Combined Cycle Gasification Plant

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Abstract: *The gasification technology promises many technological advantages compared to traditional steam boiler technology: higher electrical efficiency, lower invest, compact plants, inhomogeneous biomass is converted into a homogeneous gas and low environmental impact. Countries like Germany and Italy gives higher subsidies to the gasification based technology in order to attract capital to develop and mature the technology. Babcock & Wilcox Vølund A/S has worked with gasification since 1988 and put the first pilot plant into commercial operation in 1996 in Harboøre, Denmark. Today gas engine operation with the gasifier is highly reliable and the next step has been taken to extend the concept to combined cycle operation promising electrical efficiencies above 40%.*

Introduction:

Babcock & Wilcox Vølund A/S being a subsidiary of the Babcock & Wilcox Power Generation Group was established in 1898 and started Waste to Energy building boilers in 1931. The energy crisis in the 70'es and the increasing environmental consciousness lead to the development of renewable energy technologies in Denmark such as wind turbines and steam boiler based on wood and straw. Babcock & Wilcox Vølund A/S took part in this development from the beginning and developed technologies for burning straw and wood. In order to achieve high electrical efficiencies and economical feasibility focus was typical on plants with 5MWe and higher out put, as the isentropic efficiency for the steam turbines are to poor for small steam turbines.

Gasification started as a research area in Babcock & Wilcox Vølund A/S as a technology to combust straw, as the theory was that the straw could be gasified and the difficult alkali component could be captured in the ash. This turned out not to be the case. But, the problem still existed how to achieve high electrical efficiency an small combined heat and power plants that could be based on local biomass.

Babcock & Wilcox Vølund A/S located the small city Harboøre, which was looking for a new biomass based heat boiler. An agreement was made that Babcock & Wilcox Vølund A/S could develop and operate the pilot plant and sell the heat to the local district heating network at market price. Wood chip was chosen as the fuel, as it is the most uncomplicated biomass to work with. First step was to develop the reactor, and it was chosen to base it on an updraft technology acquired from Dr.Gatzke. The product gas from the reactor was in the first years lead to boiler and burned. In year 2000 gas engines and product gas cleaning was added to the Harboøre plant. The product gas cleaning was successful, but produced tar contaminated with waste water which practically turned out to be very difficult to clean. The waste water cleaning limited the gas engine operation the first years. After testing a number of filter technologies, it was decided to incinerate the waste water in a recuperative process.

The excess heat from the gas engines carried as hot water and the hot exhaust gas is recovered and turned into district heating.

The Harboøre plant has installed around 1,4MWe.

A second plant has been put into operation by JFE in Yamagata, Japan with an electrical output of 2MWe. A plant in Ishikawa, Japan, with an electrical output of 2,5MWe is in the commissioning phase and a plant in Japan with 11MWth is in the engineering phase.

In a cooperation agreement with Adwanced Renewable Energy Ltd. Babcock & Wilcox Vølund A/S is developing the Combined Cycle Gasification plant where the exhaust gas from the gas engines is used a combustion air for the evaporated waste water and the tar to produce a flue gas which generates steam and drives a steam turbine. The new combined cycle gasifier concept will be put into commercial operation at the end of 2009 with an expected output of 4MWe.

