Refuse Derived Fuel Gasification Technologies for High Efficient Energy Production

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1. Introduction

There is an increasing demand for replacing primary resources in manufacturing and fossil fuels in energy production with competitive and renewable alternatives. At the same time, many countries still landfill the majority of their municipal solid waste, causing significant environmental challenges and wasting a valuable resource. Waste is not only a problem to get rid of, but a source of valuable raw materials and competitive alternative to fossil fuels.

By adopting an integrated solution for waste management and energy production, a municipality can reduce the environmental impact of waste and increase its revenues from recycling and energy sales. An integrated approach starts with efficient sorting of waste to separate recyclates and wet biowaste. Residual waste is pretreated in a recycling facility to recover remaining recyclates and produce a refuse derived fuel (RDF) for efficient energy recovery. Also energy intensive industries are looking at using RDF to replace fossil fuels.

This paper provides an overview of sustainable solutions for efficient use of RDF as competitive fuel in reliable generation of power, process steam and heat for municipal and industrial applications. The main benefit offered RDF-gasification technologies is the combination of high fuel flexibility, high power production efficiency and good environmental performance. This provides plant operators with more options when sourcing fuels and more electricity production, both improving plant profitability.

The waste gasification concept turns RDF into clean gas for combustion and provides the highest power production efficiency for energy from waste. The latest experiences from the world's largest waste gasification power plant at Lahti Energy are discussed.

Turning waste into clean gas also gives the option to replace fossil fuels with RDF in existing plants including coal fired boilers and cement and lime kilns. The concept of connecting a waste gasifier to an existing plant is discussed.

2. Waste to RDF

Circulating fluidized bed (CFB) gasification enable a high-efficiency recovery process that fits well in the waste hierarchy [1]. Pretreatment of waste to produce RDF is an important step in maximizing the recycling rate of valuable materials such as metals. To make waste suitable for fluidized bed processes it is typically sufficient to have a single shredding followed by removal of metals in magnet and eddy-current separators. In case the waste contains a high amount of glass and stones an air classifier may be recommendable. Pretreatment can be at the energy-from-waste plant or in dedicated mechanical recycling facilities (MRF). Properties of resulting refuse derived fuels (RDF) vary greatly, but heating values are typically in the range of 8 to 15 MJ/kg.

3. Highest efficiency for energy-from-waste with gasification

Looking at the different utilization grades of waste the starting point was landfilling the waste without using the energy content in a productive manor. In the 1970`s grate firing was developed using steam parameters around 400 °C. The next step was the use of fluidized bed technology, first as bubbling fluidized bed technology later using a circulating fluidized bed (CFB). The use of a CFB with a superheater installed in the loop-seal of the boilers made it possible to increase the live steam temperature up to 470-520 °C and achieve a higher electrical output compared to grate firing [2, 4]. The main benefit of waste gasification compared to other waste-to-energy technologies is the higher net power production efficiency, which can be well above 31 percent using live steam with up to 540 °C [1]. In a waste gasifier, waste-derived fuels are converted into combustible and clean gas, which can be combusted in a high pressure steam boiler without corrosion risk (Figure 1).

Gasification has a long tradition at Valmet, originating from the late 1980's when Valmet delivered the first circulating fluidized bed gasifiers to replace oil with biomass in lime kiln applications at pulp mills. Valmet also carried out extensive research on pressurized fluidized bed gasification and hot gas cleanup in the early 1990's using a 15 MW_{th} gasifier test facility.

