Coal-Fired Power Plants for Co-Incineration of SRF
– Plants, SRF Quantities and Qualities, Operational Experience, Trends and Forecasts –

Stephanie Thiel

Abstract

Currently, in ten coal-fired power plants in Germany solid recovered fuels from mixed municipal waste and production-specific commercial waste are co-combusted. At other locations there were experiments conducted. Overall, in 2010 there were approximately 800,000 tons of these solid recovered fuels used. For the coming years till 2014 there is a slight decline in the quantity of materials used in co-combustions expected. The co-combustion activities are in part significantly influenced by increasing power supply from renewable sources of energy and their impact on the regime of coal-fired power plants usage. Moreover, price trends of CO_2 allowances, solid recovered fuels as well as imported coal also do have large influence. Besides usage of solid recovered fuels with biogenic content, the co-combustion of pure renewable biofuels became more important in coal-fired power plants. The power plant operators make high demands on the quality of solid recovered fuels. As the operational experience shows, a set of problems may be posed by co-combustion. The process engineering key factors are firing technique and corrosion. A significant ecological key factor is the emission of pollutants into the atmosphere. The results of this study derive from a research made on the basis of extensive literature search as well as survey on power plant operators in Germany. The data from operators was updated in spring 2011.

1. Introduction

In coal-fired power plants a multiplicity of different wastes is being co-combusted, for example sewage sludge, animal meal, acid tar and active coke.

In this study only the co-combustion of

- solid recovered fuels from mixed municipal waste (SRF-M) and
- solid recovered fuels from production-specific commercial waste (SRF-P)

is considered.

The evaluation of the reports of power plant operators shows that the co-combustion activities of solid recovered fuels from mixed municipal waste and solid recovered fuels from production-specific commercial waste in coal-fired power plants have very different results.

In some plants – after taking measures for adjustment and optimization as well as accepting the manageable side effects if necessary – the use of alternative fuel could be transformed into a successful long-term usage. In other coal-fired power plants, however, the researches were aborted due to serious damages or malfunctions in plant operation. There were also situations, when economical reasons led to the termination of the project.

A current overview of the situation of co-combustion of SRF-M/SRF-P in German, coal-fired power plants will be presented in this paper. For this purpose, both information concerning particular power plants and co-combustion projects will be compiled as well as conclusions on the situation in Germany will be made.

The trends will be highlighted against the background of changing conditions in energy and fuel markets. The keywords are the change of energy policy – i.e. further conversion of electricity and heat production from fossil fuels and nuclear power to renewable energy –, emission trade and the market of solid recovered fuels.

The suitability of solid recovered fuels from mixed municipal waste and from production-specific commercial waste for co-combustion in coal-fired power plants will be discussed from the point of view of process engineering, environment and economics. Factors of significant influence and optimization possibilities will be identified.

Based on the survey of the solid recovered fuel specifications of power plant operators (which is not included in this study due to its limited scope) the most important requirements concerning the quality of solid recovered fuels will be summarized qualitatively.

Finally, the positive and negative operating experience of power plant operators will be evaluated against the background of characteristic features of the different combustion systems as well as other essential conditions of the respective plants and projects. The procedural suitability of various types of power plants for co-combustion will be assessed with regard to the identified key factors. Finally, references for analysis of co-combustion impact on the environment will be provided.

The basis of this study is an extensive literature research and the survey on power plant operators in Germany, who have a respective experience in operation or planning. The data inquiries on the operators have been made several times since 2005. The latest update was made in March/April 2011.

2. Plants and projects of co-combustion of solid recovered fuels – situation in spring 2011

Continuous operation

Currently, in ten coal-fired power plants in Germany solid recovered fuels from mixed municipal waste and/or production-specific commercial waste are being co-combusted continuously. The power plants are listed in Table 1, including details of their location, operator, type of coal, firing system, type of solid recovered fuel, coal boilers included in the co-combustion and the start of continuous operation.

Inoperative co-combustion

In three black coal-fired power plants the co-combustion of SRF-M and/or SRF-P has been ceased after several years of continuous co-combustion, partially due to operational and partially due to economic reasons (Table 1). For two of these sites it seems conceivable though, that the co-combustion will be resumed, at least for a limited period of time.

Successful tests

In four power plants co-combustion tests, that lasted for different time periods, have been successfully conducted (Table 2). Subsequently, however, due to different reasons, no continuous operation has been undertaken or aimed yet. In two of the plants there is an option to resume the co-combustion again. In one case, there is an approval for continuous co-combustion, in the other case the claim is being processed.

Planning

There is an approval for a two-year-long trial operation for the brown coal-fired boilers in **Wachtberg/Frechen**. That involves the extension of quantities and types of used solid recovered fuels. Among other things, the trial with solid recovered fuels from mixed municipal waste was approved. So far, no SRF-M has been co-combusted yet. It remains a possibility for the future.

Stop of tests or planning of continuous operation

At six localizations the co-combustion tests or plans of continuous operation have been stopped (Table 3).

