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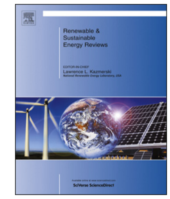

Enhanced waste to energy operability under feedstock uncertainty by synergistic flue gas recirculation and heat recuperation

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A B S T R A C T

Variations in quantities and composition of received wastes in waste to enegy (WTE) plants lead to throughput and power losses (lower profits). By disturbing the mean residence time of flue gases in the air-pollution-control-system they result in temperature and offgas flow variations affecting combustion efficiency and actual pollutant emissions. Besides energy savings, integration by flue gas heat recovery (FHR) in a heat exchanger (recuperator) enables maintaing high throughput under feedstock uncertainty (e.g. poor wastes). An effective method for reducing WTE atmospheric pollution, mainly NO_x emissions, flue-gas-recirculation (FGR) – mass recirculation of a fraction of flue gases to the combustor – may be used for the same purpose. Both FHR and FGR are related to robustness issues, limiting the actual range and effect of manipulation. Recent results indicate that FHR and FGR have opposite effects on WTE performance – increasing FGR cools down the combustor, while FHR boosts up combustion. The present work demonstrates the possibility of improving operability of WTE facilities by combined use of FHR and FGR, utilizing multiple waste mixtures with uncertain feedrates, heating value, or composition. It brings forth a key dimensionless parameter, determining the direction and magnitude of the manipulation and leads to explicit expressions for the sensitivities of power production, throughput and capacity constraints with respect to FGR and FHR ratios. Synergistic use of FHR and FGR enables maximization of throughput and power production within the process capacity constraints, without detrimental effects on destruction efficiency or final emissions. A Case Study is analyzed for a facility under a public–private-partnership contract, with received waste ranging from a guaranteed minimum 150.000–200.000 TPY and composition range: biodegradables 52–70% ww, recyclables (paper, plastics, metals, glass) 25–45% ww.

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1. Introduction

With 2/3 of municipal solid (MSW) waste being biogenic, waste to energy (WTE) plants, nowadays treat about 130×10^6 TPY satisfying a part of global energy demand, while reducing greenhouse gas emissions and providing a safe waste disposal option [1–7]. Results from intense research efforts and innovative practices [8,9] are being implemented towards reducing pollutant emissions and amounts of hazardous residues to be disposed of (e.g. fly ash). Actual emissions are lower than the strictest emission standards, [10–14], in most cases with sacrifices on the recovered energy. For instance, improved boiler design inhibits de novo synthesis of dioxins in the temperature range 200–450 °C: actual dioxin emissions are less than 5 μgr/n-TEQ per tonne of waste, while ash sintering leads to granulate featuring loss on ignition at 0.1% and leachability of lead <0.01 mg/l [8,15].

Wastes produced by consumer societies include organic materials from biogenic (food residues with high water content, paper, wood, leather) to non-biogenic (plastics, composites) and inorganic (metals, glass, ceramics, inerts). About 5 wt% of municipal solid waste is considered hazardous, containing heavy metals and hazardous organic compounds, e.g. spent paints, varnishes, synthetic wood products, solvents and cleaning agents, and expired medicines [16]. In addition, MSW constituents, such as plastics, contain chemicals which are deleterious upon release to the environment (pigments, antiblockers, concentrates, UV transformes, flame retardants, and biodegradation inhibitors [17–20]).

MSW exhibits unusually high uncertainty as a non-standardized raw material to an engineered processing facility, built and operated on the basis of a nominal design and presumed feedstock properties. Uncertainty stems from shifting heterogeneity of the feed, limited capacity for mixing and homogenization, variations in received quantities and intensely fluctuating composition, as manifested by wt% fraction of the various constituents. For instance, touristic areas in the Mediterranean feature 300% higher daily volumes [21] in summer than in winter, while the biodegradable fraction (putrescibles and paper) may reach up to 80 wt%. Furthermore, the incoming waste features continual variations in composition, due to seasonal variation, economic cycles, to the advent of consumer product manufacturing technology, health and ecological considerations, fashion trends and environmental legislation.

