Updraft Gasification: A Status on the Harboore Technology

R. Heeb
Babcock & Wilcox Vølund A/S, Esbjerg, Dänemark

Abstract

This paper presents a status for the updraft gas technology held by Babcock & Wilcox Vølund A/S. The technology is deployed at the Harboore plant in Denmark and at three new plants in Japan. Based on the experiences from the full scale long term demonstration at the Harboore plant the technology has been further developed with respect to scaling it up and new configurations to its present level where it is commercially available These configurations includes traditional gas engine based combined heat and power plant, gas generator for an external superheater for instance in connection with a waste-to-energy plant, and a combined cycle based power plant involving a gas engine.

1. Introduction

Biomass gasification has been studied intensely for more than a decade. In the recent years the focus for the gasification technology has been concentrated mainly on producing power and liquid fuels. Numerous concepts have been suggested but only few of these have been matured into full scale operation. Updraft gasification is one of the few technologies that are now deployed in full scale power producing operation. This paper gives an update on the development and the technical state of the updraft gasification technology held by Babcock & Wilcox Vølund A/S and its commercial state

2. Developing up-draft gasification to full scale

The development of the biomass up-draft gasification technology to full scale operation has been performed by Babcock & Wilcox Vølund A/S through an on-going development programme that started in the eighties. In 1989 a 1 MW pilot scale plant was erected at Kyndby værket – a utility power plant. This plant was later dismantled, but the know-how was incorporated into a full scale plant – The Harboøre plant (The Harboore plant) - together with experience from a 50 kW pilot plant and the results of numerous university studies. The Harboore plant was erected in 1996. The first step was to demonstrate that a full scale updraft gasifier could be operated in a manner that would provide a reliable supply of heat to the nearby village by utilising the raw, untreated product gas in a boiler. The experience gathered in the first years resulted in modification and optimisation of the fuel feeding system, the gasification agent, the temperature control etc. The second step was to upgrade the plant to produce power by adding gas engines in April 2000. This step involved the development of a gas cleaning system for removing the extensive amount of tar and water in the raw, untreated product gas. It was chosen to implement a wet gas cleaning system with gas coolers and a wet electrostatic precipitator. Consequently, the need for a waste water treatment system arose. Several options were evaluated and tested, including centrifuges and osmotic filtering. Finally, a waste water cleaning system based on gravimetric separation of organic and aqueous phases followed by a thermal treatment of the aqueous phase was developed and patented. The implementation and commissioning of the waste water treatment system was carried out in the period 2002 to 2003. Since then, the plant has been in ordinary operation producing power for the grid and heat for district heating. Lately, the focus of the development has been directed towards optimisation, minor improvement, retrieving experience, further up-scaling, and development of new applications derived from the experience from the Harboore plant.

3. The Harboore plant

Plant description

The Harboore plant can, for the convenience of this paper, be divided into the following main components:

- A 3.7 MW_{th} up-draft gasifier with fuel feed, ash extraction system, and air humidifier
- A gas cooling and cleaning system
- Two gas engines with generators and exhaust boilers
- A waste water cleaning system named the Tarwatc system
- A heavy tar fired boiler with storage tank for heavy tar
- A product gas fired boiler

Figure 1 shows a schematic representation of the system.

The gasifier is fuelled solely with non-pre-treated wood chips. In the gasifier the wood chips are converted with hot humid air into a product gas that leaves the gasifier at the top. The ash is continuously removed from the grate at the bottom of the gasifier. Aerosols and tar droplets leave the gasifier together with the product gas. These impurities are removed in the gas cooler and in the cleaning system. The result is a product gas free of tar and aerosols, a heavy tar fraction, and an aqueous phase with a high content of soluble organics.

