Co-Incineration of Sludge in a Circulating Fluidized Bed

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Operating results show that the co-incineration of sludge with higher calorific fuels, such as coal, biomass or residue derived fuel (RDF) in circulating fluidized bed (CFB) boilers has good operating characteristic and is in general a practical method for thermal sludge disposal. This study focuses on three circulating fluidized bed boiler plants in Germany that co-incinerate various fiber processing sludge, inherently composed of poorly biodegradable cellulose and lignin, and their related operational experience. The operating data show varying impacts on the plant performance, mechanical load and emission values depending on the sludge composition and co-incineration share. In particular fiber sludge with high ash and limestone contents affect heating surface cleaning cycles and nitrogen oxide (NO_x) emissions.

1. Introduction

In the past few years, the European legal framework, such as the Integrated Pollution Prevention and Control Directive (2008/1/EC) and Waste Framework Directive (2008/98/EC) has led to a broad discussion on sustainable solutions for the disposal of sludge.

In the past, sludge landfill was a preferred disposal method; however, in many cases landfill is no longer a practical solution because of the decrease in space available for landfills, the rising disposal fees and the growing concern about the impact of landfilling on the environment, considering potential contaminations with heavy metals and persistent organic pollutants.

Thermal utilization of sludge is an attractive and sustainable disposal method for environmental and economic reasons. Thermal treatment reduces and minimizes the solid mass and volume to be disposed and maximizes the reduction of pollutants and toxins contained in the sludge, leading to lower disposal cost and energy recovery.

The main drivers for the growing number of thermal sludge treatment solutions are the increasing number of land disposal regulations and restrictions, the political drive for waste to energy practices, the demand for final solutions without soil pollution risks, the decreasing cost difference to land disposal and the development of renewable energy sources.

Sludge can be incinerated in mono-incineration plants, i.e. mainly bubbling fluidized bed furnaces, or co-incinerated with other high calorific fuels, e.g. in cement kilns or circulating fluidized bed furnaces.

2. CFB Process Description

Fluidized bed combustion is a combustion technology used in power plants, often applied to address specific fuel challenges. Fluidized beds suspend solid fuels in upward-blowing jets of air during the combustion process, resulting in a turbulent mix of gas and solids and providing more effective chemical reactions and heat transfer.

The technology is well suited to burn fuels that are difficult to ignite, low quality fuels with high ash content and fouling potential, and fuels with highly variable heating values, including biomass, waste fuels and sludge. Figure 1 presents a typical process flow diagram of a fluidized bed boiler plant.

The primary loop of a CFB boiler is composed of a vertical furnace where the combustion process takes places, a cyclone that captures circulating bed material and traces of unburned fuel carried out from the top of the furnace, and a loop seal that returns the separated particles back to the furnace and prevents the back-flow of gas. The flue gas discharged from the cyclone is cooled down in the boiler passes and dust contained in the flue gas is removed by a filter. The flue gas is drawn out by the induced draft fan and discharged from the stack.

The tumbling action, mixing and abrasion of combustible fuel in a dense cloud of solid bed material characterizes circulating fluidized bed combustion. Due to the turbulent circulation, the fuel particles are evenly distributed across the furnace and the heat and mass transfer of the combustion is intensified. The bed material acts as heat transfer- and heat storage medium; the hot sand transfers its heat to dry and heat the fed fuel up to its ignition temperature; the heat released by the combustion of the fuel is absorbed by the bed material. A stable temperature profile is reached in the furnace, favouring a controlled combustion process. Because fuel quality variations are compensated, CFB boilers have the ability to cover a wide range of high and low calorific fuels.

This fuel flexibility combined with high efficient combustion and low emissions is a main advantage of circulating fluidized bed boiler designs, offering several fuel alternatives and increased reliability with multifuel operational concepts.