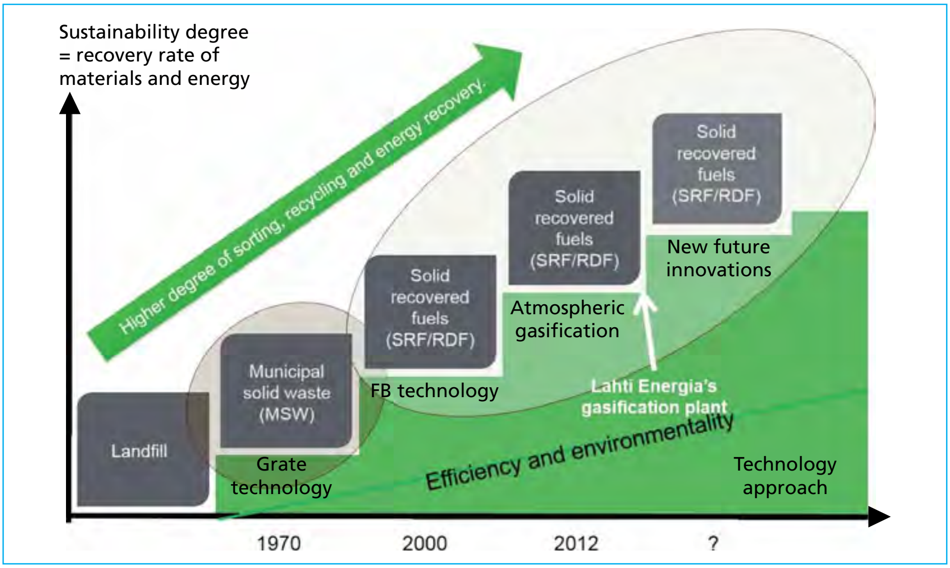

Figure 1: Utilization of waste in energy production

RDF is one of the most challenging fuels due to its high contents of chlorine, heavy metals and incombustible debris. It can cause significant fouling, corrosion and combined corrosion-erosion in the boiler if proper design measures are not taken.

Waste derived fuels can contain large quantities of debris (metal, glass, stones). To effectively remove this from the furnace a dedicated furnace floor design for waste fired boilers and the use of robust bottom ash equipment was developed [4].

Corrosion of boiler heat transfer surfaces is typically caused by condensation of alkali chlorides and/or lead chlorides. Alkali chlorides may cause corrosion at metal temperatures above 450 °C. For lead chlorides the critical temperature can be as low as 360 to 420 °C [3].

4. Circulating fluidized bed (CFB) gasification

In gasification solid fuel is converted into combustible product gas. Fuels suitable for gasification are woody biomass, bark, peat, waste-derived-fuels and agro fuels. The gasification reactions require heat, which is produced by combusting a small part of the fuel. The remaining fuel is converted into product gas under sub-stoichiometric conditions.

The required temperature in a CFB gasifier is in the range of 750 to 900 °C with an air coefficient between 0.2 and 0.4. The hot gas efficiency in CFB gasification is approximately 96 to 98 percent. The product gas consists of combustible CO, H_2, CH_4 and hydrocarbons. The gas also contains higher hydrocarbons or *tars*, which are high in heating value but may condense on surfaces and cause fouling when the gas is cooled.

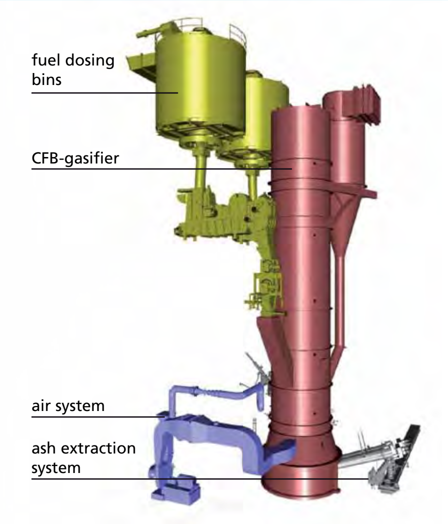

Figure 2: CFB gasifier

The heating value of the product gas is typically between 3 and 7 MJ/kg (LHV) depending mainly on fuel moisture content. In order to generate a product gas with sufficiently high heating value to support self-sustainable combustion the moisture content of the solid fuel mixture should be below approximately 40 w.-%.

The CFB gasifier used in this application is suitable for a wide range of biomass and waste-derived fuels. The gasifier is of simple construction with a refractory lined, un-cooled CFB reactor with self-supporting structure, shown in Figure 2. Its simple and robust structure ensure good maintainability and high operational reliability.

The key data of the CFB gasifier include:

- Capacity: 20 – 150 MW_{th}
- Fuel: Biomass, waste-derived fuels
- Moisture content: < approximately 40 w.-%
- Gasification media: Air
- Bed material: Sand and limestone
- Operating temperature: 750 – 900 °C
- Operating pressure: Atmospheric (5 – 30 kPa_g)
- Product gas: 3 – 7 MJ/kg (LHV)

Figure 3 shows a conceptual diagram of the waste gasification power plant concept: waste-derived fuels are gasified in the CFB gasifier into combustible product gas, which is cooled and filtered to produce a clean gas for combustion in a conventional gas fired boiler to generate high pressure steam. The steam is led to a steam turbine for power and heat production.

The dirty product gas leaves the gasifier at about 850 to 900 °C after which it is cooled in the gas cooler to about 400 °C using boiler feed water. When the gas cools the corrosive alkali chlorides in the gas condense on to the flyash particles, which are subsequently filtered out in the hot gas clean-up consisting of rigid ceramic candle filters. The filtration temperature window is carefully selected to ensure condensation of corrosive compounds but avoid condensation of tars. After extensive test campaigns in a slip stream of an existing gasifier and comprehensive theoretical modelling the temperature was set at approximately 400 °C.