In the majority of cases the failure of the use of SRF-M and/or SRF-P was caused by *problems of firing technique in pulverized coal firings (incomplete burnout or collapse of combustion), chlorine corrosion* occurred to be another serious problem *(see Chapter 6)*.

Table 1: Power plants with continuous co-combustion (situation March/April 2011)

location	operator	type of coal	firing system	type of SRF	boiler	start of continuous operation
Jänschwalde	Vattenfall	brown coal	dry pulverized coal firing	SRF-M	plants Y1 + Y2 (8 of 12 boilers)	Y1: 02/2005 Y2: 07/2005
Schwarze Pumpe	Vattenfall	brown coal	dry pulverized	SRF-M	both boilers	08/2007
Werne/ Gersteinwerk	RWE	black coal	dry pulverized coal firing	SRF-M SRF-P	unit K (only boiler)	2004/2005
Berrenrath/Ville	RWE	brown coal	CFB firing	SRF-M	both boilers	01/2007
Veltheim/ Porta Westfalica	GK Veltheim (E.ON/SWB)	black coal	slag tap firing	SRF-M	unit 3 (1 of 2 boilers)	01/2007
Pforzheim	Heizkraftwerk Pforzheim GmbH	black coal	CFB firing	SRF-M SRF-P	only boiler	11/2009
Flensburg	Stadtwerke Flensburg	black coal	CFB firing	SRF-M	boiler 9+10+11 (3 of 5 boilers)	boiler 11: 2007 boiler 9: 06/2008 boiler 10: 10/2008
Duisburg	Stadtwerke Duisburg	black coal	CFB firing	SRF-P	unit I (1 of 2 boilers)	01/2009
Osnabrück	Ahlstrom (paper factory)	brown coal and black coal	CFB firing	SRF-P	only boiler	1993
Oberkirch	Koehler (paper factory)	black coal	CFB firing	SRF-M SRF-P	only boiler	SRF-P: 2004 SRF-M: 2006
Power plants with inoperative co-combustion						
Werdohl-Elverlingsen	Mark-E	black coal	slag tap firing	SRF-M	unit E3 (2/1 of 3 boilers)	2001
Westfalen/Hamm	RWE	black coal	slag tap firing	SRF-M SRF-P	units A+B (2 of 3 boilers)	2003
Ensdorf	VSE	black coal	slag tap firing	SRF-P	units 1+3 (both boilers)	2004

CFB: circulating fluidized bed

Table 2: Power plants with successful tests (situation March/April 2011)

location	operator	type of coal	firing system	type of SRF	boiler	time of the tests
Chemnitz	eins energie in sachsen	brown coal	dry pulverized coal firing	SRF-M	both boilers	from 01/2007 to 05/2010
Boxberg	Vattenfall	brown coal	dry pulverized coal firing	SRF-M	plant III boiler N1 (1 of 5 boilers)	2007/2008
Weisweiler	RWE	brown coal	dry pulverized coal firing	SRF-M	units G+H (2 of 6 boilers)	07/2004 2d 03/2005 12d
Herdecke (decommissioned)	Mark-E	black coal	slag tap firing	SRF-M	only boiler	heating period 2000/2001

Table 3: Power plants where tests or plans of continuous operation have been stopped (situation March/April 2011)

location	operator	type of coal	firing system	type of SRF	boiler	time of the tests	problem
Wedel	Vatten-fall	black coal	dry pulverized coal firing	SRF-M SRF-P	unit 2 (1 of 2 boilers)	10/2001 – 09/2002	incomplete burnout
Werdohl-Elverlingsen	Mark-E	black coal	slag tap firing	SRF-M	unit E4 (1 of 3 boilers)	01/2001 – 04/2001	incomplete burnout
Buschhaus	E.ON	brown coal salty coal)	dry pulverized coal firing	SRF-M	only boiler	2004 (several days)	incomplete burnout
Ibbenbüren	RWE	black coal (anthra-cite coal)	slag tap firing	SRF-P	only boiler	2000	collapse of combustion
Wählitz	Mibrag	brown coal	CFB firing	SRF-M	only boiler	09/2004 (30 h) 07/2005 (30 h)	chlorine corrosion
Offenbach	EVO	black coal	CFB firing	SRF-M	1 of 2 boilers	04 – 06/2004 10 – 12/2004	chlorine content of SRF-M

Extremely low chlorine content in the production of solid recovered fuels from mixed municipal waste, which is required by some power plants operators, cannot be achieved, even when using advanced sorting technologies.

Further information about plants and projects

Additional information about the plants and projects mentioned above, regarding the approved or applied capacity for co-combustion, the actual and intended input of SRF-M/SRF-P, the use of other types of solid recovered fuel (for example sewage sludge, animal meal, wood), the development of the project or location, approval procedures as well as current decisions and plans of the operators can be found at Thiel [40].

