Enhanced power and heat generation from biomass and municipal waste

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Siemens Power Generation
Industrial Applications
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Introduction

Municipal waste and biomass is mostly used only for steam or hot water production for district heating, but the increase in energy prices has made it more customary to produce electricity production by adding a steam turbine. By also adding a gas turbine to municipal waste or biomass-burning plants, the power and heat generation can be substantially increased, not only by the gas turbine power, but also by the improved steam cycle.

Generally, the electricity production from a waste-burning plant is quite low, due to the fact that it is tricky to burn waste. Waste is a fuel with a “wide composition” that includes not only substances that require extensive exhaust gas cleanup but also corrosive elements that restrict the temperatures of the steam tubes in the boiler. Thus the steam cycle will be quite small from a thermodynamic point of view with low inlet conditions (typical temperature of 210°C) on the back pressure steam turbine.

By adding a gas turbine to the system, using the gas turbine exhaust steam generator as a superheater for the low temperature steam from the waste boiler, an effective combined cycle power plant with a larger steam cycle is generated. With this solution, the overall transformation of the fuel energy to electricity and heat for district heating will be very good.

The fuel for the gas turbine will, of course, be dependent on availability. Normally, natural gas is preferable from the point of view of both economic and environmental considerations. In Sweden, the hitherto limited availability of natural gas has meant that fuel oil and condensate (mainly propane) has been used. In the long run, gasification gas from biomass could be the sustainable energy alternative.

In Sweden two municipal waste-burning plants were refurbished in 1994 with ABB 24 MWe GT10B gas turbines (today Siemens SGT-600 at 25 MWe) and steam turbines.
In Linkoping, a town in central Sweden with 135,000 inhabitants, the environmentally well designed waste-burning plant receives waste not only from the town but also from many neighboring communities. The plant operates during the summer in heat production mode (the steam is directly condensed), but during the winter in combined cycle mode, using the oil-fired gas turbine. The production can then be 50MWe and 85MWth, using 72MJ/s oil and 230000 ton/a waste corresponding to 93MJ/s.

The oil-fired gas turbine uses a conventional combustion system, but has extremely low emissions due to the use of both water injection in the combustion chamber and catalytic exhaust NOx reduction (SCR). The NOx level is usually in the 5-9 ppmv range.

At the Linkoping plant an additional waste-burning line with boiler and steam turbine is now being installed, increasing the power production by 19 MWe and the heat generation from 600 GWh to 1000 GWh.

A more general and detailed description of this type of combined heat and power (CHP) plant, burning municipal waste and/or biomass, will be given below, with references to the retrofitting and operating experiences of the Linkoping plant.

**The fuels**

Municipal waste consists largely of recycled material, (gas, metals, newspapers, plastic bottles and cans etc) but there is a residue consisting of food leftovers, scrap paper, polyethylene etc. that has to be taken care of. Most of the waste is renewable biomass. Burning it in incineration plants, as an alternative to simple disposal, is becoming very common, especially for large and middle size towns, but even in smaller communities with district heating systems.

The combustion technology and exhaust gas treatment have improved to make the rather difficult combustion of municipal waste environmentally possible even in small plants.

The municipal energy system often includes the use of some biomass, in special boilers or added to the waste. Biomass in the form of wood chips or pellets has become a common fuel for municipal heating in Sweden, but so far not for electricity production. From the combustion point of view, biomass and municipal waste are fairly similar in heating value. Both fuels have corrosive elements of similar and different kinds, which prevent high surface temperatures in the boiler.
The municipal waste contains some polyethylene, metals etc. that will produce chlorides, ammonia and metal vapors and salts. The wet compounds could prevent good combustion with dioxin as a result.

The biomass in the form of wood chips also produces ammonia and alkali metal vapors and salts but has a more even composition and less moisture.

**The plants**
Waste incineration or biomass plants are normally just boilers for heat production. The use of the district heating system as a heat sink for electricity production will increase with increasing cost of electricity and with the expansion of \( \text{CO}_2 \) trading.

In the plants for electricity production, steam turbine systems have been included. However, due to the corrosiveness of the combustion gases, the steam temperature has to be low, in order to avoid excessively high surface temperatures on the boiler tubes.

The plants are often built up in stages following the population development and the expansion of the district heating system. The stage to include electricity production is frequently late in the process, which means that the steam cycle will not always be optimal but adjusted to fit the existing plant as well as possible.

The conclusion is that the electricity production with steam turbines has a rather low alpha ratio (= electricity/heat ratio) at around 0.2.

**The combined cycle**

A way to substantially boost the electric power and heat production from a waste incineration or biomass plant is to include a combined cycle. The low value steam from the incineration plant is then superheated in the waste heat recovery boiler of the gas turbine. The steam quality is then improved to suit a rather large back pressure steam turbine with heat condenser.