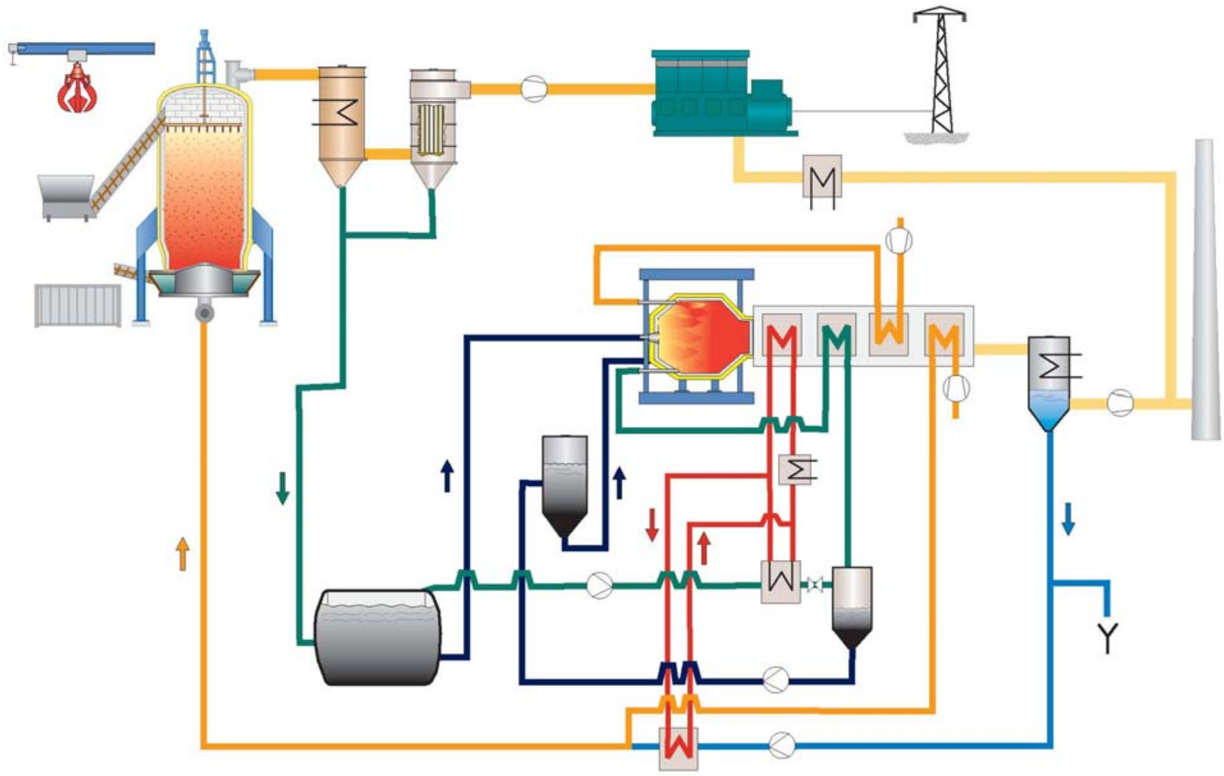

Figure 1: A schematic drawing of the Harboore CHP plant.

The heavy tar is stored and is used as an auxiliary fuel instead of oil in a separate heavy tar fired boiler for peak loads and during maintenance of the rest of the system.

The aqueous phase is handled by the Tarwatc system (TAR-WATer Cleaning system), which is, in principle, a thermal treatment utilising the organic pollutants of the aqueous phase as its energy source. The effluents from the Tarwatc system are a flue gas and a condensate consisting of water with only traces of contaminants.

The product gas is used to power two Jenbacher gas engines with a maximum rating of 648 and 768 kWe power. The engines supply heat to the district heating grid, air preheating for the supply of hot humid air to the gasifier, and energy for the Tarwatc system. The latter is subsequently recovered in the flue gas cooler/condenser of the Tarwatc system.

As the plant was originally intended solely for the supply of heat, it is also equipped with a boiler that can be fired with the product gas. This boiler was the primary heat source before the plant was fitted with gas engines. Nowadays the gas fired boiler is rarely used.

Status of the Harboore plant

The Harboore plant remains an important reference for biomass gasification and is in continuous full scale operation. The gasifier has been in operation for more than 110 000 hours. Altogether, the gas engines have been in operation for more than 70 000 hours. In Figure 2 shows the accumulated hours that the gas engines have been running. It can be seen that the gas engines were installed before the waste water treatment system, and during its implementation and commissioning the gas engines were mostly out of operation. Furthermore, it can be seen that from 2003 the operation has been stable or slightly increasing except for a fire in a gas engine control cabinet in the autumn of 2004. During 2006 the plant was operating with power production for 7947 hours, which is equal to 90.7 % availability. In the autumn of 2007 the superheater sections of the waste water treatment system were replaced after 5 years of operation, leading to a prolonged period with no power production due to delayed supply of materials.