3. Reference Experience

Andritz's knowledge in the field of power production and steam generation is built on a foundation of tradition and expertise, drawing from more than 150 years and numerous references worldwide. The development of and experience with sludge co-incineration in circulating fluidized bed boilers extends back to the very first CFB plants in the early 1980's, with successfully operating sludge co-incinerating reference plants in China (Changshu, Suzhou), Germany (Eisenhüttenstadt, Glückstadt, Leipa, Neumünster, Maxau and Witzenhausen), Austria (Frantschach, Lenzing, Steyrermühl) and the United States (Reading). These CFB boilers are designed to generate steam using most diverse main fuels, such as biomass, residue derived fuels and coal, however full load operation can as well be achieved while co-incinerating various sludge.

Table 1 presents the considered reference plants, located in Germany and co-incinerating paper sludge from paper re-pulping (Glückstadt), sewage sludge from board recycling (Witzenhausen) and mixtures of various fiber and municipal sewage sludge (Maxau). The sludge can be regarded as free of pathogens and present no risk to the health of man or animals.

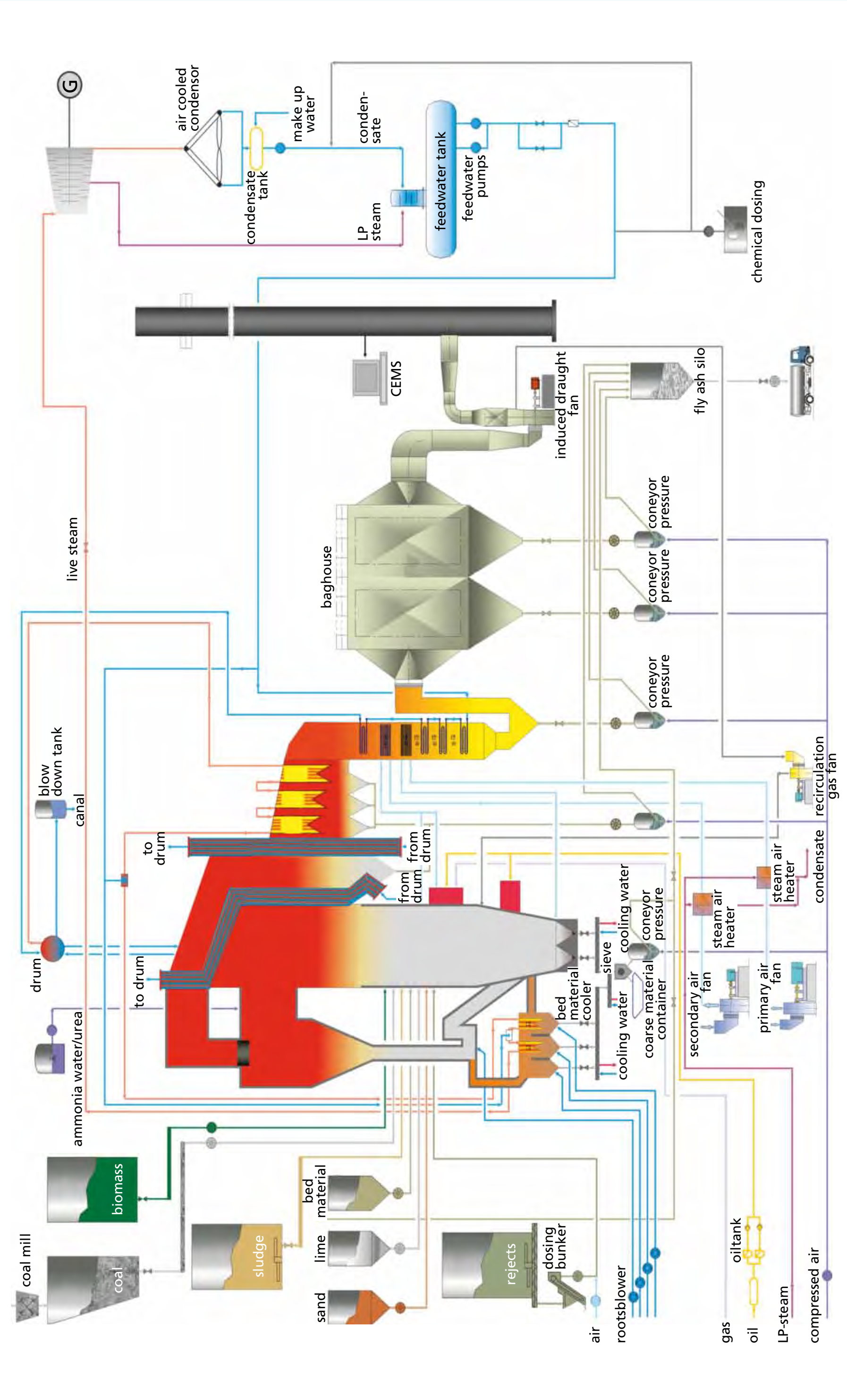

Figure 1: Process Flow Diagram

Table 1: Reference overview

Reference plant	Unit	Glückstadt	Witzenhausen	Maxau
Start-up year		2009	2008	2010
Total fuel heat input	MW_{th}	93	124	172
Live steam flow	t/h	107.5	153	198
Live steam pressure	bar a	66	66	95
Live steam temperature	°C	450	450	520
Feed water temperature	°C	130	130	130
Flue gas at Economizer outlet	°C	180	180	155
Main fuel		rejects, RDF	rejects, RDF	biomass, rejects
Additional fuel		bit. coal, paper sludge	sewage sludge	bit. coal, mill sludge
Net calorific value (NCV)	MJ/kg	8.9 – 27.5	10.9 – 19.5	6.9 – 28

3.1. Glückstadt

Glückstadt is located on the right bank of the Lower Elbe in Schleswig-Holstein, Germany, some 40 km north-west of Hamburg. The CFB boiler plant was awarded in 2007 and is operated since 2009 by the Steinbeis Energie GmbH at the site of the Steinbeis Papier GmbH's recycled fibre mill. The mill develops and produces magazine papers for heat set web offset printing and multi-functional papers for office use from recovered paper. Residues from the mill production are not put to landfill but used at site and burned in the boiler plant. On an annual basis approx. 