3. Development of co-combusted SRF quantities, current situation and forecasts till 2014

Quantities of solid recovered fuels co-combusted between 2005 and 2010 as well as quantity forecasts for the time period till 2014 have been inquired among operators of coal-fired power plants, where SRF-M and/or SRF-P is used in a continuous operation or was used in tests.

3.1. Development of total quantities in Germany

Thereafter, in Germany in 2005 there were approximately 300,000 tons of solid recovered fuels from mixed municipal waste and from production-specific commercial waste co-combusted (Figure 1).

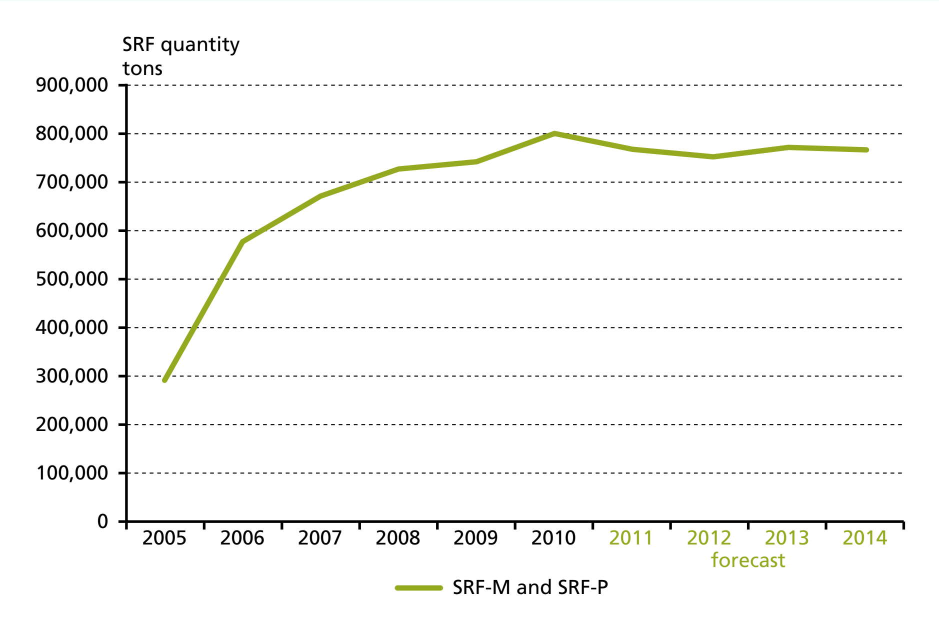

Figure 1: Quantities of solid recovered fuels from mixed municipal waste and from production-specific commercial waste used in German power plants since 2005 and forecasts till 2014

In 2006, the quantity used increased to approximately 580,000 tons. In the following years, the SRF quantities have been increasing continuously, however, with moderate growth rates. In 2010 the maximum of 800,000 tons was reached. According to operators' quantity forecasts for coming years till 2014, the yearly co-combustion quantity in Germany, with a slight decrease, is expected to be approximately 750,000 to 770,000 tons per year.

3.2. Quantities used in particular German power plants

Figure 2 shows the distribution of quantities of co-combusted solid recovered fuels between particular coal-fired power plants.

During the whole observation period, the highest amounts are attributed to the power plant in Jänschwalde, where solid recovered fuels are being co-combusted in eight out of twelve brown coal-fired boilers. The annual quantities since the fully extensive implementation of continuous co-combustion amounted to approximately 390,000 tons per year. The former voluntary self-restraint to 400,000 tons a year was repealed in 2009 and the amounts increased – the maximum amount was 472,000 tons (2010). For subsequent years, lower throughputs of less than 450,000 tons per year are planned.

The second-highest solid recovered fuel usage of approximately 100,000 tons per year is attributed to the black coal-fired power plant Werne.

In Berrenrath approximately 65,000 tons of SRF-M are co-combusted per year.

Fourth place belongs to the cogeneration plant in Flensburg, where the used quantity of about 47,000 tons (2010) should be expanded to 62,000 tons per year from 2011.

