



Dipl.-Ing. Sascha Krüger, Prof. Dr.-Ing. Michael Beckmann, Bauhaus University Weimar/Thuringia/Germany.

## 1

The importance of biomass, that is plant materials and bio waste, as initial product for quality composts and biomass fuels is increasing steadily. First of all, increased demand for quality composts is noticed and, secondly, there is an increased demand for biomass fuels as CO<sub>2</sub>-neutral energy source due to the treatment requirements for the feed.

Depending on the process and raw compost composition there will be differing amounts of heavy and non-rotting material streams. These stress the operation of a compost plant from an economic viewpoint. However, due to the process, a certain amount of not easily rotting material must be recycled as bulking agents. This process has a negative impact on the total throughput of a compost plant.

A further economical impairment is due to the fluctuating raw material composition which can differ due to the seasons of a year. In other words, the portion of not easily rotting material in the total mass will vary continuously. In addition, the demand for compost varies from season to season.

In this paper a concept is introduced which focuses on the production of quality compost and biomass fuel out of plant materials and bio waste. This enables the possibility to mainly disconnect compost operation from seasonal fluctuations in regard to demand for compost. The introduced concept makes it possible to vary the ratio between compost and fuel production in broad sectors and, consequently, react in a flexible manner to supply and demand in the specific sector.

Furthermore, the focus is on energy utilization of biomass fuels. In the production process a targeted material stream management will influence the fuel-technical parameters. This means that the chemical, mechanical, calorific and reaction-technical properties will be adjusted to the subsequent thermal utilization process.

In comparison with fossil fuels, a higher chlorine content is typical for many biomass fuels. In contrast to most substitute fuels from waste (out of mechanical-biological separation of municipal solid waste), the biomass fuels have over 90 ma.-% of the chlorine content in inorganic form. In this connection the corrosion and fouling potential of biomass fuels will also be discussed.

## 2

With the decomposition of biomass it is intended to convert biological decomposable waste into useable compost.

The decomposition process can generally be split into two phases. In the so-called high rate phase or intensive phase the material remains for some days to some weeks depending on the specific decomposition process. A so-called fresh compost forms. The second phase, the curing phase or subsequent rotting phase, lasts from approximately 4 to 12 weeks. The fresh compost turns into finished compost.

The decomposition processes that are offered most often on the market can be roughly shown in Fig. 1.

characteristic type	form		ventilation		mechanical agitation		arrangement			features
	open	enclosed	non forced flow	forced	static	dynamic	bulk material		compactet	
							pile	modular pile		
open pile composting	x		x			x	x			- trianguale- or table pile - high rate phase 4 to 6 weeks - total rotting period 3 to 6 months
enclosed pile composting		x		x		x	x			- table pile or rotting hall - high rate phase approx. 2 weeks - total rotting period 6 to 8 weeks
drum composting		x		x		x				- bulk material in rotating drum- - high rate phase 1 to 7 days - total rotting period 6 to 8 weeks
windrow / tunnel composting	x <sup>1</sup>	x <sup>2</sup>		x		x		x		- high rate phase in separated windrows/tunnels - curing phase as open pile - high rate phase 4 to 8 days - total rotting period 12 weeks
box / container / cell composting		x		x	x			x		- high rate phase in separated boxes - curing phase as open pile - high rate phase 4 to 8 days - total rotting period 12 weeks
Brikollari-process		x	x		x				x	- high rate phase as shaped product - curing phase as open pile - high rate phase 5 to 6 weeks - total rotting periode 13 to 16 weeks

<sup>1</sup>) windrow composting open to the top

<sup>2</sup>) tunnel composting closed to the top

Fig. 1. *Decomposition methods, characteristics and residence times.*

All processes are liable to seasonal fluctuations regarding to the raw compost composition and the sales potential of compost.

From an economical and ecological point of view it makes sense to remove the not easy rotting material – which is needed as a bulking agent during the decomposition process – after the first throughput.

These considerations must be seen in connection with the steadily growing demand for quality compost. Prognoses state that there will be a continuously growing demand and that the days of overproduction are over [17].

### 3

Based on the above-mentioned objective to prevent large amounts of material to be returned, seasonal fluctuations and energetic utilization of wood from hard to compost material, a process is described in the following which is already in a test operation phase in the compost operation plant located in Weira, Thuringa, Germany.

The developed process for the production of briquettes out of biomass for further use as fuel is roughly described in the following in connection with a simplified plant scheme shown in Fig. 2.

The process can be split into the three main sections A to C:

- A) Rotting,
- B) Compost production,
- C) Briquette-making.

#### 3.1 Rotting – Main Section A

The main section A *rotting* (Fig. 2) mainly consists of the compost plant and process steps:

- A.1 bin,
- A.2 agitation,
- A.3 high rate phase,
- A.4 curing phase 1,
- A.5 curing phase 2.

Bio waste (plants, garden waste, food waste, vegetables) from municipal collection is charged via bin A.1 to the plant and subsequently sent via wheel loaders (A.2) to multiple-stage rotting (A.3 to A.5). The duration of high rate phase rotting, curing phase 1 and curing phase 2 is approximately 10 days for each stage. Agitation is done in the meantime with machinery.