Updraft Gasifier

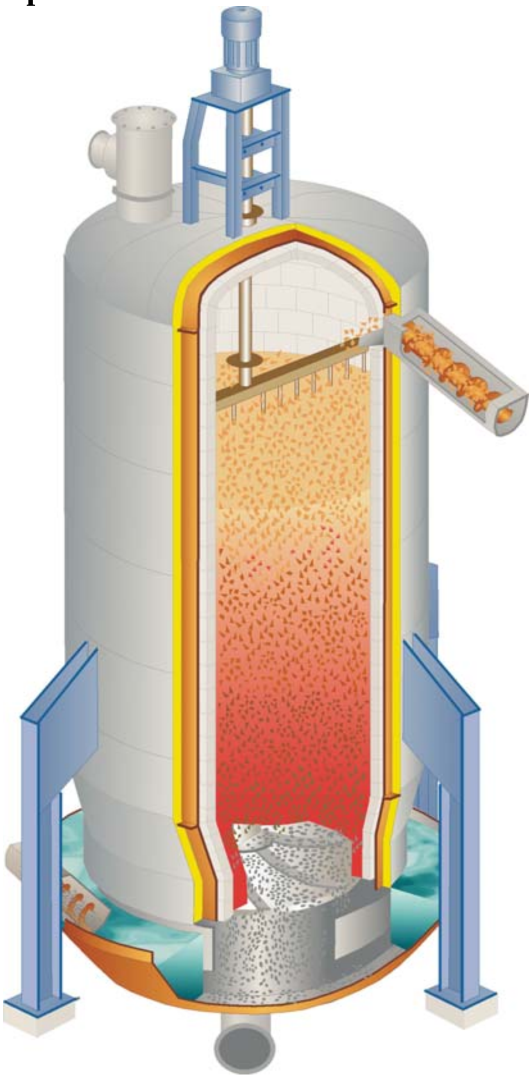

Figure 1: Gasification reactor

The reactor type used by Babcock & Wilcox Vølund A/S is in fact an updraft moving bed, as it is provided with a rotary grate distributing the oxidiser (air and steam) and extracting the ash. The grate rotates slowly – approximately one rotation per day.

However, in relation to the gas flow it can be considered as a fixed bed, where the individual reaction zones are in a given position during stationary operation. The sequence of the updraft gasifier reaction zones is as follows in downward direction

- Drying
- Pyrolysis
- Gasification (reduction)
- Combustion (oxidation).

The processes taking place in the updraft reactor is out lined in fig.2.

Because of the updraft principle, which means that the hot gas passes through the entire reactor, the temperature will be very low at the top (70 - 80°C). This gives a high thermal efficiency and at the same time it is possible to use very moist fuel, as the fuel is dried by the rising hot gas. Furthermore, the low temperature is desirable in connection with engine operation.

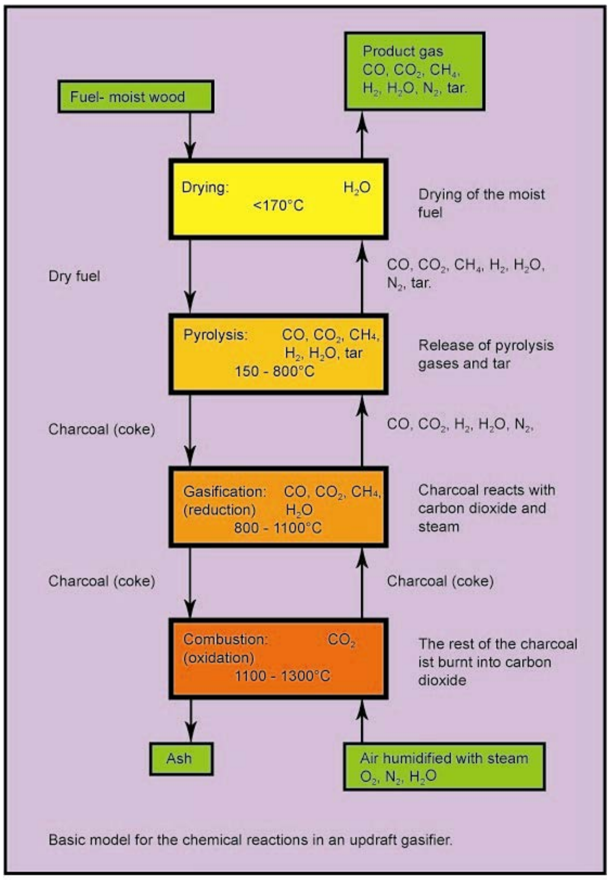

Figure 2: Reactions in the gasifier

The high moisture content in the top of the reactor makes the surface of the wood chips acts as a filter and practically no ash leaves the reactor with the product gas.

The updraft gasification proces result in a large production of tar (up to 100 g/Nm^3 dry product gas), as the tar is not subjected to sufficiently high temperatures to crack. This tar contains a large share of the energy of the gas (10-20%). The gas condensate is divided into two categories: heavy tar and tar water. The heavy tar is mainly long hydrocarbons and has a density higher than water with a heating value around 30MJ/kg. Light tar, a fraction of the tar water, is dissolvable in water with a heating value around 12MJ/kg.

In order to avoid the formation of channels and pockets in the reaction zones, the fuel must not be too fine-grained or have a too low density. Channel formation will typically lead to penetrations and areas with very high temperatures, resulting in ash sintering and formation of slag in the reactor, which is avoided with the fuel distributor (see top of fig.1).

The residence time in the oxidation layer is several days for the ash based on wood chips. Therefore, the bottom ash has superior TOC levels – typically below 1% of the ash. The overall result is a hot gas efficiency in the range of 99.8%. Furthermore, the amount of ash that goes to the land fill is minimised and there is only one ash source in the plant.

As the heat is trapped inside the reactor is may reside there for a long time if the reactor is stopped. Restarting is often just requires adding air, and the reactor is back on-line.

The reactor ramping speed is very good, typically more than 10% of full load per minute. Thus the reactor has a faster ramping speed than the gas engines, so gas is always present for use.