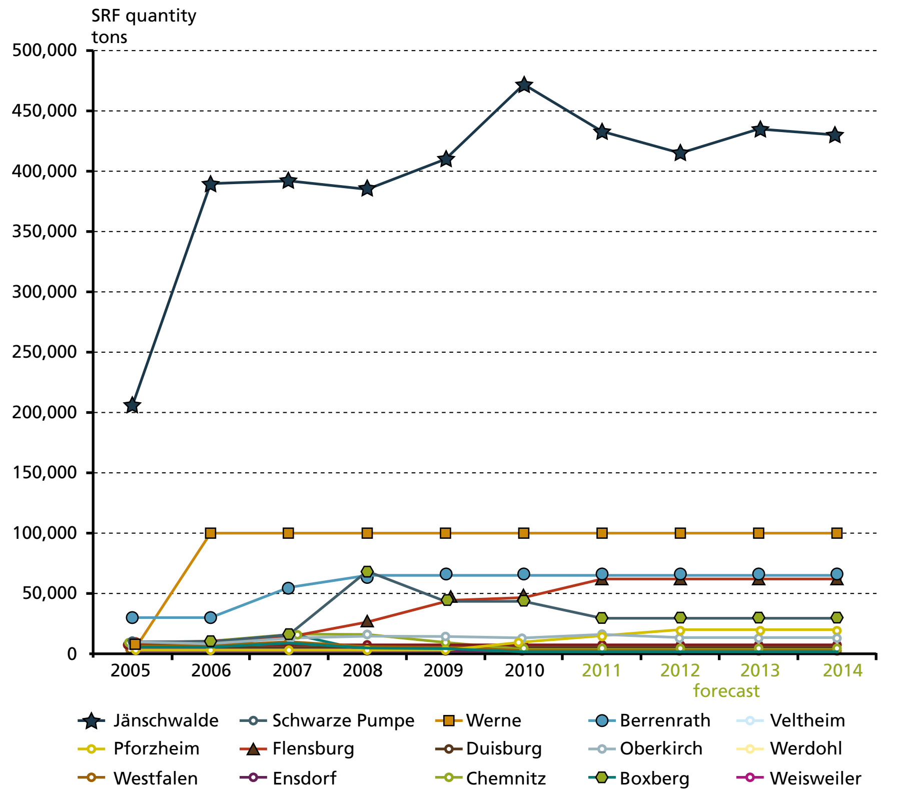

Figure 2: Quantities of solid recovered fuels from mixed municipal waste and from production-specific commercial waste used in particular German coal-fired power plants from 2005 and forecasts till 2014

Power plant Schwarze Pumpe follows with small distance with 44,000 tons (2010), where solid recovered fuel usage should be however reduced from 2011 to 30,000 tons per year.

Hence, relating to 2010, 91 % of the co-combusted solid recovered fuels were used in these five power plants sites. The remaining 9 % – corresponding to approximately 70,000 tons of solid recovered fuel – is distributed between another six power plants.

3.3. Distribution between brown coal-fired and black coal-fired power plants as well as their different firing systems

Figure 3 shows the distribution of solid recovered fuels between brown coal-fired and black coal-fired power plants as well as their different firing systems.

As for the quantities used in 2010, which were approximately 800,000 tons, 78 % was attributed to brown coal-fired and 22 % to black coal-fired power plants.

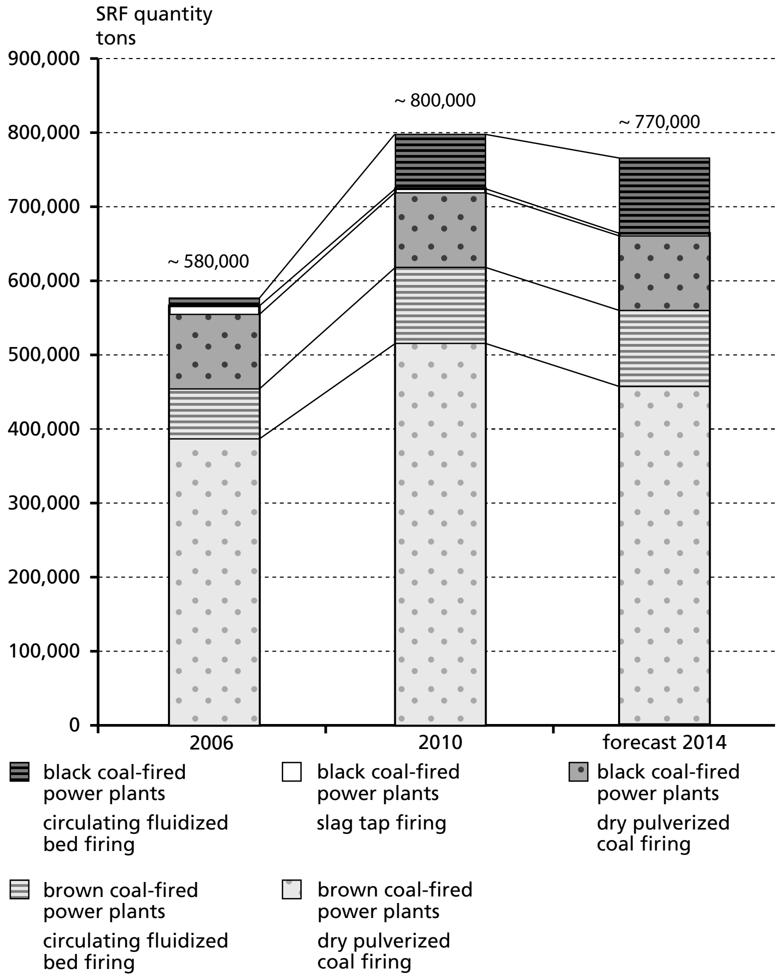

Figure 3: Distribution of quantities of used solid recovered fuels from mixed municipal waste and from production-specific commercial waste between brown coal-fired and black coal-fired power plants as well as their different firing systems – values in 2006 and in 2010 as well as forecast for 2014

The share of furnaces fired with pulverized brown coal strongly predominates with about 65 %. It is followed by brown coal-fired fluidized bed furnaces and furnaces fired with pulverized black coal (dry ash removal) with approximately 13 % each, as well as black coal-fired fluidized bed furnaces with about 9 %. The black coal slag tap furnaces have their share of less than one percent.