The rotting loss is approximately 30 ma.-% of the input material. With an input mass stream of approximately 60,000 t/a, the rotting loss is approximately 18,000 t/a. Consequently, approximately 42,000 t/a remain as rotting material. The rotting material still contains a significant share of wood and must be further prepared mechanically in main section B.

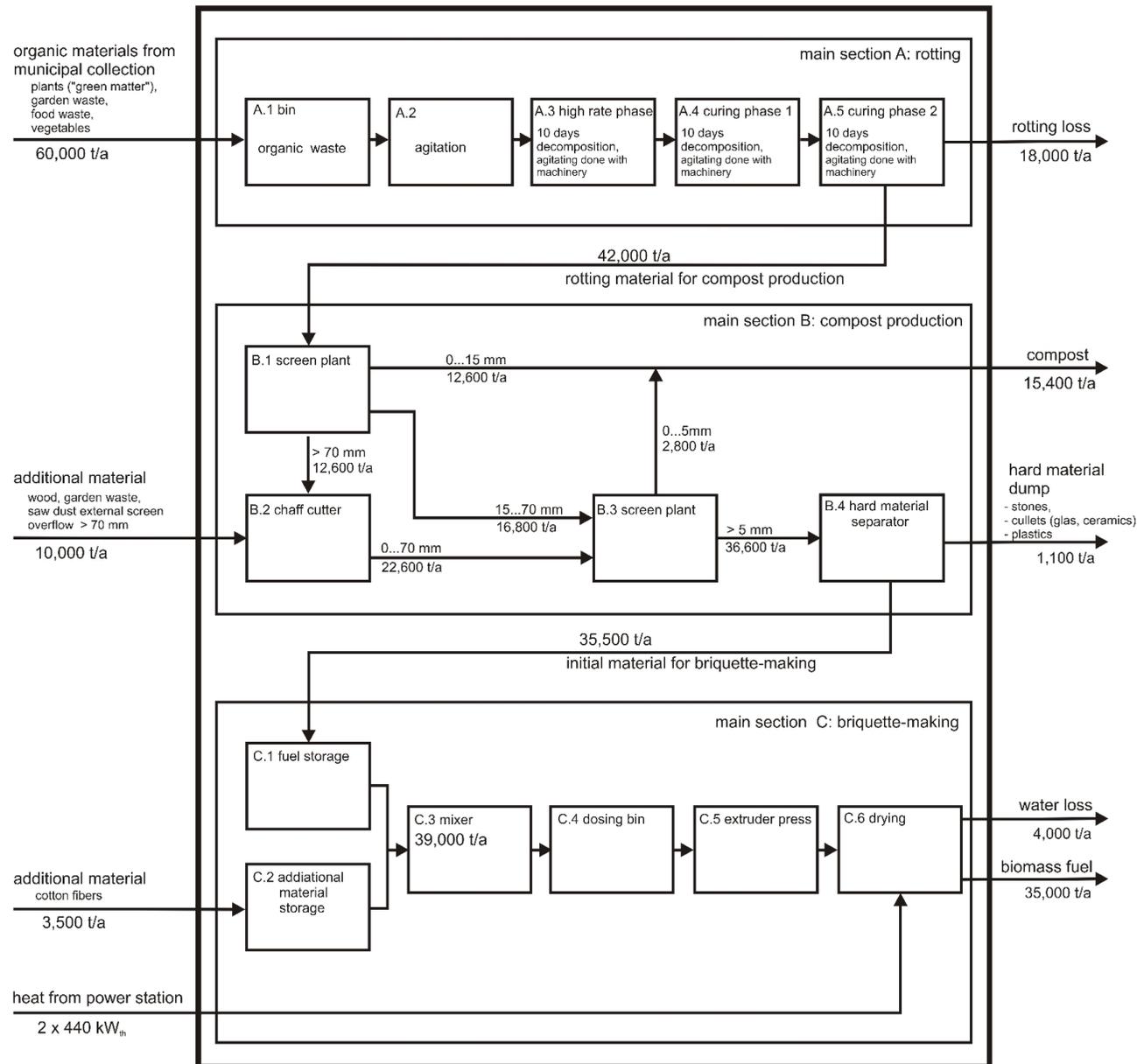


Fig. 2. Schematic illustration of the combined process.

### 3.2 Compost Production – Main Section B

The main section B *compost production* (Fig. 2) serves the further mechanical preparation of the rotting material with the objective of separating a compost fraction, high calorific value biomass fraction for further fuel briquette-making and hard material fraction for the dump site. The main section B mainly consists of

- B.1 screen plant,
- B.2 chaff cutter,
- B.3 screen plant,
- B.4 hard material separator.

The screen plant B.1 is a star screen. In a star screen the material gets screened by rotating stars with a distance piece between each star. In one screen different distances between the stars (separation sections) can be applied over the length of the screen. Underneath each section belts carry away the material. The oversize comes out at the end of the screen.

