



Optimising energy recovery and use of chemicals, resources and materials in modern waste-to-energy plants



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ABSTRACT

Due to ongoing developments in the EU waste policy, Waste-to-Energy (WtE) plants are to be optimized beyond current acceptance levels. In this paper, a non-exhaustive overview of advanced technical improvements is presented and illustrated with facts and figures from state-of-the-art combustion plants for municipal solid waste (MSW). Some of the data included originate from regular WtE plant operation – before and after optimisation – as well as from defined plant-scale research. Aspects of energy efficiency and (re-)use of chemicals, resources and materials are discussed and support, in light of best available techniques (BAT), the idea that WtE plant performance still can be improved significantly, without direct need for expensive techniques, tools or re-design. In first instance, diagnostic skills and a thorough understanding of processes and operations allow for reclaiming the *silent* optimisation potential.

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1. Introduction

The thermal valorisation of municipal solid waste (MSW) is subject to inherent limitations. Firstly, the physical appearance and the chemical composition of MSW impede a cost-effective and high-grade recovery of the lower heating value (LHV) contained by the waste. Secondly, strict regulations with regard to emissions and residue disposal tend to drive plant operators towards steady operational margins. For example, pollution abatement chemicals are often dosed in higher amounts than strictly required, in order not to exceed the legal emission limit values (ELV). Finally, where net profit generation is statutory not required – i.e. when the treatment of MSW is directly undertaken by an official authority or government Waste-to-Energy (WtE) plant operation is merely optimised to remain within acceptable budget, even if more advantageous operation is technically feasible. In the end, for a number of reasons, WtE plants are usually kept from attaining high chemical and energetic efficiency levels.

In light of recent developments in the EU waste policy, it is expected that an increased number of plant operators will optimise their processes of waste combustion, flue gas cleaning, heat recov-

ery and energy production beyond current acceptance. In this paper, experiences in the optimisation of state-of-the-art MSW combustion are shared. Figures presented here originate either from WtE plant data logging or from dedicated *plant-scale* research initiatives. Such information appears to be lacking in scientific literature. A well-documented feedback from industrial WtE practice is however important for further technological development of WtE because many plant-scale aspects cannot be studied in a laboratory environment. On the other hand, a waste combustion plant's operation is typically governed by economical drivers, which is often not in favour of steady conditions required for experimenting. Therefore it is not evident to perform WtE research and dedicated process data analysis on the industrial scale.

The following topics are discussed:

- Impact of process stability on WtE plant performance.
- Consumption of NH₃-based reagent for non-catalytic NO_x reduction.
- Early-stage assessment of boiler corrosion through chemical analysis of boiler ash.
- Increase of heat recovery at the low-temperature end of WtE boilers.
- Potential of residue recycling in dry lime (Ca(OH)₂) based flue gas scrubbing.
- Self-cementing behaviour of boiler/fly ash and APC residue in solidification/stabilisation.

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2. Issues in waste-to-energy plants

2.1. Process stability

Maintaining process stability is a challenge for combustion of household waste. Firstly, the average physical appearance and chemical composition of MSW change throughout the year. For example, seasonal changes, and the occurrence of holiday periods and weekends have a direct impact on both the amount and the LHV of the waste as delivered to a WtE plant. Secondly, the inhomogeneous nature of MSW at any time causes instant disturbances during the combustion process. As a result, the steam production baseline (i.e. the average steam flow) of a WtE boiler exhibits a fluctuating pattern over the longer term, with (superposed) short-term fluctuations. Moreover, as for any other large industrial system or process, the delaying behaviour of a boiler gives rise to intrinsic over- and undershoots on the steam curve. Whereas the latter is commonly tackled by means of conventional PID (Proportional–Integral–Differential) control on the boiler as such, other (waste-induced) effects are to be stabilised by the main control system of the combustion. In this regard, it is worth referring to a survey by El Asri and Baxter (2004), very concisely explaining WtE plant control principles.

For a WtE plant in operation, the variation in the steam flow from the boiler must be kept within a range acceptable for the steam turbine. The highest electricity output is obviously obtained when the steam production baseline is on average at the highest level allowed for by design. However, when short-term fluctuations are steadily beyond tolerance, the average steam production (and hence the waste throughput) needs to be reduced to avoid wear of the turbine. Good *stability* of the boiler steam produced (and so of the combustion process) is hence required to maximise the annual waste throughput and energy production.

2.2. Selective NonCatalytic Reduction (SNCR)

To date, WtE is already subjected to the lowest ELV amongst all NO_x emitting power industries within the EU (European parliament and council, 2010). Nevertheless, the ELV of 200 mg m⁻³,¹ is currently under political pressure and in a number of EU countries (e.g. Sweden, Austria, the Netherlands, Flanders/Belgium, Bavaria/Germany), more stringent emission limits are already applied. They are either imposed explicitly by local law or established implicitly (i.e. case-by-case) through environmental permitting or financial incentives such as NO_x tax/bonus policy.