In the time period till 2014, the quantities of used solid recovered fuel should change with slight decrease, in favor of the black coal-fired circulating fluidized bed furnaces. The share of furnaces fired with pulverized brown coal decreases.

4. Trends in co-combustion

The co-combustion of solid recovered fuels from mixed municipal waste and production-specific commercial waste in Germany is caught in an area of tension between different factors that have a significant influence on the current usage of solid recovered fuels and relating plans of power plant operators.

On one hand, the increase in electricity supply from renewable energy sources has partly an incisive impact on the operation regime of coal-fired power plants. In a number of black coal units, contrary to previous plans, the co-combustion could not be extended or even had to be significantly restricted or completely terminated due to reduced operating hours (Chapter 4.1.).

In addition, various economic incentives affect the power plant operators in their decision regarding the solid recovered fuel usage and the choice of solid recovered fuel types and quantities:

- **Price trends of CO_2 allowances**: According to the renewable carbon content in the solid recovered fuel, the power plant operators may economize on CO_2 allowances. From 2013 there will be no more free CO_2 allowances for electricity production allocated, the energy industry has to buy them by auction completely. According to specialists estimations an increase of allowance prices from about 16 EUR/t CO_2 in spring 2011 [13] to 30 EUR/ t CO_2 is possible.
- **Development of co-payments or prices for solid recovered fuels**: In recent years the solid recovered fuel market has undergone a great change, especially through the great expansion of capacity at solid recovered fuel-fired power plants. As a result, the co-payments for solid recovered fuels from mixed municipal waste and from production-specific commercial waste decreased significantly. Partly – depending on the quality of these fuels – even *prices* have to be *paid* (Chapter 4.2.).
- **Price trends in coal**: the price of coal is a significant cost factor for black coal-fired power plants. Prices of imported black coal have increased.

Emissions trading is a key factor that drives the fuel substitution. In 2009, 63 power plants were combusting (not further specified) waste, 54 of those units were able to reduce the CO_2 emissions by co-combustion and therefore savings were made on CO_2 allowances. This is a significant increase over the previous year, when 55 power plants were combusting wastes, with 46 of them having CO_2-savings [11].

Besides the co-combustion of *solid recovered fuels with biogenic content*, several power plant operators have already begun with co-combustion of pure renewable biofuels at their coal-fired facilities, and other ones plan to do that in the future (Chapter 4.3.).

4.1. Operation regime of coal-fired power plants for public power supplies

The increase in fluctuating power supplies from renewable energy sources – particularly wind and photovoltaics – have led to the reduction of operating hours in many coal-fired power plants. This applies black coal-fired power plants in a special way, since they can no longer be predominantly used as medium-load power plants, but rather serve to cover the residual load. The strong impact, which the revised operation regime has also on the co-combustion of solid recovered fuels, will be demonstrated on three examples:

In the black coal-fired power plant Westfalen/Hamm, the progression of use of units A and B has been deferred since 2010, which means they are barely operated. Thus, also the co-combustion of solid recovered fuels has come to a standstill. (Note: with the commissioning of newly built 1,600 MW double-unit power plant at this localization, which was postponed till 2012/2013, all the three existing units shall be decommissioned.)

Also in the **Veltheim/Porta Westfalica** power plant, the utilization period had to be reduced. This made it impossible to conduct the planned increase of the solid recovered fuels quantities from approximately 5,000 tons in 2006 to the level of available capacity, which is 20,000 to 25,000 tons per year. The annual quantities remained far behind the target. The operator assumes that the co-combusted quantities will further decrease in the next three years.

For the same reason, in the coal-fired power plant Werne the planned increase of SRF-M/SRF-P quantities from 100,000 to 140,000 tons per year since 2007 could not be realized.

Remains to be seen, how strongly and for how long this trend will be counteracted by the accelerated withdrawal from nuclear energy in Germany which was caused by catastrophe in the Japanese nuclear power plant Fukishima.

4.2. Co-payments or prices of solid recovered fuels

During the researches in March/April 2011, some of the power plant operators made remarks concerning co-payments or rather prices of solid recovered fuels, which they have currently been receiving or paying for the solid recover fuels they use. It will be summarized here in the anonymous form. It is to be emphasized, that the remarks enable only orientation statements because the relating qualities of solid recovered fuels have not been reported precisely, rather tendentially by distinguishing types of coal and firing system of the respective power plants.

Firstly, it needs to be stated in general that the co-payments for solid recovered fuels have declined in recent years.