In the chaff cutter B.2 is the material is conveyed by a scraper floor to a heavy roller with oscillating bearings which pushes the material into the shredding chamber. In the shredding chamber the material is treated by a heavy gyrating flail drum.

The screen plant B.3 is a drum screen. The material is introduced into the horizontal arranged rotating drum by a transport screw. Depending on the mesh size of the holes in the drum, material can fall through the wall of the drum. The oversize comes out at the end of the drum.

The hard material separator B.4 sorts out materials like stones and cullet (debris of ceramics and glass) by a linear motion design and – if still contained metals with a magnetic separator. These materials can not be used in the further process. Plastics – which are only contained in small amounts are also sorted out, because the end product (biomass briquettes) should not contain synthetic materials.

The rotting material from main section A (42,000 t/a) is charged to the screen plant B.1 in which a separation of three fractions takes place according to the screen widths:

- Fine fraction B.1 (0 to 15 mm) for further use as compost with a mass share of approx. 30 ma.-% of the input to screen plant B1, that is approx. 12,600 t/a,
- Medium fraction B.1 (15 to 70mm) with a mass share of approx. 40 ma.-% of the input to screen plant B.1, that is approx. 16,800 t/a,
- Coarse fraction B.1 (> 70mm) with a mass share of approx. 30 ma.-% of the input to screen plant B.1, that is approx. 12,600 t/a.

The coarse fraction B.1 (>70 mm) is crushed in the chaff cutter B.2 together with the coarse fraction coming from the outside out of the external preparation of biogenic

materials (approximately 10,000 t/a). Both coarse fractions mainly consist of pieces of wood.

The crushed material (approx. 22,600 t/a) is charged together with the medium fraction B.1 to screen plant B.3. This screen plant handles the separation of the

- Fine fraction B.3 (0 to 5 mm) for further use as compost with a mass share of approximately 7 ma.-% of the input to screen plant B.3, that is approx. 2,800 t/a and
- Coarse fraction B.3 (> 5mm) with a mass share of approx. 93 ma.-% of the input to screen plant B.3, that is approx. 36,000 t/a.

For further separation of trash materials the coarse fraction B.3 is sent over a hard material separator B.4:

- The fraction free of hard materials now leaves main section B as initial material for briquette-making (approx. 97 ma.-% of the input to the hard material separator B.4, that is approx. 35,000 t/a).
- The disturbing materials (approx. 3 ma.-% of the input to the hard material separator B.4, that is approx. 1,100 t/a) are sent to the dump.

### 3.3 Briquette-making – Main Section C

In main section C *briquette-making* (Fig. 2) the material prepared in the main section B (approx. 35,000 t/a) is pressed into compact briquettes together with additional materials (amendment) (approx. 3,500 t/a). Main section C includes the process steps and facilities:

- C.1 fuel storage,
- C.2 additional material storage,
- C.3 mixer,
- C.4 proportioning (dosing) bin,
- C.5 extruder press,
- C.6 drying.

The material prepared in main section B is first charged into fuel storage C.1 and then sent in to mixer C.3 together with additional materials (e.g. cotton) out of the additional material storage C.2. The share of the additional materials is approximately 100 kg additional materials per 1,000 kg processed material. Then the mixture is sent to a dosing bin C.4 and from there on to the extruder press C.5. The extruder press compacts the material to briquettes with a square cross-section having an edge length of approximately 70 mm (Fig. 3) and a length of approximately 100 to 200 mm (Fig. 4). Then the briquettes are further stabilized by drying (C.6).

Based on a water content of the briquettes before drying of approximately  $w = 30 \text{ ma.-%}$ , it is intended to achieve a water content (final moisture) of  $25 \text{ ma.-%} \leq w \leq 15 \text{ ma.-%}$  after drying. One should get approximately 35,500 t/a briquettes based on a water content  $w = 22 \text{ ma.-%}$  after drying.



Fig. 3. *Biomass briquette, cross-section.*



Fig. 4. *Biomass briquette, longitudinal view.*

### 3.4 Advantages of the Process to Enlarge Throughput of the Plant

For standard decomposition processes using bio waste from municipal collection the duration of the rotting process is approximately 10 weeks for one throughput. Usually the heavy to compost materials, such as wood, are already separated after rotting from the produced compost and sent back to high rate phase. The higher the share of heavy to compost materials is, the higher the amount that must be returned. Consequently, operational costs increase and profit declines.

From the process described here the heavy to compost materials – generally wood pieces – are already separated during first rotting and pressed to biomass briquettes after further mechanical preparation/processing steps. By separating the hard to compost materials with the objective of fuel production, the return of this fraction (see above) is avoided. Furthermore, rotting time can be significantly reduced to 30 days (approximately 4 weeks compared to 10 weeks). During this shortened rotting time only easy to compost materials, such as grass, leaves and kitchen waste, are turned into compost. The compost has been examined by the Federal Compost Quality Association (Bundesgütegemeinschaft Kompost e.V.) and has received the compost quality stamp [12].