NO_x, i.e. the sum of NO and NO₂, is a by-product of combustion. In well-controlled combustion chambers, less NO_x is formed, but the formation of NO_x cannot be totally avoided. It is therefore required to add an NH₃-based reduction step to a MSW combustor line in order to meet the daily ELV of 200 mg m⁻³. Both Selective Non-Catalytic Reduction (SNCR) as well as Selective Catalytic Reduction (SCR) are effective and chemically well-understood techniques. Due to the presence of a catalyst, SCR allows for a high removal of NO_x from the flue gas, even down to 30 mg m⁻³. However, achieving such a low NO_x emission is at the expense of a large investment cost (i.e. about tenfold of SNCR) and a high CO₂ equivalent contribution. The latter is due to the production and maintenance of the catalyst, the rather high minimum operation temperature (>180 °C) and the input (or deviation) of energy/fuel required. Given the overall limited energetic output of WtE plants (compared to power plants), it was concluded by Beckmann et al. (2009) that conventional SCR requires disproportionate efforts

per unit of NO_x extra removed below 200 mg m⁻³ and that therefore SNCR is to be preferred if possible.

To date, a limited number of WtE-plants feature a high-dust SCR system upstream of the flue gas cleaning. Such system is commonly positioned in or right behind the boiler and is operated at higher temperature than a conventional SCR system. High-dust SCR allows for a simpler and more compact NO_x removal and is energetically more advantageous compared to conventional SCR. However, these plant references are all of recent date and typically subsidised for purpose of research and development. First experiences (in e.g. Brescia WtE plant, Italy) confirm high rate of clogging and attrition of the catalytic units, as can be expected due to the high dust load. Whereas catalysts in a conventional SCR system can be used for more than 10 years, in a high-dust SCR system, a partial catalyst replacement appears to be required already after 2 years of operation. Hence, maintenance costs are significantly higher. Overall, high-dust SCR is still far from being a mainstream application in the WtE industry, and more time is required to evaluate its techno-economical value waste combustion plants.

In new WtE plants a tendency exists to adopt conventional SCR as soon as emission values are significantly lower than 200 mg m⁻³ are to be established. In existing WtE plants then again, SNCR systems are often not well tuned to their technical capacity. To the authors' opinion, the *intrinsic* potential of SNCR technology for application in WtE is not yet clear. Conditions of injection, mixing, mass transfer (liquid–gas) as well as physical properties of the flue gas in the zone of NO_x reduction are critical for the effectiveness of the NH₃-reagent. Case studies by Villani et al. (2012) indicate that there is still major room for improvement of SNCR systems in WtE plants.

2.3. Corrosion assessment

Corrosion of boiler superheaters is well-recognized and causes a significant maintenance cost in existing WtE plants. The key elements in the corrosion are identified as chlorine and sulphur, which are present in MSW in higher doses than in other solid fuels. Moreover, for MSW the Cl/S-ratio exceeds 2, i.e. the inverse of most fossil fuels for power plants (Born, 2005). Cl and S together represent less than 1 wt% in MSW. Both elements form however highly volatile compounds and are to a large extent transferred into the flue gas during combustion at a temperature typically above 1000 °C, transfer coefficients for Cl and S being around 90% and 80% respectively (Belevi, 2000). As a result, concentrations in the raw flue gas are typically 800–1200 mg m⁻³ for HCl and 100–300 mg m⁻³ for SO_x.

About 15% of the SO_x is rapidly captured during early cool-down in solid salt deposits (on fly ash particles and boiler walls in the post-combustion zone). The chlorine however remains for a longer time in the flue gas, either as gaseous Cl₂/HCl or as Na/K-chlorides, that deposit at temperatures lower than 700 °C. As the gaseous Cl₂/HCl arrives at the superheater section downstream, corrosion is triggered if the flue gas temperature still exceeds 650 °C and if the superheater surface is at a contact temperature significantly above 400 °C. If this situation persists for too long time, a liquid phase containing alkaline Na/K-chlorides, will emerge on the corroding surface. Finally, SO₃²⁻/SO₄²⁻ ions also dissolve from ash deposits and will act as electrolytic amplifiers, boosting up the speed of corrosion by at least one order of magnitude. In general, an oxidative chlorine-induced multiple reaction scheme is agreed upon, although a number of unknowns is still remaining. For more details on chemistry and mass transfer limitations, the reader is referred to e.g. Lee et al. (2007) and Horn et al. (2008).

On-line cleaning systems are helpful to restrict fouling on superheater parts (in the convective boiler zone downstream), but also on membrane walls (in the radiative boiler zone

¹ m³m refers to 1 m³ at a temperature of 273.15 K, a pressure of 101.3 kPa, after correction for the water vapour content and with an O₂ content of 11%.

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