Waste Combustion or Gasification: Comparing Apples with Apples?

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1. Introduction

Thermal waste treatment is a reliable and proven process built on decades of reliable operation coupled with continuous improvement and development. Despite its proven track record with regard to economical, efficient and safe operation, it faces repeated competition from purportedly new and innovative technologies. Gasification is currently being touted as the front runner in terms of economics and efficiency. Unfortunately the comparison of technologies is rarely based on a comprehensive review or comparable system boundaries. This article provides a complete and objective analysis of the principal process technologies, looking closely at their respective pros and cons. In addition, the authors present some new innovations in combustion technology, that forms the basis for further efficiency gains in energy-from-waste plants.

2. Thermal waste treatment – a valuable solution

Municipal solid wastes must be treated in accordance with European Union Directives. As such their treatment must follow the waste hierarchy. The law requires that discarded materials primarily be reused and non-recyclable waste be treated with minimal impact on human health and the environment. And finally recoverable materials should be directed towards manufacturing processes for new products.

Thermal waste treatment, i.e. waste combustion combined with integrated resource recovery, meets this requirement like no other. Firstly, the energy contained in waste is recovered and reintroduced into the grid, be it in the form of electric power or heat or both. Waste combustion also is uniquely able to separate and purify the discarded materials. This is particularly true of today's waste, which contains increasing quantities of complex composite materials. Specifically, the modern packaging industry is known to apply innovative solutions in an effort to minimize the use of valuable components such as aluminum. These valuable fractions must be recovered by separating them from their substrate and redirecting them for further use. Similarly, wastes often contain impurities and dirt. Such substances negatively impact the downstream production processes and must be removed in order to protect workers involved in those processes. Waste combustion destroys and removes such impurities in a very effective and safe manner. What remains after treatment is a mixture of clean, separated and easily reusable materials.

The costs of the thermal treatment of waste can be easily presented in a transparent manner and billed to the generator of such waste. This provides strong motivation to minimize the volumes of waste generated. European statistics clearly show that areas with high thermal treatment rates coincide with the highest recycling rates at 50 % and above. The comparatively high treatment costs for energy-from-waste plants create a sound economic basis for the separate collection of certain recyclable materials such as metals, glass, and paper, avoiding the need for other inducements. Thermal waste treatment thus fulfills a double role.

3. Thermal waste treatment – an important link in the closed loop of materials

As a whole, waste combustion is by far the most efficient process for the recovery of energy and materials from non-recyclable waste. As such it represents a very important step in the cycle of materials in terms of sustainable resource management. Without this step, the global economic loop – consisting of mining, processing, use, disposal, and recovery – would suffer a significant loss of energy and valuable materials.

Despite such advantages, energy-from-waste plants frequently face significant criticism, mostly on a very emotional basis and without supportable facts. Alternatives are presented that are not proven, and that are based on promises that cannot be met. One such alternative *innovative* technology that is presented at regular intervals is gasification. Two approaches can be discerned here:

- an integrated process, where an attempt is made to separate the gasification process from the oxidation step but where the two steps are coupled in a single reaction chamber

- complete separation of the gasification process in order to produce a fuel gas for processing in a power plant or an other industrial application.

The first approach is nothing other than the combustion process described above. The physical separation of the two process steps may allow for the sampling and analysis of the fuel gas prior to its oxidation, but basically waste is gasified on a grate and the fuel gas created rises to the post-combustion chamber for oxidation with the injection of secondary air. The radiant heat generated by the flame in this post-combustion zone promotes the gasification of the fuel bed on the grate below, just like in a conventional waste combustion plant. The only difference between the two is the distance between gasification and oxidation – thus requiring more building height – and the ability to sample the gas. There is no discernible advantage in terms of energy efficiency or ash quality.

The second alternative – the synthetic gas production process – yields a syngas similar to earlier coal gasification plants. As in the case of combustion, elevated temperatures are required to gasify the waste fuel. Lacking the radiant heat from the oxidation flame, these temperatures must be generated by alternative means. There are two options:

- partial oxidation of the waste fuel in the presence of pure oxygen
- external introduction of energy by means of a premium (fossil) fuel in a burner.

