuel. However, the flue gas treatment design is also influenced by the legal situation.

Fuel impact on pre-processing

FBC plants have higher requiremtents on fuel particle size than grate furnace plants [9]. Thus, solid fuels are usually chopped to obtain a suitable size distribution. In case of waste fuels, impurities like nails and other tramp iron have to be separated prior to chopping. [2]

Sludges have to be dried to obtain a specified solid content. If the solid content is too low, the mono-combustion of sludges is not possible and a support fuel is needed. Sludges are usually mechanically dried, but in some cases also thermal drying or/and solar drying is applied. The solid content varies for the different plants but is usually between 20 and 40 per cent [2].

SYSTEM CONFIGURATIONS

In this section common configura-tions of flue gas treatment systems and fuel pre-processing systems are given and discussed.

Flue gas treatment systems

Figure 1 describes the components and arangements of flue gas treatment systems employed for FBC plants utilizing biomass and biomass waste. According to [1], plants related to the heat and power industry usually employ selective non-catalytic reduction (SNCR) (B) or selective catalytic reduction (SCR) (D) and air staging for the NO_X control. Gravity separators (C) and fabric filters (F) are used for dust removal. Dry flue gas cleaning systems (E) are optionally employed before the fabric filters.

Plants related to the pulp and paper industry employ gravity seperators (C) and electric and/or fabric filters (F) for dust removal. Furthermore, some plants have dry flue gas cleaning systems (E) installed before the filters [1].

Plants related to the sewage sludge treatment industry usually have the most complex flue gas treatment systems. They consist of gravity and/or centrifugal separators (C), a dry flue gas cleaning system (E), electrostatic or fabric filters (F), a wet flue gas cleaning system (G), and a SCR in clean gas mode (H) [1].

Some plants throughout all industries can dose limestons or other additives into the combustion zone for flue gas de-accidification (A) [1]. Additionall, some of them use activated carbon filters as police filteres, but they are not discussed here.

