Increasing energy efficiency in Waste-to-Energy: from waste processing to combined heat and power production

B. Verbinnen[1], J. De Greef[2], J. Van Caneghem[1]

[1] KU Leuven Campus Group T, Andreas Vesaliusstraat 13, 3000 Leuven, Belgium
[2]Keppel-Seghers Belgium NV, Hoofd 1, 2830 Willebroek, Belgium
Keywords: Waste-to-Energy, Energy Efficiency, Combined Heat and Power, Municipal Solid Waste
Presenting author email: bram.verbinnen@kuleuven.be

Introduction

Municipal Solid Waste Incineration (MSWI) has become the most widespread Best Available Technology (BAT) to treat residual streams of waste in a reliable and safe way. As such, MSWI has contributed to achieve the landfill diversion targets in many EU member states. Modern waste incinerators, also named Waste-to-Energy (WtE) plants, have furthermore evolved to sources of electricity, heat and steam for energy-consuming industries, agriculture and residential heating. However, due to properties inherent to MSW and similar fuels, and due to the historical development of MSWI, the exploitation of WtE plants as combined heat and power (CHP) plants is not straightforward. The aims of this paper are to develop a better understanding of these limitations and to point out possibilities for increasing the level of energy recovery and utilization in WtE plants. Finally, some design and operational challenges for waste-fired CHP plants are further elaborated.

Energetic optimization of a WtE process

When electricity is the only energy form produced in a steam cycle, losses due to energy conversion are considerable. Furthermore, for turbine-generator systems of a rather small scale – as is the case for typical-sized WtE plants compared to coal power plants – optimization possibilities in the steam cycle are also limited. Then, focus rapidly shifts to the incineration and heat recovery as such when aiming for higher plant efficiencies. By combining several measures, a (relative) total improvement of the electrical efficiency up to 10% is possible in a stand-alone WtE plant. These measures include, but are not limited to: optimization of process control, lowering of excess oxygen, internal recycling of process heat, recovery of low-temperature heat, and increase of boiler steam temperatures.

Design and operational settings for Combined Heat and Power (CHP) provided by WtE

In case of steam and/or heat export the overall efficiency of a WtE plant becomes more dependent on the energy demand as such, rather than on limitations at the incineration side. As the typical efficiency of a modern WtE boiler is about 85%, an equal level of plant efficiency can be established by exporting all steam as produced. Typically, a combined situation occurs, whereby the WtE plant delivers steam, heat and electricity in variable rates throughout the year. Unlike fossil-fueled CHP plants, wherein the amount of fuel can be adapted to the demand of energy at any time, waste-fueled CHP plants must also ensure an annual throughput of waste. This implies that waste is to be incinerated also in times when the energy demand is low. Then, when the steam produced cannot be taken e.g. by an industrial consumer, it shall be possible to deliver this heat e.g. to a buffering heat network, or to supply electricity to the grid. Hence, the design of a waste-fueled CHP shall include for several interfaces, allowing the WtE plant to continue its waste-processing operation under all conditions.

Customers for steam include chemical processing industries, paper mills, large greenhouses, district heating, etc. Typically, they are in operation year-round, 7 days out of 7, and 24 hours a day. Hence, during 100% of the time it is possible to supply (a base load of) steam, in fact exceeding the state-of-the-art availability of WtE technology (>90% on yearly basis). Nowadays, attempts are undertaken in many WtE plants to extend the operation period between two consecutive shutdowns, e.g. by installation of redundant equipment, additional on-line boiler cleaning systems and more frequent technical inspection/repair of smaller plant items. Nevertheless, a WtE line has to be taken out of duty on regular basis, e.g. to enable internal cleaning and repair of the boiler system. This implies that variations throughout time of the amounts of energy to be supplied strongly influence the configuration of sizes/numbers of WtE lines in a waste-fueled CHP plant. The design should anticipate to downtimes of the WtE process lines. Also, the Rankine steam cycle might have to be installed with high level of equipment redundancy, including e.g. a multi-staged turbine and a (water-cooled) condenser with sufficient oversize capacity (allowing to bypass the steam turbine for at least part of the time). For obvious reasons, to ensure 100% availability, the investment for a Rankine cycle in a waste-fueled CHP plant is typically much higher than for a (more basic) cycle in a typical stand-alone WtE plant.

Different types of energy customers can have very different demands for steam, heat and/or electricity. Whereas a chemical factory typically depends on a large and continuous steam supply for processing purposes, smaller industrial production units (e.g. mills in paper industry) rather require a flexible/discontinuous supply of steam. Alternatively, when coupled to a district heating network or large green-houses, the WtE plant must cope with seasonal variations. In this way, the design of Rankine cycles for CHP-coupled WtE plants can become very complex, especially when multiple energy customers with divergent needs are to be supplied with different types of energy.

Finally, steam (flow) stability is of utmost importance in case of steam export to industrial consumers. Steam stability is typically evaluated based on a continuous measurement of the steam flow (as minutely averaged process values) during a defined period (e.g. a 12-hour or 24-hour period). This measurement is then repeated several times during e.g. 1 week or 1 month. During a single measurement, the steam temperature and pressure shall remain constant to obtain a reliable result. Steam stability can be defined in different ways, e.g. as the standard deviation of the process values of the steam flow, relative to the average of those process values, or as the average of (absolute) deviations from the setpoint, relative to the setpoint value. It is important to understand the precise definitions behind a given steam stability figure to make a correct assessment of the steam production performance of a WtE CHP.

Conclusions

Due to properties inherent to waste (MSW, RDF or equivalent), the efficiency of a WtE process is limited. However, with state-of-the-art waste incineration technology, WtE plants can be integrated in combined heat and power (CHP) schemes, to deliver steam, heat and electricity to energy consumers in the vicinity. In this way, plant efficiency – or alternatively stated, the level of energy utilization – can be brought up to 3 times the efficiency of a stand-alone WtE plant. This offers a potential to replace significant amounts of fossil fuel for industrial, agricultural and residential purposes. As a result of stringent emission limits and minimum waste throughput targets imposed on waste incineration, the operational flexibility of a WtE plant is more restricted than for e.g. fossil-fueled or biomass power plants. Nevertheless, the demand of large and small energy consumers can be satisfied by deliberated configuration of a CHP-coupled WtE plant (i.e. numbers and sizes of incineration lines) and tailored design of the steam cycle. Furthermore, a waste-fired CHP plant must meet several criteria by design and operation, such as a high yearly availability, the ability to deliver different types of energy to multiple energy consumers, the ability to cope with diverging operation modes in time (e.g. continuous versus discontinuous energy supply, variable/seasonal demand, etc.), and a stable steam supply.