The separation of the heavy to compost fraction and its further preparation to a biomass fuel briquette reduce the burden on operations in a compost plant.

## 4

Considering the current situation of the biomass fuel market there are good marketing possibilities for biomass briquettes. The biomass briquettes can be used in combustion plants (e.g. larger plants with steam generator, smaller plants for heating) and for gasification processes (e.g. small gasifiers with gas motor behind). The fuel-technical properties are decisive for the specific use of these briquettes. These properties must suit the intended application (type of combustion or gasifier). Specific properties to mention are the calorific value, ash content, water content, burnout behavior, mechanical strength, so-called fire resistance and trace materials.

Analysis values of the prepared material for briquette-making [14] (“finished mixture“; according to C.3 in Fig. 4) and for the finished briquettes, when compared with the fuel criteria according to RAL-GZ 428 (Institute for Quality Certification and Designation) (RAL quality stamp) indicate, that a good quality is achieved (Table 1). A higher chlorine content is typical for many biomass fuels in comparison with fossil fuels. In contrast to most substitute fuels out of refuse (from mechanical-biological preparation/processing of municipal waste), over 90 ma.-% of the chlorine content is in inorganic form with biomass fuels. The same applies to the biomass briquettes discussed here. In this connection the corrosion and contamination potential will be discussed in more detail later on. Depending on the amendments (see main section B and C in Fig. 2) and the raw material the composition of the end product may vary

From the process discussed here there are several possibilities, based on process control, to have a targeted influence on the fuel-technical properties of the biomass briquettes in order to react to varying requirements of the power plant operators. The following gives a brief survey of the fuel-technical properties.

Sample		RAL-GZ 428/5 and 428/3	finished mixture (example) <sup>1</sup>	briquette, before drying (example) <sup>1</sup>
water	[ma.-%]	≤20	20.7	17.9
ash 815 °C	[ma.-%]	-	11.0	35.4
heating value	[MJ/kg] <sub>wf</sub>		18,730	13,760
arsenic	[mg/kg] <sub>wf</sub>	≤2	≤2	≤2
lead	[mg/kg] <sub>wf</sub>	≤30	32	60
cadmium	[mg/kg] <sub>wf</sub>	≤2	<0.6	1.0
chrome total	[mg/kg] <sub>wf</sub>	≤30	31	177
copper	[mg/kg] <sub>wf</sub>	≤20	76	171
mercury	[mg/kg] <sub>wf</sub>	≤0.4	0.36	<0.07
fluorine total	[mg/kg] <sub>wf</sub>	≤100	62	87
chlorine total*	[mg/kg] <sub>wf</sub>	≤600	3,100	4,300
chloride (Cl), inorganic.	[mg/kg] <sub>wf</sub>		not determined	4,210
PCP	[mg/kg] <sub>wf</sub>	≤3	≤0.05	≤0.05
PCB	[mg/kg] <sub>wf</sub>	≤50	0.118	<0.005

<sup>1)</sup> The shown examples don't derive from the same raw material.

Tab. 1. Fuel criteria according to RAL-GZ 428 and analysis data “finished mixture“ and briquette (examples).

\* Chlorine contents of various biomasses [15] (examples); Cl in [mg/kg]<sub>wf</sub>: wheat grain 673; rice grain 567; rice huls 673; bio compost 1339; wheat straw 3300; grass 7315.

#### 4.1 Targeted Setting of Fuel-Technical Parameters

Fuel-technical properties can be described by

- mechanical,

- chemical,
- calorific,
- and reaction-technical parameters [3] [7].

For the production process of the biomass briquettes the setting of fuel-technical parameters can be specifically accomplished by

- targeted material flow management of the input streams, including additional materials
- adaptation of process parameters
  - for separation and crushing processes,
  - for pressing process and
  - for drying.

For example, by changing the screen mesh width (e.g. in screen plant B.1) the compost share in the screen overflow can be increased (reduce mesh width) or reduced (increase mesh width). Furthermore, the share or mixture of additional materials at B.2 (e.g. wood share) or C.3 (e.g. cotton) can be set variably. This enables setting the calorific value, strength or ash content of the briquettes. These parameters can be further influenced by varying the incline and frequency of the flip-flow screen at screen plant B.3 and at the hard material separator B.4. One also can adjust the fire resistance of the briquettes by way of the parameters for the briquette-making process (e.g. grain size, grain size distribution, water content, additional materials, briquette size, pressing pressure of the extruder press). During final drying (C.6) the calorific value and the strength of the briquettes can be further influenced.

In addition to the fuel-technical analyses (elementary and trace compositions, calorific value and ash melt behavior), examination of the combustion behavior in a batch reactor [8] was done and tests were conducted in a biomass incinerator with a grate system (mixture out of 80 ma.-% old wood and 20 ma.-% biomass briquettes). The briquettes showed the same ignition and burn behavior in the batch reactor and biomass incinerator. As shown in Fig. 5, the initial shape of the briquette is well maintained in the burnout zone of the grate of the biomass incinerator. This provides good fire resistance, low decay tendency and reduced danger of dust discharge. The burnout of the briquette was almost complete at the ash discharge of the combustion grid and in the batch reactor (Fig. 6)



Fig. 5. Biomass briquette, burnout zone of the grate.