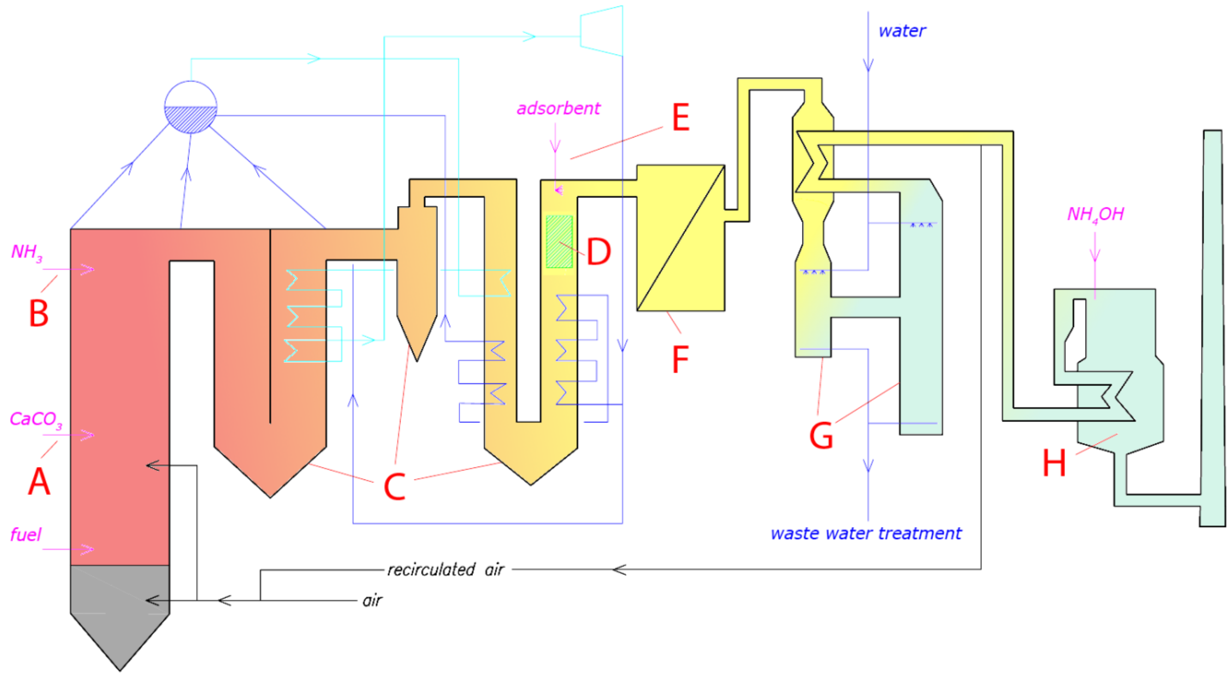

Figure 1. General system configuration of flue gas treatment systems of combustion plants. A) combustion zone flue gas deaccidifation B) selective non-catalytic reduction (SNCR) C) gravity and optional centrifugal separator D) selective catalytic reduction (SCR) in high dust mode E) dry flue gas cleaning system F) electrostatic and/or fabric filter G) wet flue gas cleaning system H) SCR clean gas mode, based on [1]

Slika 1. Opća konfiguracija sustava za obradu dimnih plinova postrojenja za izgaranje. A) komora izgaranja s fluidiziranim slojem B) selektivna ne-katalitička redukcija (SNCR) C) gravitacija i izborni centrifugalni separator D) selektivna katalitička redukcija (SCR) u načinu rada visoke prašine E) sustava za čišćenje suhih dimnih plinova F) elektrostatski i / ili filtar od tkanine G) sustava za čišćenje mokrih dimnih plinova H) način SCR čistog plin, na temelju [1]

Since the different plants were authorized according to different legal standards, no general statement concerning the impact of the fuel to the flue gas system is possible. The complexity of the flue gas treatment systems generally increases if waste fuels are utilized. Table 4 shows the flue gas treatement configurations of the plants from Table 4. Austrian fluidized bed combustors utilizing biomass fuels, based on [1].

.

Table 4. Installed flue gas cleaning equipment of Austrian fluidized bed combustors, Source: [2,10–15]
Tablica 4. Instalirana oprema za čišćenje dimnih plinova komora izgaranja u Austriji s fluidiziranim slojem, izvor: [2,10–15]

location	flue gas treatment system[1]
Gratkorn 1	C, F
Bruck	C, F
Frantschach	C, F
Pitten	A, B, C, E, F
Gratkorn 2	C, E, F
Lenzing	A, C, E, F
Simmering I-III	C, F, G, H, police filters
Steyrermühl	A, C, E, F
Güssing	F
Bad Vöslau	F, G
Timelkam	A, B, C, E, F
Hallein	B, C, E, F
Simmering	A, C, D, E, F
Heiligenkreuz	B, C, E, F
Oberwart	F
Villach	F
Großwilfersdorf	F, G

A: de acidification E: dry flue gas cleaning;
B: SNCR F: electrostatic and/or fabric filter
C: gravity and/or centrifugal separator G: wet flue gas cleaning system
H: SCR clean gas mode
D: SCR high-dust mode

Pre-processing systems

Fuel pre-processing systems for solid fuels generally consist of following steps: removal of impurities (ferrous, non-ferrous metals), shredding and sieving. The pre-processing of sludges includes the increase of the solid content throug drying. Three common types of drying are employed: solar drying, mechanical drying and thermal drying.

Bark, rejects, and sawdust are usually utilized as deliverd, wood chips are either delivered or produced out of wood at the power plant site. Depending on the quality of the rejects, they may have to be dried and metals have to be separated. The other fuels from Table 2 have to be pre-processed anyway. Impurities have to be removed from waste wood before chopping, while residual wood is chopped as delivered. Due to the properties of fiber sludges mechanical drying is sufficient to reach an acceptable solid content. In contrast, sewage sludges are usually thermally dried with waste heat or solar heat. [2]

SUMMARY AND CONCLUSION

This work gives an overview of Austrian FBC plants utilizing biomass and biomass waste as well as the utilizedfuel typesand their contamination with sulfur, nitrogen and chlorine. In addition an overview of common flue gas treatment and fuel pre-processing systems is given.