The advantage of the reactor is the simple design which gives outstanding availability. The reactor in Harboøre is only emptied due to shut down for one week per year for inspection and repairs.

Combined Cycle Gasification Plant

The combined cycle gasification plant is a natural extension of the Harboøre and Yamagata plant, where the energy in the exhaust gas and the tar is used to generate additional electricity.

Furthermore, one of the weaknesses with gas engines is that the combustion takes place very fast at high temperature which makes it difficult to combust the CO (main product gas energy carrier) and the high temperatures result in undesirable NOx emission. In order to meet emission requirements in most EU countries a CO catalyst must be used and in some cases also a NOx catalyst with NH_3 injection. The gas engines operating on the product gas typically has an oxygen content around 8%, which is sufficient for formation of thermal NOx.

The adiabatic combustion chamber has several functions mainly to incinerate the evaporated organic compounds contaminated waste water and to recover the energy from the heavy tar. The oxygen requirement for this combustion comes from the gas engine exhaust gas which contains oxygen corresponding to an excess air number of 3,5. The adiabatic temperature of burning heavy tar, evaporated waste water and exhaust gas is approx 1700ºC sufficient to burn the complex heavy tars, and as the exhaust gas is added in stages to eliminate the CO and significantly reduce the NOx. The gas condensate production varies with the wood quality, and should the tar production be too small, product gas can be added to the adiabatic combustion to maintain sufficient combustion temperature.

As the exhaust is clean and the tar is filtered before being led to adiabatic combustion chamber the flue gas is practically dust free and the heat recovery boiler is a simple standard heat recovery boiler. The flue gas is cooled to extract water for the usage in the plant. The combustion quality demonstrated in the Harboøre fulfils waste water requirement and can be directed to sewage system after pH afjustment without further cleaning.

The heat recovery boiler steam parameters are chosen to match the steam turbine giving the best overall steam cycle efficiency. The steam condensation heat can be used for district heating or cooled away to produce even lower pressure in the back end of the turbine.