Fig. 6. Biomass briquette, burnout, batch reactor.

In section 4.2 more information is given about the examinations in the batch reactor in connection with chlorine release and corrosion potential.

#### 4.2 Corrosion and Contamination Tendency of Biomass Fuels

In order to evaluate the corrosion potential of a fuel it is not only sufficient to determine the chlorine content in the fuel. One must further consider the type of bond (organic, inorganic), the compound itself (e.g. PVC, KCl, NaCl) and the complex action of further fuel components such as alkalis, sulfur, heavy metals (mainly zinc and lead), ash content and ash melt behavior. Some knowledge has already been gained about the incineration of fossil fuels with high chlorine (e.g. [19]) respectively high salt contents (e.g. [10]) and municipal solid waste incineration (e.g. [11]). This knowledge gives important information about the corrosion potential in connection with the use of biomass fuels in thermal processes.

For evaluating the corrosion potential of a fuel, the bond type of the chlorine (organic or inorganic) must be considered in addition to the already mentioned chlorine content. Chlorine with an organic bond is usually found in fuels with a high content of plastics (mainly PVC) such as RDF (Refuse Derived Fuel). The chlorine share with inorganic bond is at maximum 2 % with these fuels [16]. It is known from examinations focusing on the thermal decomposition of PVC in helium atmosphere and a heating-up rate of 20 K/min that at approximately 300 °C the separation of chlorine is practically quantitatively and HCl forms [18]. In contrast to RDF, approximately 95 % of the total chlorine content of biomass briquettes (produced from fractions of compost plants) is present in the form of alkali and alkaline earth chlorides (inorganic bonded chlorine) which can be released as chlorides (Fig. 7) depending on the temperature level and SO<sub>2</sub>-concentration or released by way of sulfating reactions as sulfates with the result of chlorine formation (HCl and Cl<sub>2</sub>). With the combustion waste gas these volatile chlorides are transported to the convective heat exchanger surfaces. Since the various salt species (alkali and alkaline earth chlorides) enter saturation at different temperatures there will be a fractioned deposition of the salts in the deposits on the heat exchanger surfaces [22], [23].

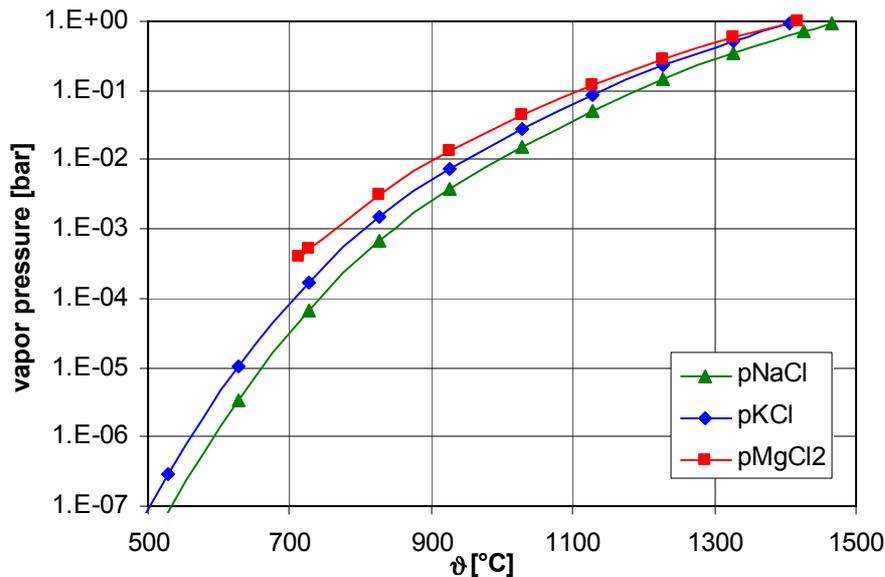


Fig. 7. Vapor pressure for NaCl, KCl and MgCl<sub>2</sub> vs. temperature [9].

Considering this situation combustion tests were conducted with the biomass briquettes in a batch reactor. For the qualitative determination of the components in the combustion gas, which can form deposits on *cold* steam generator walls and pipes, a probe cooled with compressed air was installed. With combustion chamber temperatures in the range of 900 to 1,000 °C, the surface temperature of the probe was cooled down to approximately 300 °C. At this *cooling spot* deposits formed which were then examined in the lab in regard to their chlorine content. Only slight deposits were found on the probe. The chlorine content of coatings was 5 to 7 ma.-%. This corresponds to the standard values of chlorine contents in the deposits of biomass combustion plants. In the deposits of municipal solid waste incinerators between 5 and 15 ma.-% chlorine is found depending on the examined area. In regard to the corrosion risk it must further be pointed out that in biomass fuels (e.g. wood pellets or garden waste) the sulfur to chlorine ratio is significantly lower compared to the standard fuels such as lignite or coal (Fig. 8).