140,000 tons of rejects from the local production and externally sourced residue derived fuel and approx. 80,000 tons of local paper sludge are incinerated in the boiler. The power gained is brought back into the production circuit as electricity and steam, supplying the total steam requirement for the mill. Coal is used as back-up fuel only to secure the power supply at all times. Remaining ashes are partly used as filler for the cement industry, partly brought to landfill.

The paper sludge is mechanically dewatered in a belt drying process. The sludge has a high fiber and dry matter content of more than 50 % w and a crumbling consistency comparable to papier mâché. The feeding line to the boiler furnace consists of a sludge silo with scraper and discharge screw and a stuffing screw to convey the sludge to the feeding chute at the furnace wall.

Table 2: Glückstadt paper sludge analysis

Glückstadt paper sludge	Unit	Range
Carbon	%w, ar	10 – 13
Hydrogen	%w, ar	0.9 – 1.2
Oxygen	%w, ar	10 – 17
Nitrogen	%w, ar	< 0.1 – 0.4
Sulphur	%w, ar	< 0.1
Chlorine	%w, ar	< 0.1
Ash	%w, ds	38 – 60
Moisture	%w, ar	40 – 55
Lower heat value	kJ/kg, ar	1,400 – 2,100
Densitiy	kg/m³	530 – 740

Table 2 presents an analysis of the paper sludge co-incinerated in the CFB plant Glückstadt. Bulking agents (calcium carbonate, kaolin etc.) and coating colours are added to the fiber process to meet the demand for high quality paper brilliance and opacity. The sludge is remarkable for its low moisture but high ash content, including large portions of limestone.

Under normal operation at full load, the sludge co-incineration amounts to 8 – 10 t/h or around 30 % w of the total fuel flow. This high amount has a significant impact on the plant's performance, the mechanical load and the emission values.

The excellent burn-out characteristics of the CFB combustion process are not affected by the co-incineration of paper sludge: carbon monoxide (CO) emissions remain with and without sludge co-incineration far below the approved limits with measured values of 0 – 2 mg/Nm³. The analyses of unburned matter in bed ash as well as in various fly ash qualities show values around or below the limit of detection with approx. 0,1 %w.