An attempt has been made to detect a relationship between the fuel properties (especially quality) and the flue gas treatment systems and the fuel pre-processing systems. A combustion calculation for the considered impurities clearly shows that lower quality fuels (waste) require more complex flue gas cleaning systems. Nevertheless, the decision of approval has also a significant influence on the complexity. Concluding no general statements can be made; the complexity of the flue gas treatment system varies on a case-by-case basis.

Acknowledgement

The authors thank the Austrian Research Promotion Agency (FFG) to support the project "IEA FBC – Implementing Agreement" (# 843139) and the IEA FBC – Implementing Agreement for fruitful discussions.

REFERENCES

[1] A. Purgar, F. Winter, Chemie Ingenieur Technik 85 (2013) 303–307.

[2] J. Stubenvoll, Technische Maßnahmen zur Minderung der Staub- und NOx-Emissionen NO_X bei Wirbelschicht- und Laugenverbrennungskesseln (Technical measueres for the reduction of dust- and NO_X-emissionsduring fluidized-bed combustion), Umweltbundesamt GmbH, Vienna, 2007.

[3] Energy Research Centre of the Netherlands (ECN), Phyllis2 database for biomass and waste, acessed 04.03.2016, available at http://www.ecn.nl/phyllis2.

[4] K. Reisinger, C. Haslinger, M. Herger, H. Hofbauer, BIOBIB- a Database for Biofuels, THERMIE - Conference: Renewable Energy Databases, Harwell, United Kingdom, 1996, available at: http://www.vt.tuwien.ac.at/biobib/oxford.html.

[5] F. Winter, C. Wartha, H. Hofbauer, in: A. Bridgwater, D. Boocock (Eds.), Developments in Thermochemical Biomass Conversion, Springer Netherlands, 1997, pp. 1303-1315.

[6] Austria, Feuerungsanlagen-Verordnung (Combustion Plants Regulation), StF: BGBl. II Nr. 331/1997, federal law consolidated version 19.09.2011 (BGBl. II Nr. 312/2011).

[7] Europen Parliament, Directive on industrial emissions (integrated pollution prevention and control), Directive 2010/75/EU, Directive of the

European Parliament and of the Council, 2010 L334/17.

[8] Austria, Emissionsschutzgesetz für Kesselanlagen (Emission protection law for boiler installations), StF: BGBl. I Nr. 127/2013, federal law consolidated version 09.07.2015 (BGBl. I Nr. 81/2015).

[9] M. Lackner (editor), F. Winter (editor), A. K. Agarwal (editor), Handbook of combustion, Wiley-VCH-Verl, Weinheim, 2010.

[10] Wien Energie GmbH, Plant description biomass power plant Simmering, 2016, http://www.wienenergie.at/biomassekraftwerk, accessed 05.03.2016.

[11] Energie AG, Umwelterklärung: Für das Kraftwerk Timelkam (environmental statement for the power plant Timelkam, 2013, http://www.energieag.at/eag_at/resources/ 339536979223644121_1032824194389255355_XlFTNbBZ.pdf, accessed 05.03.2016.

[12] Energie Burgenland GmbH, Power plant description, 2016, http://www.energieburgenland.at/oekoenergie/biomasse/innovation/biomassevergasung.html, accessed 05.03.2016.

[13] H. Stoiber, Stand der Umsetzung der Abfallverbrennungsverordnung – Endbericht (progress on the implementation of the waste incineration directive – final report), Umweltbundesamt GmbH, Vienna, 2007.

[14] H. Knautz, C. Ramakrishnan, P. Ramharter, R. Zweiler, Decentralized energy utilization in fluidized beds: Incineration of low calorific fuels (<7MJ/kg) in small to medium size plants, 19th International Conference on Fluidized Bed Combustion (FRBC), Vienna, Austria, 2006.

[15] A. Glatzer, H. Schild, Operational experiences from Austrias first medium sized sewage sludge mono-incineration plant in Großwilfersdorf / Austria, 4th Central European Biomass Conference, Graz, Austria, 2014.