With such a cycle the performance figures are very much improved with an alpha ratio of 0.52 and a total efficiency of around 90%.
The gas turbine fuel
The fuel for the gas turbine could be the conventional ones, natural gas or diesel oil. Preferably industrial waste gases (refinery gas, coke oven gas etc) or, in the future, biomass-based fuels could be used. In Sweden, one plant is fired with diesel oil and another with liquid propane, gasified on site.

Plant description
In Sweden, two incineration plants have been retrofitted with combined cycles as described above. In one of the plants the gas turbine has been closed down and sold off for two reasons:
- the municipality did not expand as expected
- the fuel cost went up more than expected. At the start of the project, propane was a surplus product from the Norwegian oil and gas fields, but has later become quite expensive.

Figure 1: The Garstad incineration plant on the outskirt of Linkoping, Sweden

The Garstad Incineration plant at the city of Linkoping, Sweden
This incineration plant is serving not only the regional center Linkoping, but also several communities in the region with a population of around half a million. The fuel is basically sorted municipal waste that was previously disposed of, mainly of the biological type (food, some scrap paper scrap, etc). Some biomass, mainly wood chips, is added if the waste is too wet for clean combustion.

The plant is now being expanded by the addition of an extra incineration line.
The waste combustion system

Some 230 000 tons per year of waste are processed by the current line, corresponding on average to a heat input of 93 MWth.

The furnace of the boiler is the moving grate type with preheated combustion air blown in from under the grate. Exhaust gases are re-circulated to reduce NOx emissions. The gases are cleaned in several steps:

- electrostatic filter for particle removal
- wet scrubbing to remove chlorides, ammonia and metals
- calcium and ash additive to absorb dioxin and SO2
- fabric filter to finally remove the additives

The heat recovery is done in four steps

- generation of around 73 MW of saturated steam at 1.8 Mpa/207°C in the boiler walls and tubes
- heating of district heating water in two economizers, of which the last one condenses the scrubber water
- preheating of combustion air
- the combustion gas is blown out in the stack at 70°C

Figure 2: The waste incineration boiler

The combined cycle

The combined cycle consists of a 25 MW gas turbine type SGT-600 (GT10B) coupled to a generator via a gearbox. The other end of the generator rotor is connected to a 25 MW steam turbine.

The gas turbine exhaust gases are ducted into a waste heat recovery boiler, which includes a superheater for the steam from the incineration boiler, a boiler section and an economizer part for condensate preheating.

Figure 3: The combined cycle scheme


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**The gas turbine**

The twin shaft SGT-600 gas turbine has a ten-stage compressor with a pressure ratio of 14 and a mass flow of around 78 kg/s. The two-stage compressor turbine drives the compressor at a speed of around 9500 rpm. The two-stage power turbine operates at 7700 rpm, driving a 3000 rpm generator via a gearbox.

The exhaust gas flow of 80 kg/s has a temperature of 535°C at nominal conditions.

**The combustion system and the fuels**

The gas turbine is equipped with a conventional combustor and 18 fuel injectors for dual fuel operation. The present fuel is good diesel oil with high ash melting point (>900°C) to minimize risk of corrosion of the gas turbine hot parts. The diesel oil is mixed with water in the fuel injectors at a w/f ratio of 0.8 to reduce NOx from around 210 ppmv to 40 ppmv.

The addition of water with the fuel increases the turbine output by around 1 MWe, but also the stack losses by 3.7 MW.

Natural gas will become available at the plant within a few years, which will not only reduce the cost for the gas turbine fuel, but also provide more operating hours and longer times between overhauls.

The present conventional combustor and dual fuel injectors of the SGT-600 can be used with natural gas, but they can also be directly exchanged to a Dry Low Emissions (DLE) combustion system, suitable for natural gas and mixtures of natural gas and biogas. With the DLE burners, the water injection can be deleted and the stack losses reduced. The total efficiency will be increased to around 93%. The NOx level at the gas turbine exhaust will come down from 40 ppm to 25 ppm.

At the site there is a biogas plant producing gas by fermentation of waste from farming. The gas is used mainly as fuel for busses, cars and trains. In the future, this type of gas could be mixed with the natural gas to fuel the gas turbine.

**The steam turbine**

The admission data of the low pressure steam turbine are 1.5 MPa/430°C. During operation, the turbine is coupled directly to the same generator as the gas turbine, that is, at 3000 rpm,
producing 25 MWe electric power. The steam turbine has a “district heating exhaust” which means that the steam flow is divided in two parts, condensing at somewhat different pressure levels in order to achieve the highest heat recovery.

Figure 4: The turbine string
1) 25 MW Back pressure steam turbine, 2) Generator, 3) 25 MW Gas turbine

**The Waste Heat Recovery Unit (WHRU)**

The gas turbine exhaust gases are ducted to an unfired boiler equipped with a superheater, boiler and economizer. Some steam is raised in the WHRU, but the main flow is the saturated steam from the incineration boiler. The economizer is used to preheat the condensate. The stack temperature for the oil-fired gas turbine is limited to 135°C to prevent SO$_3$ condensation and corrosion. For a natural gas fired unit, the exhaust temperature could be lowered to 85°C, reducing the stack losses.