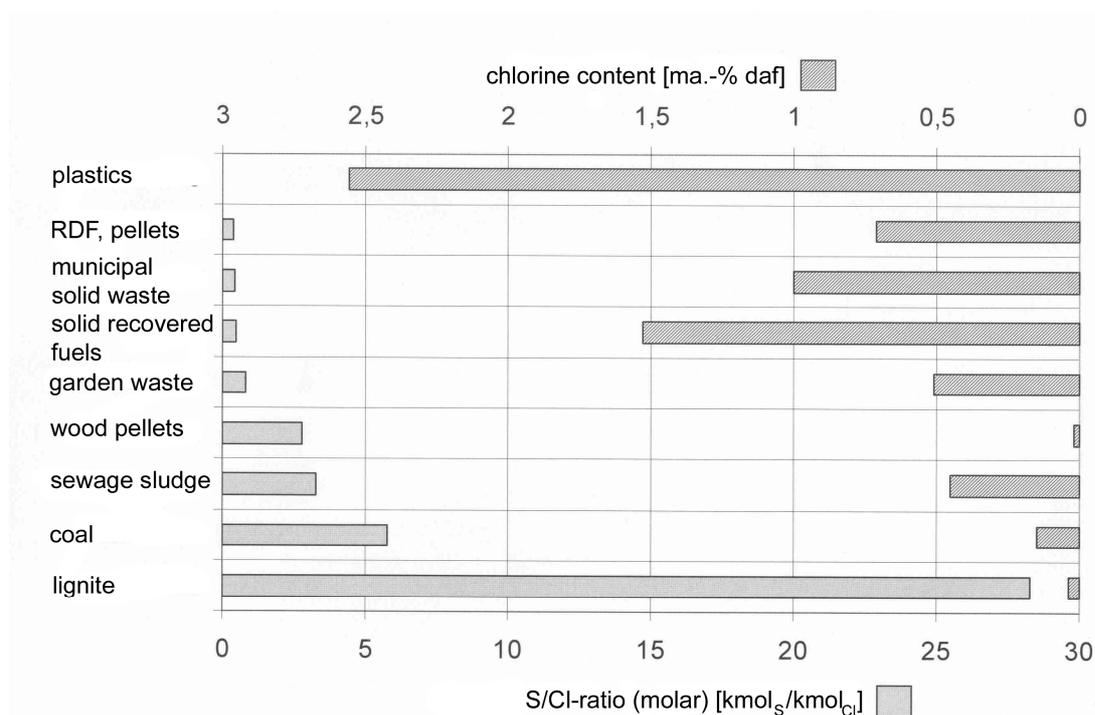


Fig. 8. Chlorine content and molar ratio sulfur to chlorine for selected standard fuels, biomass fuels and RDF [9].

Sources: Plastics, sewage sludge, lignite, coal: [1]; RDF, pellets, garden waste: [25]; municipal solid waste: [2], solid recovered fuels: [24]; wood pellets: [13].

The corrosion potential is decisively influenced by the sulfur content in the fuel, respectively the  $\text{SO}_2/\text{SO}_3$ -concentration in the flue gas [9]. Operations at coal fired power plants showed that an increased sulfur to chlorine ratio in the fuel reduces its corrosion potential. The damages or importance of the coatings and coating development as cause of damages and the dynamics of connected damaging processes are described in [11], [22], [20].

The so-called sulfating reaction for chlorides is decisive, that means the transformation from chloride salts to sulfates. With very low  $\text{SO}_2$ , respectively  $\text{SO}_3$ , concentrations there are already alkali and alkaline earth salts in sulfatic form (as sulfates). The chlorine is driven out of the deposits and consequently the corrosion potential of the deposits is reduced.

There are very complex chemical interactions during the thermal treatment of biomass fuels. Furthermore, the specific process parameters for incineration, respectively gasification (e.g. air ratio, primary to secondary air ratio), have a major influence on the corrosion and contamination of the heat exchanger surfaces. In addition, the corrosion and contamination behavior upon using biomass fuels in incinerators cannot be simply "scaled-up" from a test or pilot scale to industrial plants.

One must generally conduct tests in the specific plants in order to obtain information about contamination and corrosion so as to optimize plant operations (upon using a specific fuel). Concerning fuels with unknown corrosion potential the willingness of plant operators to conduct long-term tests is understandably low because of the potential danger of damages. There is, however, the possibility of conducting the following short-term examinations to first estimate the corrosion and contamination potential of a specific fuel or plant operation:

- Ash to salt proportion (ASP) examination in the waste gas stream (approx. 1 day),
- Online measurement of heat flux density on the steam generator (approx. 1 week).

One can obtain specific information about the corrosion potential of the incineration products in the flue gas with the assistance of the ash to salt proportion (ASP) of the particle loads in the waste gas. It is thus possible to estimate the contamination and corrosion tendencies depending on the given or specifically implemented operation situation (e.g. by selecting a specific fuel). To carry out the ASP measurement a special probe is installed in the flue gas stream. The probe separates particles out of the flue gas stream. Generally these measurements are done approximately 5 to 10 times a day as part of an examination campaign and 2 to 4 measuring days per operation variation are integrated into one result. The linkage of the results from these measurements to long-term experience, comparisons with other plants and results from plant shutdown inspections enable an estimation of the corrosion and contamination potential of the operational situation at the time of the measurement. Corresponding procedures are being developed as part of research projects and plant operation examinations [20], [21].