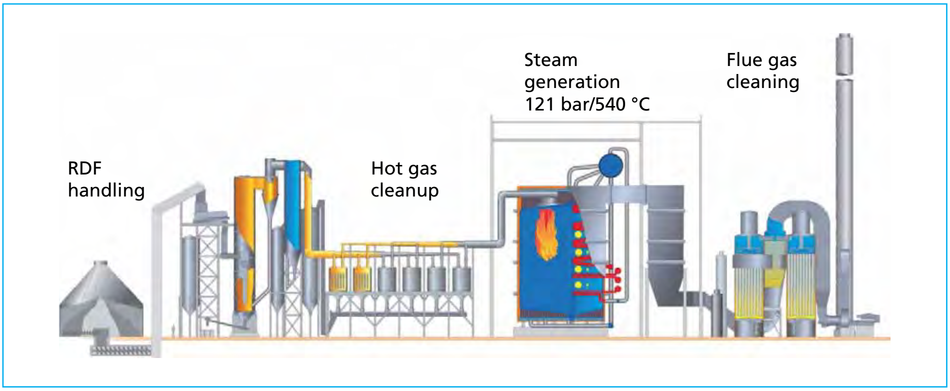

Figure 3: Conceptual diagram of a waste gasification power plant

Solid waste is not directly burned, but turned into a clean gas prior to combustion. This enables high steam parameters in the boiler without corrosion risk and gives a high overall power production efficiency. In traditional incineration steam parameters are limited to 400 °C at 40 bar due to corrosion, whilst in waste gasification these are 540 °C at 120 bar and can be even higher. This gives a much higher net power production efficiency of well above 31 percent compared to an average below 20 percent for traditional incineration.

5. World's largest RDF gasification power plant: Lahti Energy

End of 2011, a 250 ktpa waste gasification power plant based on gasification technology was started up in Lahti, Finland. The Lahti plant is the largest and most efficient waste gasification power plant in the world. It processes 250,000 tons of RDF per year and produces 50 MW of electricity and 90 MW of district heat from 160 MW of solid waste fuel power.

Lahti Energy is an energy production and distribution company owned by the city of Lahti in southern Finland. The waste gasification project received significant funding from both the EU and Finnish government. The major delivery contracts were signed in November 2009 and construction works started in spring 2010. The plant started gasifying waste in December 2011 and was handed over for commercial operation in June 2012. The total investment of Lahti Energy was approximately EUR 160 million.

The scope included the delivery and installation of the plant automation and the main plant components, including the fuel feeding, two gasification trains, common gas boiler and flue gas cleaning. Figure 4 shows an overview of the plant.