A gasification chamber is typically designed as a compact vessel, thus requiring the pretreatment of the fuel. In order to properly feed and heat the waste fuel, it must first be shredded. This process step requires significant quantities of energy, maintenance effort and building space.

4. Syngas production – ideal for homogenous fuels

The gasification of waste fuel in a gasifier thus consumes some of the energy contained in the waste or requires a significant additional injection of high-quality fuel. Both approaches yield a hot fuel gas consisting of hydrogen, methane (and other hydrocarbons), and carbon monoxide, slightly diluted with moisture and CO_2. Contaminants contained in the waste such as chlorine, sulfur, ash, and heavy metals are present in the fuel gas as impurities.

In order to utilize the fuel gas in a future application these impurities must be removed. This is easily accomplished in a gas treatment plant similar to those used in combustion plants. However, in order to scrub the fuel gas it must first be cooled to temperature levels adequate for the process, either by air cooling, quenching or heat recovery. Without the recovery of this heat, the gasification process would suffer a significant energy loss. On the other hand, doing so requires a heat recovery boiler suitable to be operated with an explosive gas. The cleaned fuel gas can then be compressed and stored in suitable pressure tanks or transported to its location of use. The most efficient process currently available for converting a fuel gas into electric power is the combined cycle gas turbine process, where the gas is combusted in a gas turbine driving a generator. The hot turbine exhaust is then cooled in a heat recovery boiler to generate steam for expansion in a steam turbine which drives its own generator. In summary, for maximum energy efficiency a syngas plant therefore requires the following systems: fuel pretreatment (size reduction), gasifier, oxygen generator, heat recovery from hot fuel gas, water/steam cycle 1, steam turbine 1, fuel gas cleaning, fuel gas compressor and storage tank, gas turbine, heat recovery boiler, water/steam cycle 2, steam turbine 2. Such a complex processing plant has yet to be built for the treatment of waste and is hardly proven to be economical.

Gasification plants for the production of syngas have been in operation for decades and have proven to be effective when processing fuels such as coal, wood or other mono fractions. Municipal waste on the other hand is a very inhomogeneous and forever changing mixture of materials. With such fuel, a gasification plant is likely to reach its limits. To our knowledge, no such plant has been able to demonstrate its economic viability.

5. Waste combustion – ideal for heterogeneous fuels

Waste combustion processes have been proven to be very reliable in processing the heterogeneous mixture of materials known to be found in municipal waste. In addition, these processes are based on the same basic gasification step discussed above.

5.1. Gasification

Any combustion process must begin with the gasification of the fuel being combusted, be it a wood fire in a fire place, an internal combustion engine, or a waste combustor. The gasification step yields the known fuel gas consisting of hydrogen, carbon monoxide, and simple hydrocarbons such as methane. Only after this fuel gas has been generated can it be oxidized in the presence of oxygen. In order to gasify solid fuels like wood or plastics, they must be heated to high temperatures. Under these conditions these substances disassociate into the compounds listed above.

In a waste combustion plant these temperatures are generated in the furnace when the fuel gas burns in the presence of secondary (overfire) air. The radiant heat from this flame zone heats the fuel bed on the grate to cause it gasify. The fuel gas emanating from this process then rises to the post-combustion chamber to be oxidized when it meets the oxygen from the combustion air. Since the two processes – gasification and oxidation – occur in close proximity to each other, they are frequently perceived as a single process.

The oxidation step converts the fuel gas components (hydrogen, carbon monoxide and methane into moisture (H_2O) and carbon dioxide (CO_2). Other contaminants such as chlorine and sulfur are contained in the fuel gas as well as in the final exhaust gas. Inert components in the waste are partially entrained by the process as boiler ash. The hot exhaust gas leaves the furnace at temperatures between 1,000 and 1,200 °C and enters the heat recovery boiler as a mixture of CO_2, H_2O, excess oxygen, unused nitrogen, contaminants and fly ash.

The fuel bed travels across the grate and decomposes under the influence of the radiant heat and due to the gasification process. What remains is the inert (non-combustible) fraction of the waste which contains all the valuable resources to be recovered and recycled.