A further measuring method to estimate the contamination potential of a fuel involves the online heat flux measurement on membrane walls of steam generators of incineration plants [6], [4], [5]. This method enables measurement of the operation-specific heat resistances (deposit layers) on the membrane walls of steam generators. For conducting the heat flux measurements, thermocouples are fixated on the outside of the fin of the membrane wall and at the outer vertex of the tubes of the membrane wall. Using the temperature difference between the two measuring locations, it is possible to calculate the heat flux density on the membrane wall, respectively changes of the heat flux density in regard to location and time. If during current operation of the plant a fuel with high contamination potential is charged, the resulting formation of deposit layers can be directly detected. Consequently, no long-term tests in industrial boilers are necessary in order to determine the contamination potential of a fuel.

## 5

The objective of the process described here is, among other things, the concurrent production of quality compost and biomass fuel out of bio and plant material waste.

The operation parameters can be varied to the extent that the ratio of the amount of compost and fuel as well as the quality of compost and fuel can be set in wide ranges.

Consequently, plant operation in the compost plant can be largely disconnected from seasonal fluctuations of raw material composition and demand for compost.

The fuel-technical analyses of the biomass fuel, examinations in the batch reactor and biomass incinerator show that the fuel is well suited in regard to its ignition and burnout behavior. Further examinations involving deposit formation, corrosion tendency and connected optimization of fuel quality during production must be conducted for each new application case.

Examinations are required for the specific operation plant due to the complex interaction of fuel components and process parameters during thermal utilization of the biomass briquettes. Estimates of contamination and corrosion tendencies are already possible with short-term analyses and measuring methods such as ASP and online heat flux density measurement. Consequently, the danger of damages, as is given for long-term tests, is very low.

**6**

- [1] Bachhiesl, M.; Tauschitz, J.; Zefferer, H.; Zellinger, G.: Untersuchungen zur thermischen Verwertung von Biomasse und heizwertreichen Abfallfraktionen als Sekundärbrennstoffe in Wärmekraftwerken. Forschung im Verbund Schriftenreihe Band 73, 2001.
- [2] Barin, I.; Igelbüscher, A.; Zenz, F.-R. (ZEUS GmbH): Thermodynamische Analyse der Verfahren zur thermischen Müllentsorgung. Studie im Auftrag des Landesumweltamtes Nordrhein-Westfalen, 1995.
- [3] Beckmann, M.; Horeni, M.; Scholz, R.; Rüppel, F.: Notwendigkeit der Charakterisierung von Ersatzbrennstoffen. Erschienen in: Thomé-Kozmiensky, K. J. (Hrsg.): Ersatzbrennstoffe 3- Immissions- und Gewässerschutz, Qualitätssicherung, Logistik und Verwertung, Deponierung der Schwerfraktion. TK-Verlag Thomé-Kozmiensky, Dez. 2003, S. 213-230, ISBN 3-935317-15-8.
- [4] Beckmann, M.; Krüger, S.; Spiegel, W.: Charakterisierung und messtechnische Erfassung von betriebsspezifischen Wärmewiderständen an Membranwänden in Abfall und Biomasseverbrennungsanlagen. Erschienen in „Korrosionsforum 2“, Okt. 2005, Herausgeber: Born, M..
- [5] Beckmann, M.; Krüger, S: A Method for Non-Invasive Online Heat Flux Detection on Membrane Walls of Steam Generators, IT3 Conference, Savannah, Georgia, May 2006.
- [6] Beckmann, M.; Krüger, S: Online Heat Flux Measurement on Membrane Walls of Steam Generators of Municipal Solid Waste Incinerators, IT3 Conference, Houston, Texas, May 2005.
- [7] Beckmann, M.; Scholz, R.: Biomasse und Ersatzbrennstoffe als schwierige Brennstoffe. Erschienen in: Thomé-Kozmiensky, K. J.; Beckmann, M. (Hrsg.): Ersatzbrennstoffe und Biomasse zur Substitution fossiler Brennstoffe. TK-Verlag Thomé-Kozmiensky, Nov. 2006, S. 105-137, ISBN 3-935317-24-7.
- [8] Beckmann, M.; Scholz, R.: Zum Feststoffumsatz bei Rückständen in Rostsystemen. Brennstoff-Wärme-Kraft (BWK), Bd. 46, Nr. 5, 1994, pp. 218-229.
- [9] Beckmann, M.; Scholz, R.; Horeni, M.: Energetische Verwertung von Ersatzbrennstoffen mit hohem Chlorgehalt. Kasseler Abfalltage, 2006.
- [10] Bieber, M.: Untersuchungen zur optimalen Verbrennung von Salzkohle in der stationären Wirbelschichtfeuerung. Erschienen: TU Dresden March 10, 1992.
- [11] Born, M.: Rauchgasseitige Dampferzeugerkorrosionen (Erfahrungen bei der Schadensminderung). Freiberg: Verlag SAXONIA Standortentwicklungs- und -verwaltungsgesellschaft mbH 2003, ISBN 3-934409-20-2.
- [12] Bundesgütegemeinschaft Kompost e.V., Köln: Fremdüberwachungszeugnis 2005, Fertigkompost, Anlage Weira.