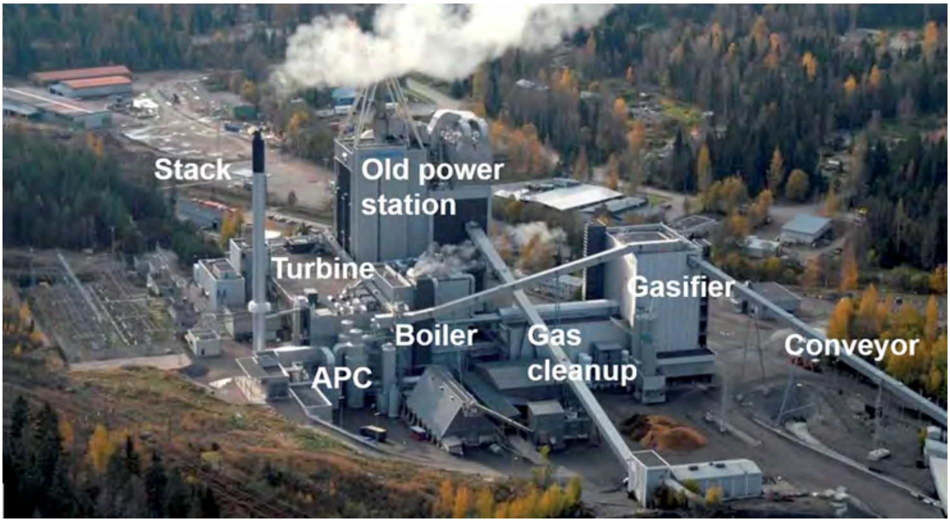

Figure 4: Lahti gasification power plant

The plant is a full-scale commercial plant designed to utilize pretreated waste with specification in Table 1 derived from sorted household waste, classified industrial waste, demolition wood and industrial waste wood. The plant consists of two 80 MW_{fuel} gasification trains which feed a common gas boiler. Each gasification train consists of a fuel feeding system, gasifier, gas cooler and hot gas filter. After the boiler fluegases are cleaned in a conventional bag house filter with upstream injection of sodium bicarbonate and activated carbon for control of acid gases and heavy metals. NO_x is controlled with injection of ammonia into the boiler and downstream catalyst system, so-called SCR. Live steam values of the boiler are 120 bar (g) and 540 °C. The design power production efficiency is 31 percent (in CHP mode) with an overall CHP efficiency of 87.5 percent.

Table 1: Fuel for Lahti gasification plant

	Design fuel
Fuel	RDF from MSW and C+IW
LHV	18 – 24 MJ/kg, dry
Moisture	< 30 w.-%
Ash	< 15 w.-%, dry
Cl	< 0.6 w.-%, dry
Na + K	< 0.3 w.-%, dry
Hg	< 0.1 mg/kg, dry

The experiences from the first years of operation have proven both the technology and cost structure to be viable for large-scale power generation from RDF. Until end of March this year the plant has collected about 12,000 operating hours of which about 8,000 hours on RDF and the remaining hours on a mixture of RDF and construction wood waste. The key results in Lahti include the demonstration of high power production efficiency for energy-from-waste as well as a major reduction of fossil fuels and CO_2 emissions at Lahti Energy.

Operation of the plant has in general been stable and easy to control. The plant has met its guaranteed capacity and steam parameters. The gasifier has operated reliably without disturbances of the fluidization due to bed agglomeration. Extensive tube wall thickness measurements and visual inspections in the gas cooler and boiler

showed no material loss after 4500 operating hours. Also today after more than 12,000 hours there are no signs of corrosion or erosion. This means that the main principle of avoiding corrosion despite high steam parameters in the boiler has been successfully demonstrated. Environmental performance of the plant has been excellent with all fluegas emissions well within the limits of the environmental permit. Combustion of the product gas in the gas boiler has been in compliance with the fluegas residence time requirement of the Waste-Incineration-Directive of two seconds at 850 °C and has been stable without need for support fuel during continuous operation.
The first years of operation have also shown the importance of fuel quality for high availability. The metal content in the RDF has been high, which caused jamming of fuel handling systems and disruptions in the fuel feeding. Thanks to sufficient redundancy in the system, on-line repair was generally possible without causing unavailability. Additional, a more selective metal removal was installed in the fuel handling system and fuel quality monitoring of suppliers has improved. Also the moisture content in the RDF has in some periods been higher than the design value causing somewhat reduced plant output.

The availability during the first year of operation was about 80 percent and some loss of production was caused by damages in the hot gas filter. A system to keep the surface of the ceramic candle filters clean was taken in operation in May 2013, significantly improving availability.

6. Co-firing waste in existing power plants to replace fossil fuels with RDF

The possibility to convert waste into a clean gas for combustion gives an exciting new possibility, namely co-firing of waste to replace fossil fuels in existing solid fuel fired boilers, cement kilns, lime kilns or other applications where solid waste cannot be directly fired.
In this co-firing application a waste gasifier with hot gas clean-up is retrofitted to an existing boiler or kiln, as shown in Figure 5.