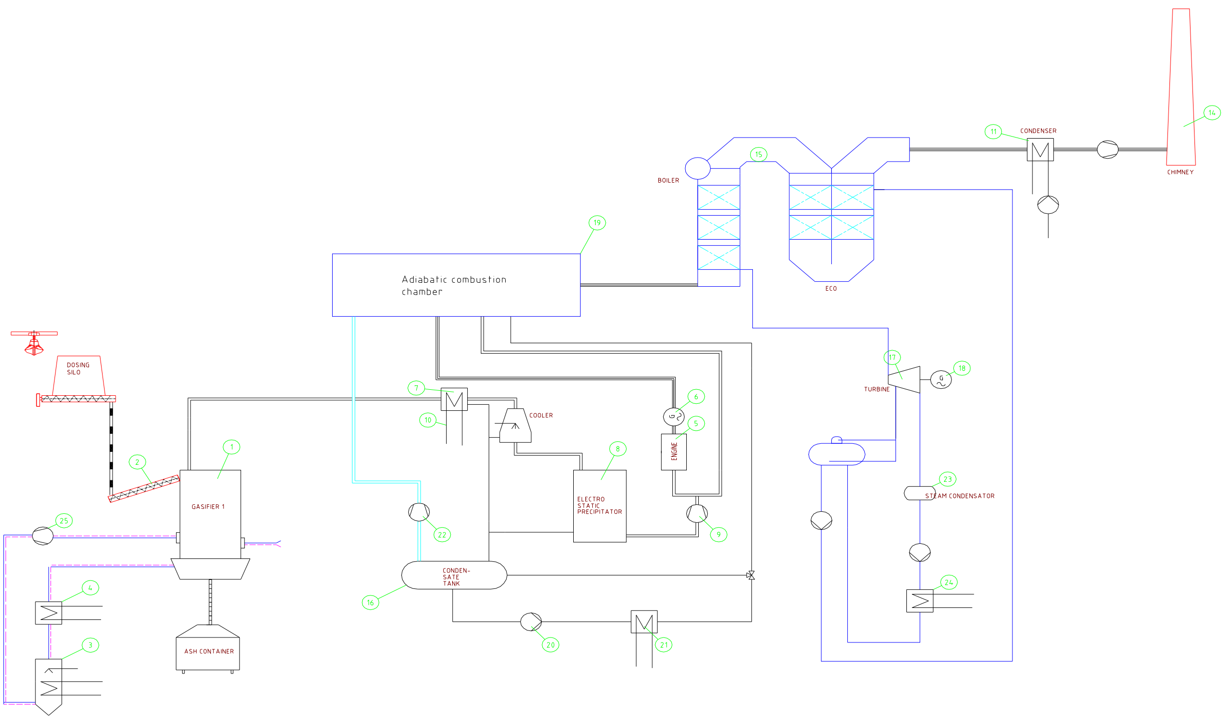

Figure 3 *The Combined Cycle Gasification Plant. The wood chips are delivered (2) to the reactor (1). The Gas is cooled (7) and particulates are removed in the wet electrostatic filter (8) before being sucked (9) to gas engines (6). The hot exhaust gas goes with the evaporated waste water from the evaporation tank (16) and the tar to adiabatic combustion chamber (19). The waste water is evaporated in vacuum with excess heat (21) from the gas engines. The flue gas goes to heat recovery boiler (15) which produces superheated steam which drives the steam turbine (17). Excess heat from the gas engines are used to heat the condensate (24).*

Approximately 75% of the energy is present in the cold product gas after cleaning (tar removal and condensation of water), which with a gas engine with an efficiency of 37% result in overall gas engine alone electrical efficiency of 28% (as measured in Harboøre). The waste heat recovered from the cooling of the product gas along with the waste heat from the engines is used for evaporation of the waste water and heating of the tar to around 90ºC.

The energy in the gas engine exhaust gas constitutes around 29% of the energy input to gas engine or around 26% of the fuel heat input to the plant. Along with the 13% of the energy input which comes from the heavy tar and the 12% of the energy input which is used to heat the tar and evaporate the water, 26%+13%+12%= 51% of the waste energy is led to the heat recovery boiler. Due to the relative low exit temperature of the adiabatic combustion chamber, the thermal efficiency of the heat recovery boiler is only around 82%, but still allows some 42% of the fuel input to be recovered on the high pressure side of the steam cycle. The turbine efficiency is poor on such a small steam flow and after steam consumption for the feed water tank and other minor consumers only around 30% of this is expected to be converted to electrical energy (12%), thus giving an overall efficiency of 28%+12% = 40%.

For higher steam flows the steam turbine isentropic efficiency will go up, and two pressure boiler or reheat of the steam may be applied to improve the steam cycle efficiency which will push the overall electrical efficiency towards 45%.

Turn-down
The updraft gasifier has displayed unique turn-down ability and is able to work controlled in a range from 20-100% product gas output. Also the product gas flow is very stable providing excellent conditions for the gas engines.

Typical size of gas engines is up to approx. 2MWe per engine. For the plant under implementation 3MWe is required, thus two or three engines have been foreseen.

The typical district heating net in the Nordic countries has a turn-down of 1:10 with 10 times higher district heating demand in the winter than in the middle of the summer. ~~This span is usually covered with one base load boiler with electricity production. A typical boiler plant can achieve a turn down to 40%, the winter peak is provided with wood pellets or oil/gas fired boilers~~. The combined cycle plant with two reactors can cover the entire district heating variation, although it would result in a poor overall utilisation of the plant (too few full load hours). However, heavy tar may be stored and applied during the coldest period of the winter. The heavy tar is comparable with heavy fuel oil, and standard HFO burner can easily burn the tar with minor adjustments.

Application
The overall high electrical efficiency (40%) on a small plant (4MWe) changes the feasibility in power production. The price for the combined cycle plant is comparable with traditional biomass steam boiler plants (approx. 4MEUR/MWe), but with much lower fuel consumption (around half). This mean that the plant can be fed from wood fuel resources within reasonable distance of the plant (50-70km) and the cost for fuel transportation is lowered. Furthermore, the plant can supply some 5MW thermal in the form of 90ºC hot water to the district heating net. The Combined Cycle Plant therefore offers very good solution for countries like Italy with local wood resources and a critical need for distributed power production. Also, due to the high electrical efficiency, high turn down and a good ramping speed the plant is foreseen play a major role in renewable electricity supply for "Island" cities which is not connected to a major grid. The combined cycle gasifier may be used for balancing small grids where wind turbines or photovoltaic also are connected.

The heavy tar (bio oil) may stored but can also be refined to bio diesel and used for the trucks and machines transporting the fuel.

Conclusion

The first 4MWe combined cycle gasification plant is under implementation in Calabria, Italy and is expected to start commercial operation by the end of 2009.

The combined cycle gasification plant builds on the references of the Harboøre plant which has logged more than 110.000 operation hours on the reactor and 50.000 hours on the engines.

The plant in Yamagata, Japan is nearly two times larger and has proven also to operate satisfactory. The combined cycle plant reactor is a small scale up from the reactor in Yamagata.

The technology has proven to be very reliable and will in the long run out-compete traditional steam boilers for wood chips firing.