Hydrogen chloride (HCl) emissions in the raw flue gas after combustion are remarkably low with 200 mg/Nm³ compared with average 600 – 1,000 mg/Nm³ measured in other reference plants. In addition, due to the high amount of limestone in the sludge and subsequently in the fly ash, the flue gas cleaning system is operated without additional additive dosing while complying with and falling significantly below all local HCl limits with measured emissions between 0 – 3 mg/Nm³.

Basic nitrogen oxide (NO_x) emissions, i.e. emissions without any denitrification measures, are noticeable increased in Glückstadt, compared to values from reference plants not having sludge co-incineration that operate even without selective non-catalytic reduction system (SNCR) below the German emission limit of 200 mg/Nm³ for waste incineration. The high quantity of limestone contained in the sludge favour the catalytic oxidization of nitrogen and nitrogen compounds, leading to an increase in NO_x emissions. To reduce the emissions, the Glückstadt plant is equipped with a SNCR with urea injection at various boiler locations. In comparison to RDF-CFB plants without co-incineration of sludge, the required amount of denitrification additive to achieve similar NO_x reduction rates is significantly increased; still the measured slip rates of unreacted ammonia at the boiler outlet are very low, even in case of high additive dosing. The bigger part of the added urea seems to be subject to decomposition before it reacts with the NO_x. The high limestone content of the paper sludge and its catalytic effect on the one hand increases the formation of NO_x and on the other hand decreases the impact of injected urea due to decomposition.

A significant influence of the residual oxygen in flue gas on the NO_x emissions was measured in comparison to RDF-CFB reference plants without sludge co-incineration. NO_x emissions below 200 mg/Nm³, corrected to 11 vol.-% oxygen, are safely met; limits below 100 mg/Nm³ require optimization of the excess air amount and a quite homogeneous fuel quality without major variations in composition and heating value.

About 3 to 4 tons of ash per hour are fed with the paper sludge. This remarkable increase in fuel ash has a favourable impact on the combustion process in the furnace, leading to a balanced and uniform process and the dilution of the fly ash, and reducing the risk of chemical ash reactions in the boiler pass, e.g. aluminium oxidation. In addition, the sludge's fine-grained ash is less abrasive; no abrasion has yet occurred at the refractory lining in the furnace and only limited abrasion was found in the target area of the cyclone. Compared to RDF-CFB reference plants without sludge co-incineration, only limited chlorine corrosion on the heating surfaces has been detected. Apparently chlorines are being contained in the ash; the detailed chemical reason will be presented in a future paper, but the favourable impact on the corrosive wear is evident.

Still the large amount of ash increases the fouling risk on the heating surfaces. The bright sludge ash and its inherent reflection potentially disturb and decrease the heat transfer by radiation. In consideration of these risks, the sequence of heating surface cleaning cycles by water cannoning, soot blowing, header rapping and shot cleaning was shortened.

The Glückstadt CFB boiler plant is designed to be operated with RDF as main fuel. In order to take out the major part of the fly ash at high temperatures, the boiler plant is equipped with a multiple-cyclone separator upstream of the economizer. Due to the fine average ash grain size a significant part of the fly ash is not captured by the separator and is passed over to the economizer, increasing the formation of ash layers on the horizontal economizer tubes. When the originally installed shot cleaning system turned out to be inadequate to efficiently clean off the ash deposits on the economizer tube banks, the economizer pass was upgraded with a sonic cleaning system.

3.2. Witzenhausen

B+T Energie GmbH operates a 124 MW_{th} (fuel heat input) circulating fluidized bed boiler plant in Witzenhausen, Hesse, Germany at the site of DS Smith Plc's recycled fibre mill. The mill produces raw paper for corrugated cardboards. The CFB boiler plant is designed to accept all incoming rejects and sludge from the current mill production and at the same time supplies the mill with steam and power. On an annual basis 295,000 tons of rejects from the local production and residue derived fuel supplied from external mechanical-biologic treatment plants, approx. 5,000 tons of sewage sludge and 2 Mio. Nm^3 of biogas from the water treatment plant are incinerated in the boiler.