The superheater is divided in two parts in order to position an ammonia-based Selective Catalytic Reactor (SCR) for NOx reduction at a suitable temperature level. The combination of this SCR and the water injection in the gas turbine combustor means that the NOx emission level is very low, around 5-7 ppmv at 15% O2 on diesel oil. For a gas-fired unit with DLE burners in combination with the SCR, NOx-levels as low as 3 ppmv at 15% O2 would be achieved.

The Swedish system for NOx taxation is designed so that, if a plant is below the national average, tax is refunded, while a plant operating above the average level has to pay tax. This means that the Garstad plant, which has the lowest NOx emissions in the whole of Sweden, is earning money on the NOx tax refunds!
**Operation of the plant**

The waste incineration boiler has to be operated continuously in order to process the waste, but the heat demand varies with the ambient conditions. In Sweden, the winter consumption of district heating is high, but it is low in the summertime. Air conditioning is almost negligible, but in Linkoping the market for district cooling is expanding slowly, mainly for office buildings where there are a lot of computers affecting the working environment.

In order to fit the heat demand, the plant can be operated in different modes.

**Heat production only**

The plant can be operated for heat production only. All the steam from the boiler is then directly condensed to produce district heating water with an incoming temperature of 50°C and an outgoing temperature of 90 to 115°C, depending on the time of the year. The total heat production from the direct condenser and the economizers in the incineration boiler is around 87MW, which translates into a fuel utilization of 93%.

**Operation with the combined cycle**

The steam from the incineration boiler is then going to the WHRU of the gas turbine for superheating before expansion in the steam turbine.

There are two modes of gas turbine operation due to a difference in production tax on electricity produced in a “district heating” mode or in a “power generation” mode. The power generation mode ( = gas turbine at full load) is only profitable when electricity prices are high, so even in wintertime the plant has most often been operated in the district heating mode ( = 60-70% gas turbine power), producing as much district heating as at the “heat production only” mode.

**Comparison of different plant configurations and operation modes**

There are three alternative plant configurations:
- heat only,
- electricity production with steam turbine
- electricity production with combined cycle with different variations:
  - electricity production with combined cycle in district heating mode and power production mode
gas turbine fired on oil with wet NOx reduction

- electricity production with combined cycle in power production mode, with the gas turbine fired on
  
  - natural gas with conventional combustor and wet NOx reduction
  - natural gas with DLE combustor

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<th>Waste or biomass fuel MWth</th>
<th>Heat only</th>
<th>Steam turbine</th>
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Table 1: Comparison of different operating alternatives

The heat-only alternative consists of
- an incineration boiler producing saturated steam at 1.8 Mpa/207°C with economizers for district heating water production
- a heat condenser at atmospheric pressure

The steam turbine alternative is then
- an incineration boiler, producing superheated steam at 1.6 Mpa/350°C with economizers for district heating water production
- a back pressure steam turbine with admission data 1.4 Mpa/350°C
- a heat condenser at atmospheric pressure

The combined cycle alternative is an assembly of
- an incineration boiler producing saturated steam at 1.8 Mpa/207°C with economizers for district heating water production
- a 25MW gas turbine with exhaust temperature 535°C, fired by diesel oil or natural gas with wet NOx reduction or DLE on natural gas

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• a waste heat recovery boiler producing superheated steam at 430°C and an economizer for district heating water production
• a back pressure steam turbine with admission data 1.5 Mpa/430°C
• a heat condenser at atmospheric pressure

The heat-only and the combined cycle alternatives can be used at the same plant, depending on the conditions. In Sweden, the normal mode of operation is to use the combined cycle alternative in the wintertime and the heat-only alternative in the summertime.

When comparing the steam and combined cycle alternatives, the major general differences are
• the alpha ratio. The ratio of electricity/heat production has gone up from 0.20 to 0.52
• the total efficiency, which is somewhat lower for the combined cycle case due to the two stacks. The difference between the oil and gas fired combined cycle is mainly dependent on the difference in stack temperatures, 135°C for oil and 85°C for gas
• the gas fired combined cycle with DLE combustor shows the best result

Conclusions
• Waste incineration and biomass-fired plants will be used in the future for electricity production.
• The retrofitting of steam turbines to the plants is not very effective due to the low steam data. The power to heat ratio will be low, around 0.2.
• A way to substantially improve the electricity production is to retrofit with a combined cycle fired with current conditions on diesel oil or natural gas but in the future on biogas. A power to heat ratio of >0.5 can be reached. An optimized plant could reach a power to heat ratio of =0.6 and a total efficiency of 93%.
• In the future the fuel to the gas turbine could be gasified biomass, which would make such a plant fit the strategy to operate mainly on renewable energy.

* Illustrations courtesy of Garstadverket, Tekniska Verken i Linkoping AB