5.2. Heat and energy recovery

The hot exhaust gases are cooled in the heat recovery boiler immediately following the combustion step. The heat is converted into steam, which in turn is used in a conventional Rankine water/steam cycle to drive a turbine and its generator. Alternatively a turbine bleed may feed a heat grid.

5.3. Gas cleaning

The final process consists of a multi-step flue gas treatment system where contaminants such as HCl, SO_2, NO_x, particulate matter, heavy metals, and dioxins are removed. These processes have experienced such significant improvements in recent decades that exhaust gas qualities at the stack meet even the strictest emission limits. In terms of heavy metal concentration, they even comply with workplace exposure limits.

6. Comparison of the processes

When comparing various processes, the most important aspect is to ensure the consistent definition of boundary conditions. When analyzing the combustion process, the principal energy input is represented by the untreated municipal solid waste delivered to the plant. When additional fuels such as premium fossil fuels are added, the comparison becomes difficult since these fuels could be put to better use in more advanced applications.

The entire energy input must be compared to the electric power output after subtraction of the parasitic load of the plant, including all previous and subsequent processing systems. Typical energy losses that must be considered include stack losses due to warm exhaust gases, heat losses at the condenser of the steam plant, unburned carbon in the ash of the combustion or the gasification process, as well as the electric power required to run the entire plant.

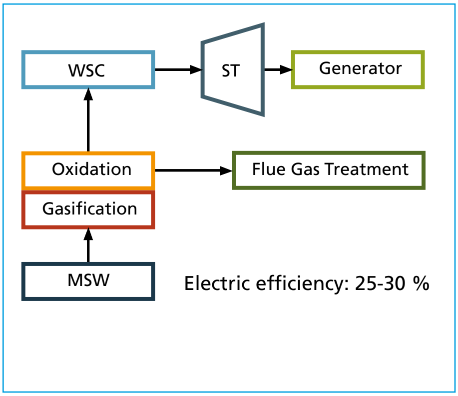


Figure 1: Conventional Waste Combustion Process

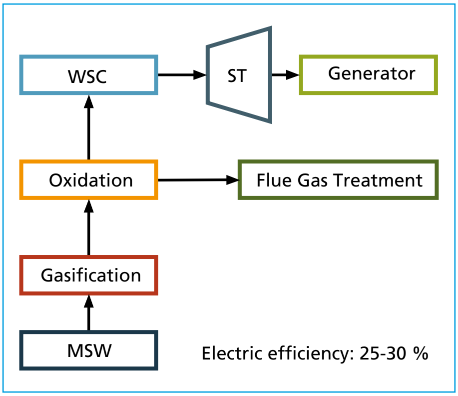


Figure 2: Waste Combustion Process declared as gasification

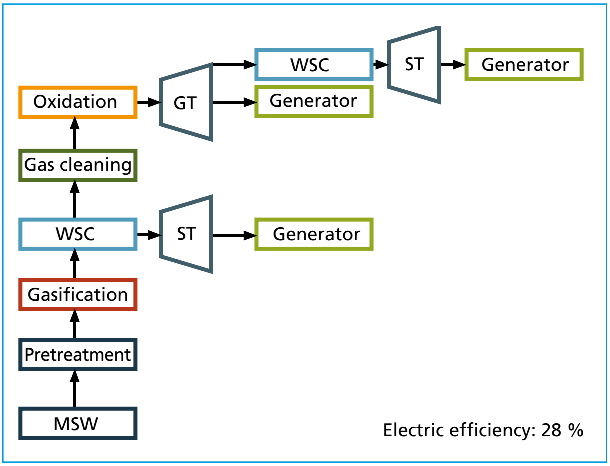


Figure 3: Waste Gasification Process

Today's waste combustion plants can reach net electric efficiencies between 25 and 30 % (e.g. RRRC Riverside: 27 %; AVI Amsterdam: 30 %). These values apply equally to plants where the gasification step is slightly removed from the oxidation process.

The syngas process on the other hand has the advantage of utilizing a very efficient thermal process for the combustion of the fuel gas. The combined cycle gas turbine process may well achieve efficiencies of around 50 %. However, when taking the gasification process into consideration, even a very innovative one as described by Baggio et al in [1], results in total efficiency of 28.3 %.