The operator of a **brown coal-fired power plant with pulverized coal firing** mentioned to have been paid in 2007 between 25 and 40 EUR/t of solid recovered fuels from mixed municipal waste.

These have decreased within the past four years to a current 5 to 15 EUR/t. Another power plant operator have been conducted talks with solid recovered fuels suppliers, who could provide it with the estimated 10 EUR/t to maximum 15 EUR/t co-payment.

Considerably more profound preparation of SRF-M is required in the case of **black coal-fired power plants with pulverized coal firing**, that reflects itself in the lower co-payment of +/- 0 EUR/t, as declared by the operator of a respective plant.

According to the information provided, operators of different **black coal-fired power plants with CFB** *pay* following *prices* for different types of solid recovered fuels:

- SFR-M from sorted mixed commercial waste, including the addition of 15 wt.-% waste wood chips: 13 EUR/t,
- SRF-P with a certain content of renewable carbon and low content of chlorine: > 10 EUR/t,
- SRF-P from plastic: a double-digit Euro figure,
- Waste by-products of sorting facilities for yellow-bag recyclables and rejects: 0 to 10 EUR/t depending on the chlorine and water content and calorific value.

4.3. Biofuels

In Table 4 there are coal-fired power plants listed, where biofuels are co-combusted or where it is planned.

Table 4: Co-combustion of biofuels in coal-fired power plants – examples

power plant	type of biofuel	status
Berrenrath	waste wood	continuous operation
Bremen/industrial port	spelt, coffee grounds	continuous operation
Duisburg	fresh wood, waste wood (A1)	planning
Flensburg	waste wood chips, fresh wood chips	continuous operation
Moorburg/Hamburg[1]	biomass	use is examined
Offenbach	wood pellets (A1) wood chips (A1)	continuous operation permit for continuous operation striven
Wachtberg/Frechen	fresh wood, green waste, waste wood (A1 and A2)	test operation, application for continuous operation planned
Wedel	biomass pellets	tests

[1] new-build power plant, commissioning planned for 2012

Examples of co-combusted biofuels are: waste wood of A1 and A2 classes, fresh wood – for example from maintenance works –, green waste as well as coffee grounds and spelt. Price increases have been recorded for all the wood assortments. Different exotic biofuels, such as rice husks or olive pits have also been taken into consideration by some operators; however the calculation from the economic point of view has not been conducted (yet).

5. Solid recovered fuels – characterization and quality requirements of plant operators (solid recovered fuels specifications)

The firing of coal-fired power plants is always designed for a defined fuel range. The more narrow the range of the chosen fuels is, the better the firing can be optimized regarding the operation and efficiency.

In addition to the furnace itself there are also the upstream and downstream parts and peripheral devices – such as grinding, ash removal, heat transfer system, emission control and conveyor systems – designed for the respective regular fuel as well as the solid residues produced during its combustion, exhaust gas flows, etc. with their specific properties. The combustion behavior of coal is essentially characterized by the properties that belong to the normal analytical scope of fossil solid fuels, such as its elementary composition (water content, ash content, C, H, S, O, N content of the organic fuel substance), calorific value and fusibility of fuel ash.

Beyond that further properties, such as grindability, ease of ignition, reactivity and combustion behaviour, gain in importance.

The reasons of the growing requirements concerning the scope and thoroughness of fuels characterization are the need of increasing accuracy of plant design as well as the growing use of different types of imported coal [14].

The target of substituting a part of regular fuel with solid recovered fuels in the process of energy conversion implicates the need for characterization of solid recovered fuels in reference to the fuel technical properties [4].

The characterization, quality assurance and standardization of solid recovered fuels is in process at the national and European level (compare inter alia CEN [10], Gütegemeinschaft Sekundärbrennstoffe und Recyclingholz e.V. [16], Flamme & Geiping [15], Beckmann & Ncube [4], Kolb et al. [23], Weber [43], Kock [22]).

Figure 4 shows different qualities of solid recovered fuels that have been used in coal-fired power plants.

Figure 4: Examples of different qualities of solid recovered fuels used in coal-fired power plants (left: pelletized SRF < 10 mm; middle: SRF fraction from the mechanical-biological treatment plant Kahlenberg/Maximum Yield Technology process; right: SRF hard pellets)

Source of the photo in the middle: Professor Dr.-Ing. Gerhard Rettenberger; Zweckverband Abfallbehandlung Kahlenberg

Specifications of solid recovered fuels used in twelve of the mentioned coal-fired power plants, organized accordingly to coal type and firing systems, are shown in an anonymous form in Thiel [39].

The individual requirement profiles concerning the solid recovered fuels to be co-combusted include chemical, mechanical, calorical and other properties. The scope of specifications varies – from restriction to those parameters, that are indispensable in terms of process technology and legal approval requirements, to the addition of further parameters, some of them of low relevance.