Landfilling sucessfuly deals with MSW heterogeneity and uncertainty issues by placing the polluting MSW feedstock in enclosed spaces and acting as a buffer, evenly distributing or delaying the releases to the environment for several decades, while occupying and degrading large areas. In contrast, WTE plants instantaneously (i.e. in a few seconds) convert MSW to flue gas and ash: ferrous and aluminum metals are recovered from bottom ash, while landfilled ash residues amount to 25–30% of feedstock. Flue gases are released into the atmosphere after clean up in the air pollution control system (APCS). MSW uncertainty impacts operability and performance: for instance, if the WTE facility must treat dried WTP sludge as well, in order to reap potential greenhouse gas benefits, seasonal varations in quantity are larger, while plant operation is faced with operability problems due to (a) varying LHV of sludge (b) larger flue gas volumes, associated with biosludge incineration and (c) more enthalpy carried with the discharged flue gases due to increased moisture. Similarly, variations in the inert wastes content of MSW in the upturn of economic cycles (surging civil works or construction / demoliition activity) affect WTE plant operability, not only due to ash handling, but also due to the impact of inerts in the combustion mechanism, enthalpy balance and energy recovery (higher enthalpy loss with the discharged ash). A similar impact stems from the shifting content of residual (green bin) waste [22] due to source separation of recyclables, mandated by legislation [23–25]. The latter favors material recycling over energy recovery from biodegradable fractions, which include paper products, further upsetting the WTE feedstock charging rates, composition, lower heating value (LHV) and inert content.

Energy integration by flue gas heat recuperation (FHR) (exchange of sensible heat of flue gases with the feed, air or wastes) is employed for raising net energy efficiency. For instance, a fraction (appropriately set by the operator) of the flue gas may be heating up the air feed in a heat exchanger (recuperator) [26]. Corrosion of the heat exchange equipment is an issue, while robustness problems may arise in cases of poor wastes, low in LHV or high inert content. Since FHR essentially heats-up the reactor, it may be used to increase the incinerator throughput in case of poor wastefuels. Flue gas recirculation (FGR) [27–31] (or exhaust (EGR) [32, 33] in internal combustion) has proved effective in reducing WTE atmospheric pollution, mainly NO_x, while resulting in lower total offgas flowrates due to lower excess air requirements. Acting as a dilution mechanism, it also leads to lower reported emission concentrations of other pollutants (e.g. volatile metals), which must be corrected to 11% oxygen (as required by Directive 2000/76/EC [13]). Compared to heat recuperation, FGR being a mass recycle, differs substantially from heat integration; the latter redirects enthalpy to the combustor and raises its temperature, thus necessitating a lower throughput of rich wastes [26]; oxygen concentration in both the primary and secondary air is not affected (21 vol%) by FHR. In contrast, under FGR, a fraction of the incineration chamber flue gases is recycled back to the combustor, mixed with the secondary combustion air. Due to enthalpy loss in the boiler and the recirculation duct, FGR essentially cools down the combustor and enables higher throughputs of richer wastes. Offgas volumes increase with rising throughput, albeit at a lower pace, leading to lower residence times in the APCS. FGR may induce robustness problems [5,34] as well. Corrosion of downstream equipment and possible incomplete combustion of refractory wastes are associated with high FGR, compeling an optimal trade-off (optimal FGR ratio). Feedstock variations modify the optimum. In general about 10–20% (v/v) of flue-gas is recirculated with the secondary air [35] which increases turbulence and ensures complete combustion.

The present work focuses on the possibility of combined use of FHR and FGR for improving the operability and performance of waste to energy facilities. By enhanced operability it is meant the extended capability for aversion of throughput and electrical power losses, under a wider range of feedstock uncertainty, while offgas volumes, APCS mean residence times and emissions are not adversely affected.

2. Method description

2.1. Direct operation: combustion mass balance

In a WTE plant a mixture of wastes is combusted to flue gases and ash, in temperatures reaching 950–1200 °C (furnace). Ash is conveyed to the ash collection equipment for special treatment and disposal. The flue gas producing combustion reaction in the temperature range may be represented as

$$Cx_1\, Hx_2Ox_3\, Sx_4Clx_5Nx_6\, Px_7\, Brx_8\, Fx_9$$
$$+(1+E)(x_1+\varphi+x_4+5/4x_7-0.5x_3)O_2$$