- [13] Clausen, J. Chr.; Schmidt, E. R.: Specifications for Solid Biofuels in Denmark. Erschienen in: Institut für Energiewirtschaft und rationelle Energieanwendung Universität Stuttgart - IER (Hrsg.): Biomasse als Festbrennstoff. Schriftenreihe "Nachwachsende Rohstoffe", Landwirtschaftsverlag GmbH Münster, ISBN: 3-7843-2821-0.
- [14] DBI-AUA GmbH Analytik – Ökotoxikologie, Halbrücker Str. 34, 09599 Freiberg. Prüfbericht Nr.: 05-1412: Fertigmischung Labor-Nr.: 05-1412-09. May 11, 2005.
- [15] Gütegemeinschaft Kompost Sachsen-Thüringen e.V., Datenbank „Organische/mineralische Abfälle und Wirtschaftsdünger“.
- [16] Heyde, M.; Thiele, A.; Wiethoff, S.: Qualitätssicherungsmaßnahmen für Vorprodukte aus gemischten Abfallquellen. Erschienen in: Thomé-Kozmiensky, K.J. (Hrsg.): Ersatzbrennstoffe 4 – Optimierung der Herstellung und der Verwertung. TK Verlag Thomé-Kozmiensky Neuruppin 2004, ISBN 3-935317-18-2, S. 255-266.
- [17] Kehres, B.: Informationsdienst Humuswirtschaft & KomPost 1/06, Bundesgütegemeinschaft Kompost e.V..
- [18] Knümann, R.; Schleussner, M.; Bockhorn, H.: Untersuchungen zur Pyrolyse von PVC und anderen Polymeren. VDI Berichte Nr. 922, VDI-Verlag GmbH Düsseldorf 1991, ISBN 3-18-090922-6, pp. 237-246.
- [19] Liu, K.; Pan, W.-P.; Riley, J. T.: An Atmospheric Pressure Fluidized Bed Combustion System Burning High-Chlorine Coals in the Convection Section. Published in: Corrosion-March 2000, NACE International, Corrosion – Vol. 56, No. 3. pp. 298 – 306.
- [20] Metschke, J.; Spiegel, W.: Systematisierung und Bewertung von verfügbaren Maßnahmen zur Korrosionsminderung in der betrieblichen Praxis von MVA mittels partikelförmiger Rauchgasbestandteile. Endbericht EU 22, 12/2004, im Auftrag des Bayerischen Staatsministeriums für Umwelt, Gesundheit und Verbraucherschutz unter Beteiligung des Europäischen Fonds für Regionale Entwicklung (EFRE), available at [www.chemin.de](http://www.chemin.de).
- [21] Spiegel, W.: Analyse des Rohgases und der Kesselablagerungen zur Beurteilung der Ersatzbrennstoffqualität. Erschienen in: Thomé-Kozmiensky, K. J.; Beckmann, M. (Hrsg.): Ersatzbrennstoffe und Biomasse zur Substitution fossiler Brennstoffe. TK-Verlag Thomé-Kozmiensky, Nov. 2006, S. 335-355, ISBN 3-935317-24-7.
- [22] Spiegel, W.; Herzog, Th.; Magel, G.; Müller, W.; Schmidl, W.: Belagsgeschichten. Vortrag am 2. Diskussionsforum „Rauchgasseitige Dampferzeugerkorrosion“ in Freiberg, 2005, available at [www.chemin.de](http://www.chemin.de).
- [23] Spiegel, W.; Herzog, Th.; Magel, G.; Müller, W.; Schmidl, W.: Dynamische chlorinduzierte Hochtemperaturkorrosion von Verdampfer- und Überhitzerbauteilen aufgrund spezieller Belagsentwicklungen: Häufiger Befund in Abfall- und Biomasse-gefeuerten Dampferzeugern. VGB PowerTech, Heft 1/2, 2005, pp. 89-97.
- [24] Steinbrecht, D.; Neidel, W.: Verbrennung von BRAM in der stationären Wirbelschicht. 4. Dialog Abfallwirtschaft M-V, June 21, 2001 Rostock.
- [25] Thomé, E.: Energetische Verwertung von Ersatzbrennstoffen in einem umgebauten Kraftwerkskessel. Erschienen in: Thomé-Kozmiensky, K.J.: Ersatzbrennstoffe 2 –

Verwerter, Qualitätskontrolle, Technik, Wirtschaftlichkeit. TK Verlag Thomé-Kozmiensky Neuruppin 2002, ISBN: 3-935317-08-5, pp. 210-211.