The task of processing mixed municipal wastes with heterogeneous composition and high level of pollutants aimed at producing solid recovered fuel products to be used for co-combustion in coal-fired power plants makes high demands on performance of processing technology. First of all, this applies to chemical properties of fuels – especially for the depletion of chlorine and heavy metals – as well as for the seperation of ferrous and non-ferrous metals, that are equally crucial for all types of coal-fired power plants. Moreover, especially for pulverized black coal-fired power plants challenging specifications are defined regarding the mechanical fuel properties – maximum particle size, dispersibility, seperation of combustible and inert contaminants – and the caloric properties.

Additional notice: The high processing effort is associated with a corresponding expenditure of energy in the production of solid recovered fuels. For energy balancing of co-combustion of solid recovered fuels from mixed municipal waste and production-specific commercial waste in power plants this energy expenditure has to be considered as part of the entire process chain. An exemplary estimation of the energy balance for a specific system with sensitivity analysis was performed as part of the underlying study [39].

6. Problems with the co-combustion – operational experience of power plant operators

The stronger the properties of solid recovered fuel differ from the properties of regular fuel and the higher the share of solid recovered fuel in the fuel mixture is, the greater the effects on the plant operation and the quality of the output streams are to be expected. As a result, currently existing problems with coal combustion may be exacerbated on one hand, and on the other hand unknown problems may occur.

There have been eleven problems identified that accordingly to the experiences of operators are most significant for them.

On one hand there are problems which are manageable by optimization of solid recovered fuels quality and/or adjustments in some plant components (Group III). On the other hand though, there are problems that despite the undertaken measures lead to the conclusion, that the co-combustion must be permanently limited (Group II).

And finally, the co-combustion may be related also to serious procedural problems of the power plant operations or significant economic barriers, that makes the operator exclude the usage of solid recovered fuels from mixed municipal waste and from production-specific commercial waste in principle (Group I).

Hereafter, the problems encountered are listed with allocation to the three particular groups. There are references provided for particular problems, which are complemented by personal inquiries on power plant operators, summarized and discussed in Thiel [39].

Group I: Possible final exclusion factors

Due to massive disruptions of plant operations

- Incomplete burnout [21, 12, 27]
- Collapse of combustion
- Chlorine corrosion [7, 6, 2, 9, 18, 5, 37, 36, 31]

Due to required investments (economics)

- HCl emission – Retrofitting of emission control requirements at CFB plants [45]

Group II: Possible permanently limiting factors

- Fouling and slagging of the boiler heating surfaces [28, 9, 2, 14, 31, 20, 3, 30, 1, 38, 27]
- Increased chloride load of the flue gas desulfurization and FGD products [30, 25, 19, 32]

Group III: Problems manageable by optimization of solid recovered fuels quality and/or adjustment in some plant components

- Problems with discharging, conveying and dosing [19]
- Mechanical problems due to metallic contaminants [32, 35]
- Chemical and thermal problems due to aluminum in CFB boilers [35]
- Erosion of boiler [30, 9]
- Exceeding the capacity of the ash discharge systems.

Thus, there are two key factors that determine technical and operational success or failure of the co-combustion project: the firing technique and corrosion. Different types of power plants offer various favorable conditions for the co-combustion regarding these two factors in dependency to the firing system and type of coal.

Firing techniques – burnout and the stability of combustion

Particularly advantageous are power plants with combustion conditions or operational modes that facilitate a complete burnout of all the (solid recovered) fuel particles. That includes the **brown coal-fired power plants with pulverized coal firing**, equipped in 90 % with burnout grate in order to improve the burnout of insufficiently comminutable structures of fibrous wood (Xylitol). A similar effect can be reached by wet ash recirculation, i.e. repeated recirculation of coarse ashes that still contain fuel particles through the coal mills back into the furnace. Furthermore, in contradiction to other firing systems, solid recovered fuels before entering the combustion chambers are again being comminuted and sifted together with coal in beater-wheel mills.

Characteristic features of the **cyclone furnace of black coal** are the spirally centrifugal flows and extremely high temperature up to 1,800 ° C in the cyclone chamber, what leads to a particularly intensive combustion reaction.

In the circulating fluidized bed combustion of brown and black coal, a successful burn-out is ensured by the intense exchange of heat and material between the hot bed material as a heat carrier, the fuel and combustion air in turbulent mixing and long residence time.

Difficult but manageable is the co-combustion in **black coal-fired power plants with pulverized coal firing**. The prerequisite though is that the solid recovered fuel particles burn out in the air within a few seconds – just like the fine coal dust. That makes very high demands on the profundity of solid recovered fuel preparation and its suitable supply. The unburned residual components remaining occasionally in the coarse ash are to be separated by supplementary ash treatment before landfilling.