7. Tuned combustion processes increase efficiencies

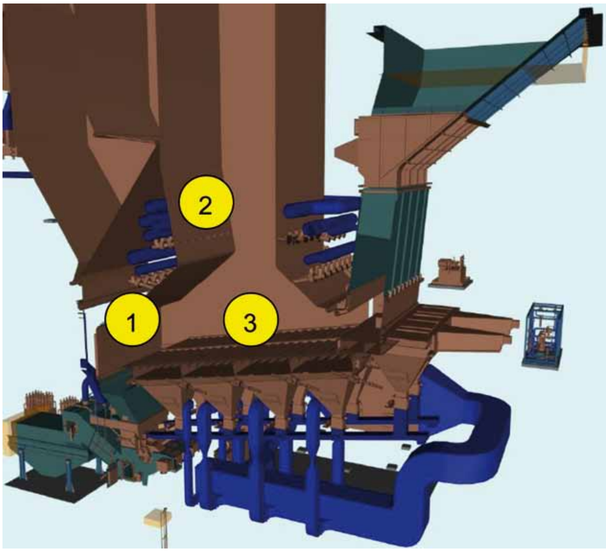
Efforts to improve energy efficiencies in waste combustion plants focus on minimizing stack losses, energy losses in the flue gas treatment systems, and heat losses from the steam condensation plant. Stack losses are a function of stack temperature and oxygen concentration of the exhaust gas. Higher excess air ratios in the combustion process produce higher exhaust gas volumes and elevated oxygen concentrations in the stack. Designing a process with reduced combustion air supply results in significantly smaller stack gas flows. While stack oxygen concentrations above 7 % were common 10 years ago, today's combustion processes can operate at levels of 4 % or below. The resulting exhaust gas flow reduction can reach 30 %, resulting in significant efficiency gains. Such tuned processes demand perfectly designed combustion air delivery and excellent control systems. They are, however, well proven and will soon become routine, one example being the plant Renergia in Perlen (Switzerland) that is currently under construction.

Figure 4:

Plant Renergia in Perlen (Switzerland)

This plant features the latest innovations from Hitachi Zosen Inova AG (HZI) in terms of combustion technology. The concept is based on an in-depth analysis of the gasification processes on the grate of a combustion plant, the aim being to design the most efficient waste combustion process which avoids the shortcomings of the separated syngas process in an elegant manner. The highly tuned process requires the latest know-how in terms of measurements and controls. An array of innovative measurement concepts ad control algorithms are able to control the process within narrow boundaries.

Renergia in Perlen (Switzerland): Advanced Waste Combustion at its Best



Clearly defined pre-mix zone (1), followed by secondary air injection (2)
Open furnace geometry for optimized gasification (3)

Figure 5:

HZI Furnace Design

The new energy-from-waste plant Renergia currently being constructed by HZI in Perlen (Switzerland) is a prime example of what an advanced waste combustion system is capable of. The indicative parameter of this design is its ability to operate at very low residual oxygen levels in the exhaust gas.

The innovative combustion process is based on a careful, computer-assisted analysis and detailed measurements of the complex processes involved in the gasification of heterogeneous waste fuels and their interaction with the reactive steps in the post-combustion zone. The separate analysis of the drying, gasification, and combustion phases resulted in a novel integrated process.

Gasification of dried fuel produces a fuel gas with the well-known composition: up to 10 % hydrogen, 10 % carbon monoxide and considerable concentrations of methane and similar hydrocarbons. A significant finding was the realization that no residual oxygen is present in the exhaust gas from the gasification and flame zone of the grate. As such, two distinctly different gas phases are present at the entrance to the post-combustion zone: no residual oxygen on the feeder side and essentially unused hot combustion air opposite. Such diverse conditions must first be homogenized before the gas can be processed effectively in the oxidation zone. This premixing step is the key on HZIs new combustion process.

Although these primary findings were not unexpected, their simulation led to an improved understanding of the interactive influences of furnace geometry and process parameters. This has allowed for an optimization of the delivery systems for combustion air, primarily in the post-combustion zone.

The resulting thermal process must be controlled within narrow boundaries to achieve its full performance. This requires a sophisticated control system with supplementary algorithms based on the acquisition of previously unknown data. The expanded combustion control system continuously measures process parameters using innovative new approaches, and acts on an array of control points within the plant.