Table 3: Witzenhausen sewage sludge analysis

Witzenhausen sewage sludge	Unit	Average
Carbon	%w, ar	8.60
Hydrogen	%w, ar	1.30
Oxygen	%w, ar	5.40
Nitrogen	%w, ar	1.00
Sulphur	%w, ar	0.20
Ash	%w, ds	45
Moisture	%w, ar	70.00
Lower heat value	kJ/kg, ar	2,000
Density	kg/m^3	800

Waste water, fiber and deinking sludge are disposed to the site's own local waste water treatment plant. After treatment and pre-drying by a screw compressor to a dry matter content of 30 % w, the sewage sludge is combusted in the CFB boiler. The feeding line to the furnace is designed for a capacity of 5 m^3/h and consists of a slurry pump and a feeding lance with atomizing steam injection.

Table 3 presents an analysis of the sewage sludge co-incinerated in the reference plant Witzenhausen.

Under normal operation at full-load, the average annual sludge portion amounts to approx. 0.6 t/h or 1.5 % w of the total fuel flow. This marginal amount of sludge co-incineration has no measureable impact in Witzenhausen; even at maximum design capacity, i.e. 4.0 t/h of sludge co-incineration, the plant performance, the flue gas emissions and the fouling and slagging potential is first and foremost related to the combustion of the challenging main fuels, rejects and RDF.

Essentially CFB boilers have such a stable combustion that minor co-incineration of sludge is feasible without major influence on or disturbance of the process.

3.3. Maxau

Stora Enso's Maxau mill is located near the banks of the Rhine in Karlsruhe. Recovered paper serves as the main raw material for high-quality magazine paper and newsprint production, beside local wood fibre and pulp arriving at the mill's harbour on ships from mills in Finland and Sweden. The site has its own deinking facility, ground wood mill and thermo-mechanical pulping system for the processing of sawmill scraps.

More than half of the power requirement and all of the required steam for production is generated in the site's own power plants. The latest CFB boiler plant is fuelled with mixtures of local production rejects and externally sourced biomass (bark and wood wastes) and bituminous coal; the co-incinerated mill sludge is a mixture of local accumulating biological, deinking and fiber sludge. Table 4 presents the related analysis.

Table 4: Maxau mill sludge analysis

Maxau mill sludge	Unit	Range	Heavy metals	Unit	Range
Carbon	%w, db	20 – 35	Antimony	mg/kg, db	< 2
Hydrogen	%w, db	2 – 5	Arsenic	mg/kg, db	< 3
Oxygen	%w, db	20 – 30	Cadmium	mg/kg, db	< 1
Nitrogen	%w, db	< 2,0	Chromium	mg/kg, db	< 30
Sulphur	%w, db	0.2 – 1.2	Cobalt	mg/kg, db	< 1
Chlorine	%w, db	< 0.15	Copper	mg/kg, db	< 230
Ash	%w, db	30 – 55	Lead	mg/kg, db	< 45
• Sodium + Potassium	%w, db	< 0.3	Manganese	mg/kg, db	< 100
• Aluminium	%w, db	< 1.0	Mercury	mg/kg, db	< 0,5
Moisture	%w, ar	35 – 60	Nickel	mg/kg, db	< 10
Lower heat value	kJ/kg, ar	2,000 – 5,000	Thallium	mg/kg, db	< 1
Density	kg/m³, ar	450 – 750	Tin	mg/kg, db	< 5
			Vanadium	mg/kg, db	< 5
			Zinc	mg/kg, db	< 110

The sludge is stored in a separate silo beside the boiler house. The feeding system consists of a silo scraper and a discharge and dosing screw, that drops the sludge onto the drag chain conveyor of the biomass feeding line; the sludge is fed together with the biomass.

The boiler is designed for a maximum sludge input of 46 t/h at full load operation or 15 % MW_{th} of the total fuel heat input.