According to previous experience, co-combustion in **black coal slag tap firing is difficult and in some cases not manageable**, despite undertaken optimization measures. As far as firing technique was concerned, the following problems occured:

- Firstly, incomplete burnout (double-U-slag tap furnace, designed for low-grade coal) and
- Secondly, the collapse of combustion (two-stage double slag tap furnace for particularly hard and low volatile anthracite coal)

Corrosion

Circulating fluidized bed combustion chambers are particularly prone to corrosion (brown and black coal). The addition of limestone in the fluidized bed as a primary measure for desulfurization can lead to reversal of the sulfur-chlorine ratio in the exhaust gas. Moreover, in the reaction with the chlorine in the solid recovered fuel calcium chloride can be formed, which condenses in the deposits on the steam generator tubes and then leads to the wearing off of tube walls material. Due to these operating conditions, the corrosion in CFB power plants is the most difficult to manage, and this is why the minimization of chlorine load is of great importance.

In addition, the corrosion potential of **low NO_x pulverized coal firing** – reducing atmosphere with high CO content – is higher than the one at overstoichiometric operation mode and steady-going process control. Finally, the co-combustion in **brown coal-fired power plants** is associated with an increased risk of corrosion, since these plants are usually designed for the relatively low chlorine content of the regular fuel. Power plants, where **brown coal with low sulfur content** is combusted, such as those found in the Rhineland, are particularly affected. Thus, in all these cases, limitation of the chlorine content in the solid recovered fuels is of central importance.

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Innerstetal 16
D-38685 Langelsheim

Phone +49 53 26 501 0
Telefax +49 53 26 501 25

info@uhlig.eu

www.uhlig.eu

Arne Manzke
+49 5326 501 52
arne.manzke@uhlig.eu

Sven Laudenbach
+49 5326 501 36
sven.laudenbach@uhlig.eu

Michael Bartels
+49 5326 501 45
michael.bartels@uhlig.eu

In terms of **environmental impact** the main co-combustion problems to examine are:

- Accumulation of heavy metals in the power plants by-products and effects on their environmental impact and recyclability [26, 2, 9, 30, 31, 39] as well as
- Emission of heavy metals – in particular of highly volatile heavy metals – into the atmosphere [30, 3, 42, 1, 26, 44, 24, 29, 39].

7. Conclusion

Solid recovered fuels from mixed municipal waste and/or production-specific commercial waste have been co-combusted in Germany since the 1990s in power plant units. After moving at a low level for several years, since 2004 (according to estimations 100,000 tons) the quantities of co-combusted solid recovered fuels increased significantly. In 2005, the quantities used had already tripled to 300,000 tons and by 2009 reached 740,000 tons.

Currently, in ten coal-fired power plants in Germany solid recovered fuels from mixed municipal waste and/or production-specific commercial waste are being co-combusted continuously. In other three power plants continuous co-combustion has been suspended. Moreover, in the previous years there were tests conducted at other locations that lasted for different periods of time. Totally in 2010 there were approximately 800,000 tons of SRF-M/SRF-P used. 78 % was used at brown coal-fired and approximately 22 % at black coal-fired power plants. According to operators' quantity forecasts for coming years till 2014, the yearly co-combusted quantity in Germany, with a slight decrease, is expected to be approximately 750,000 to 770,000 tons per year.

Several trends in the *energy and fuel markets* have a major impact on the co-combustion:

It is a rising electricity supply from renewable energy sources that has significant influence on the development of co-combustion activities, especially in black coal-fired power plants for public energy supplies, which have partly undergone significant changes in the operation regime. In several black coal-fired units the use of solid recovered fuels had to be significantly reduced or completely stopped.

Significant market-related factors are the price trends of CO_2 allowances, imported coal as well as prices of solid recovered fuels.

The increase of allowance and coal prices puts the co-combustion in favor. Inhibiting effect is that the co-payments for solid recovered fuels from mixed municipal waste and production-specific commercial waste have fallen considerably due to the large capacity expansion at solid recovered fuel-fired power plants.

Depending on quality, the power plant operators have to pay for these fuels to some extent.

Besides the use of *solid recovered fuels with biogenic content*, co-combustion of purely renewable *biofuels* gains importance in coal-fired power plants.

The power plants operators make high demands concerning the quality of solid recovered fuels. Specifications of solid recovered fuels include chemical, mechanical, caloric and other properties.

The task of processing mixed municipal wastes with heterogeneous composition and high level of pollutants aimed at producing solid recovered fuel products to be used for co-combustion in coal-fired power plants makes high demands on performance of processing technology.

As the operational experience of previous years has shown, there are several problems that may arise by co-combustion of solid recovered fuels. Two *process-related key factors* that determine technical and operational success or failure of the co-combustion project are the firing technique and corrosion. In terms of *environmental impact* the main co-combustion problem is the growing emission of pollutants into the atmosphere resulting from increased input and insufficient removal of pollutants. That concerns especially highly volatile mercury, but also other heavy metals that are emitted in gaseous form or particle-bound with the particulate matter. Different types of power plants offer various favorable conditions for the co-combustion regarding these key factors in dependency to the firing system, type of coal, flue gas cleaning system, technical design and operating mode.

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