These control modules allow operation of the combustion process with significantly reduced excess air ratios while simultaneously achieving markedly improved emission concentrations – especially in the case of carbon monoxide and nitrogen oxides. HZI demonstrated this process in a suitably modified waste combustion plant for an extended duration. That plant operated with residual oxygen concentrations at the exit of the boiler in the vicinity of 2 %. Such a process demonstrates a significant improvement in terms of energetic efficiency due to the reduction of stack losses.

The conclusion: Waste combustion is a process which is continuously being improved. An objective comparison with other purportedly *advanced* processes concludes that waste combustion ranks higher in terms of economics and ecological impact.

8. Performance and efficiency of flue gas treatment systems are essential

Aside from energetic efficiency, comprehensive treatment systems must also consider the quality of end-products and emissions. Combustion systems for waste produce bottom ash. Similarly, syngas plants manufacture ash; however this product contains residual concentrations of fixed unburned carbon. This carbon represents an energy loss on the one hand and also diminishes the ash quality, which impairs its future application in other processes. Emissions of contaminants which leave the plant through the stack or the gas turbine exhaust are similar in both cases. The specific design of the combustion (oxidation) process can impact the generation of nitrogen oxides. However, current design philosophies, in conjunction with appropriate reduction processes, achieve similar emission levels as found in the gas turbine exhaust.

Nevertheless, cleaning the exhaust from any thermal process, be it a syngas or a *conventional* combustion system, requires a significant input of energy. This is primarily true because of the need to inject water in order to control temperatures at levels indicated by the chemistry involved. Approaches to improve the energy efficiency of flue gas treatment systems therefore usually focus on eliminating the need for water evaporation with a view towards avoiding a concomitant increase in reagent consumption. As such, gas cooling is being attempted in a manner which recovers the heat and transfers it to the water/steam cycle in order to increase electricity production at the turbine. Most of today's thermal treatment plants rely on air-cooled condensers to condense the turbine exhaust steam. These systems are preferred because they avoid the visible steam plume typical of water-cooled alternatives. However, this advantage has its price in the higher condensation temperatures, which result in elevated exhaust steam pressures and thus reduced power output. Water-cooled steam cycles utilizing a cooling tower or a surface water body as a heat sink offer significantly better efficiencies.

9. Complexity has a price and impacts availability

The cost of a thermal waste treatment plant has a direct correlation with its complexity. The multi-stage electricity generation system of the syngas process is one very obvious difference in the comparison of the two processes described in this paper. Two steam generators coupled with their dedicated water/steam cycles, steam turbines and generators produce electricity in conjunction with the gas turbine and its third generator. This process is significantly more complicated than the single boiler and steam turbine found in an energy-from-waste plant. Increased complexity also has a tendency of reducing system reliability. The failure of a single system component can negatively impact the availability of the entire plant.

10. Conclusions

A comparison of waste treatment methods must build on a consistent definition of boundary conditions to ensure that all aspects enter into the analysis. In particular, the pretreatment of waste fuels must not be ignored and the thermal process must not be viewed in isolation. Frequently a thermal process such as the combined cycle gas turbine process is shown to be highly efficient while ignoring the energy requirements of the prior gasification step.

Gasification with simultaneous combustion of the fuel gas is identical to conventional combustion. Such a process has no advantages in terms of energy efficiency or product quality.

Gasification in the sense of syngas production is not appropriate for the treatment of the heterogeneous mixtures found in municipal solid waste. The complexity of a syngas plant results in increased investment costs and reduced availability. Energetic efficiencies are at best similar to those of conventional, proven combustion systems.

Today's waste combustion systems achieve high energetic efficiencies and are thus to be considered *advanced* technology.

11. References

[1] Energy and environmental analysis of an innovative system based on municipal solid waste (MSW) pyrolysis and combined cycle; Paolo Baggio a, Marco Baratieri a, Andrea Gasparella b, Giovanni A. Longo; Applied Thermal Engineering 28 (2008) 136-144

[2] The Viability of Advanced Thermal Treatment of MSW in the UK; Fichtner Consulting Engineers Ltd; Published by ESTET in March 2004