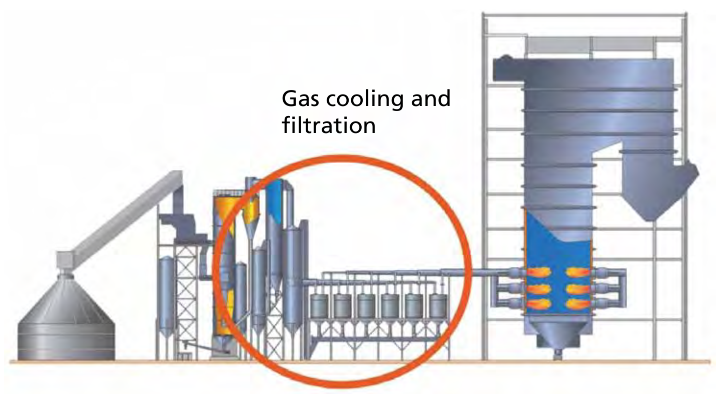

Figure 5: Co-firing of waste in existing utility boiler or kiln

Waste is gasified into a product gas which is cooled and filtered to produce a clean gas for combustion in the existing boiler or kiln. The gas is cleaned from dust, corrosive compounds and heavy metals prior to combustion. Co-firing has therefore minimum impact on boiler operation, corrosion, ash quality and emissions. In case of disruption in the gasifier or unavailability of waste the plant can easily shift back to the main solid fuel and keep full capacity. The modifications required to the boiler are also fairly minimal including new burners to burn the gas. The overall investment is significantly lower than for a stand-alone energy-from-waste plant and the power production efficiency is equal to that of the existing boiler plant. Replacing fossil fuels with waste via gasification is an attractive option to save fuel cost and reduce CO_2 emissions without jeopardizing the reliability and availability of the existing boiler or kiln.

The principle has been demonstrated for biomass in Vaasa where a 140 MW_{th} biomass gasifier and biomass drying system to produce a gas for combustion in an existing coal fired boiler at the Vaskiluoto plant was installed. This gasifier has been taken into commercial operation end 2012 and since then replaced about 40 percent of the annual coal consumption of the power plant with low cost, domestic biomass fuels and peat. The gasification plant including the boiler modifications were delivered and installed with a total investment cost of approximately EUR 40 million.

7. Conclusion

The waste gasification solution has been demonstrated at large scale in a stand-alone EfW CHP plant and the first years of experience at Lahti Energy have proven both the technology and cost structure to be viable for large-scale power generation.

The waste gasification concept with hot gas cleanup turns waste into clean gas for combustion. This provides many benefits for our customers, including the highest power production efficiency for energy-from-waste and the possibility to replace fossil fuels partly or completely in existing boilers and kilns by co-firing of clean gas from waste gasification.

Waste gasification is based on the circulating fluidized bed technology, which provides similar fuel flexibility as CFB combustion in terms of fuel properties such as heating value, ash content and moisture content, and enables the use of alternative fuels such a low grade biomass waste streams and recycled wood wastes.

In summary, application of waste gasification can be in stand-alone CHP plants using waste as competitive fuel for high efficiency power and heat generation, either in municipal or industrial applications. Another option is the retrofit of existing plants with a waste gasifier to replace fossil fuels with clean gas from waste gasification in existing boilers and kilns.

The main benefits using gasification for energy production are:

- Increased revenue from energy business – electricity and heat sales – by providing higher power production efficiency than traditional incineration,
- Increased recycling of valuable materials by separation of metals and other materials before combustion or gasification,

- Low environmental impact and simple downstream fluegas treatment, with emissions and ash quality in compliance with the most stringent European environmental legislation. This may also increase public acceptance and facilitate permitting. Operators are also able to adapt more stringent emission requirements in the future.
- High fuel flexibility for a wide range of fuel properties and the possibility to co-fire multiple fuels, including biomass, waste and fossil fuels. Operators are also able to adapt to future changes in RDF quality due to increased sorting and recycling.

8. Summary

Conversion of solid fuel into product gas enables replacing conventional fuels (oil, coal, natural gas…) with cheaper fuels (biomass, waste-derived…) also in applications where solid fuels cannot be used directly. Gasification and gas cleaning process also enables utilization of difficult fuels in high efficiency power boilers.

Valmet has been developing gasification technology since the late 1980's. Today's gasification concepts are based on atmospheric CFB gasifiers. The gasifiers are suitable for gasifying biomass and waste-derived fuels. The capacity of one gasification reactor is in range of 20–150 MW_{th}. Sand and limestone are used as bed material. The gasifier is self-supporting in structure. It's simple and robust structure maximizes operability and minimizes downtime. The structure has been tested in full scale and that has proven to be reliable.

In Lahti/Finland the first-of-its-kind gasification power plant was constructed in 2012 for Lahti Energy Ltd. that utilizes waste-derived fuels. The plant is a full-scale commercial plant and consists of two 80 MW_{fuel} gasification trains (160 MW_{fuel} in total) which feed one gas boiler. Each train has a fuel feeding system, a gasifier, a gas cooler and gas filters. The boiler is followed by a conventional dry flue gas cleaning system and a stack. Boiler can reach 100 percent output also with natural gas which is used as a backup fuel.

Live steam values of the boiler are 120 bar and 540 °C. The plant produces 50 MW of power and 90 MW of district heat. Valmet supplies main units of the plant, namely fuel feeding, gasifiers, gas coolers, gas filtration systems, gas boiler and flue gas cleaning system. The plant was handed over end of 2012. Total investment of the plant is 157 million EUR . In this paper the first year of operation is presented.

9. References

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