Similar to the experience in Glückstadt, the good burnout characteristics of flue gas and ash are not affected by the high sludge co-incineration share. The large quantities of limestone fed with the paper sludge, reduce HCl emissions to minimum values and limit additive dosing in the flue gas cleaning system. Sulfur dioxide (SO_2) emissions, resulting from the rare firing of bituminous coal as back-up fuel, are captured by the limestone in the furnace; an additional dosing of external limestone as additive to the process is not required while co-incinerating sludge.

In contrast to the operational experience in Glückstadt, the co-incineration of sludge has no influence on NO_x emissions. During normal operation, with waste wood and rejects as main fuels and without SNCR system operation, the approved emission limit of below 200 mg/Nm³ is reliably met. With SNCR system operation, even NO_x values below 100 mg/Nm³ are easily reached, without increased ammonia slip.

The high ash content of the sludge causes increased fouling of the heating surfaces and as a consequence leads to increased boiler cleaning efforts. Still the economizer tube bank design with its conservative dimensioned, rectangular fins, turned out to be well suited for operation in Maxau. No signs of builds-ups or blockages were found and only the tube level on the edge of the soot blowing cleaning ranges shows fouling on fins. Figure 2 illustrates the condition of the tube bank after ten months operation.

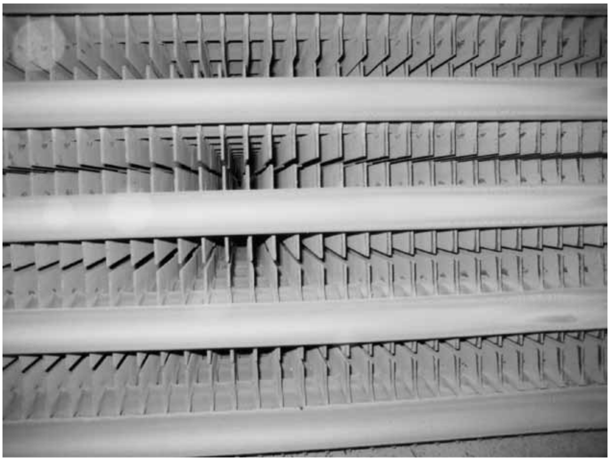

Figure 2:

Economizer tube bank, Maxau

After the first years of operation, the wear rates of the heating surfaces are very low; with increased co-incineration, the paper sludge tends to reduce the corrosive potential of flue gas and ash in Maxau.

4. Conclusion

The co-incineration of sludge in circulating fluidized bed boilers has good operating characteristics and favourable effects, but presents certain challenges that should be carefully taken into account, essentially depending on the sludge type, its composition and pollutants and co-incineration share:

- No negative impact on the combustion process and the burn out conditions has been detected in the selected reference plants, neither in flue gas (the CO emissions remain very low), nor in different ash qualities (the unburned carbon in bed and fly ash is around or even below the limit of detection).
- High limestone input tends to increase the NO_x formation and reduces the effect of injected denitrification additives. The co-incineration of sludge with high calcium (Ca) content may have an unfavourable impact on NO_x emissions. But on the contrary the limestone may reduce the dosing of additives for desulfurization and dechlorification in the flue gas cleaning system.
- The increased ash amount and its fine grain size distribution leads to a higher fly ash content in flue gas, affecting the build-up of ash layers on heating surfaces (fouling) reducing heat transfer rates and increasing boiler cleaning efforts. In addition the fine grained ash reduces the separation efficiency of mechanical removal systems installed along the flue gas path. On the other hand critical ash components are diluted by the increase in fly ash, as long as the sludge itself is not contaminated with pollutants. These effects should be considered for the design of the heating surfaces and boiler cleaning equipment, but also for the capacity load of the fly ash discharge and conveying systems.
- Hydrogen chlorides (HCl) are captured by calcium components, leading to a significantly reduced HCl concentration in flue gas. The reduced level of available chlorine decreases the corrosive impact of flue gas and ash on the heating surfaces.

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