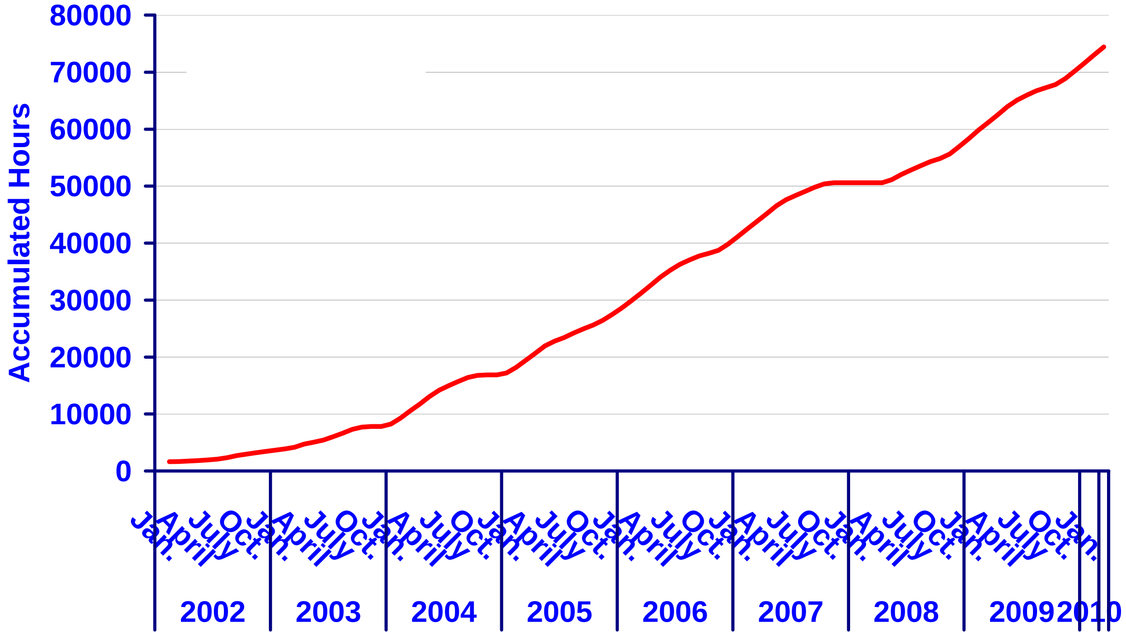

Figure 2: The accumulated operating hours for the gas engines.

During tests, the Harboore gasifier is capable of a power efficiency 27-29 $\%_{gross}$, related to input of wood chips as received. However, evaluated over a longer period of time the efficiency is lower (the average for 2006 was 23 $\%_{gross}$) for several reasons, including maintenance and load variations. The load is determined by the heat uptake in the local village e.g. during the hot period the plant is running at less than 30 % load.

11-13 % of the energy from the wood chips is converted into hydrophobic or heavy tar with a lower heating value of approx. 29 MJ/kg. This tar is stored and used as a heat source in peak load situations and during outages, saving the equivalent amount of oil.

The typical composition of product gas produced at Harboore is shown in Table 1.

Table 1. Typical composition of the dry cleaned product gas at Harboore. The balance is anticipated to be N_2.

Parameter	Data
Temperature	73-76 °C
H_{lower}	6.5-8 MJ/Nm^{3}dry
H_2	16-19 %
CO	27-33 %
CO_2	6-10 %
CH_4	4-7 %
O_2	< 0.5 %

The TOC of the ash is 0.5 to 1 %.

<u>Experience from operating the Harboore plant</u>

Over the years a vast amount of experience has been obtained from operating a CHP plant based on an up-draft gasifier. Some of the more significant findings have been summarised below.

- The up-draft gasifier at Harboore is very reliable with more than 8000 hours of operation per year.
- The maintenance of the gasifier is simple and the cost is low.
- The gasifier is capable of running at 25 % load for a prolonged period of time.
- The gasifier ramps up and down faster than the gas engines, which have a ramping time of 15 min. from 0 to 100 % load.
- The gasifier can be set on stand by (~0 load) for 1-3 days
- The fuel properties, e.g. moisture content and particle size, are important for the operation of the gasifier, the gas cleaning system, and the waste water system.
- The capacity of the gasifier does not correspond to the original design capacity.
- The Cl-content in the fuel is important to the oil quality of the gas engine. Chlorine accumulates in the engine oil, shortening the time between oil changes. The wood chips fuelling the Harboore plant originate from areas affected by deposition of NaCl from sea spray.
- The intercooler needs cleaning at least once a year to preserve full rating of the gas engines.
- Both gas engines have been serviced after 20 000 h operations and have proven to be in good condition, showing no problems with corrosion; in fact they had a lower

mechanical wear compared to engines running a similar number of hours on natural gas.
- The CO emission from gas engines is high but a long time test shows that it can be reduced by means of a catalyst.
- It is possible to ensure a product gas quality suitable for operation of gas engines
- The waste water cleaning system is capable of achieving the desired waste water quality and with a good energy performance. However, advanced skills are required to design, commission, and operate the water cleaning system in order to avoid corrosion and unscheduled shut-downs.
- The tar has proven to be a valuable by-product, substituting oil for heating.
- The design of components for handling waste water before cleaning requires a careful, detailed design.

4. Commercialisation of up-draft biomass gasification

In the previous sections the development of a gasification concept to a full scale power producing plant is outlined. This part of the development is recognised as a long and costly process by R&D teams working with biomass gasification, which is in accordance with the experience with up-draft biomass gasification. However, the process of going from an established reference plant to having a fully commercialised technology is also a long and costly process. A process that is less debated by biomass gasification academics compared with the first step of the development, partly due to the development stage of the biomass gasification technologies and markets. Up-draft biomass gasification is now commercially available but awaiting a wider market penetration.

The up-draft biomass gasification technology developed by Babcock & Wilcox Vølund A/S is presently being commercialised in different configurations developed on the basis of the reference plant in Harboore:

- Combined heat and power stations (traditional CHP)
- District heating stations/Burnable gas generator
- As energy supply for an external superheater in connection with an industrial facility such as a waste-to-energy facility
- A combined cycle gasifier-based power plant (CC-CHP)

The traditional CHP concept is a 2. generation of the Harboore technology including a range of modifications. The CHP concept is licensed to JFE Corporation in Japan. JFE has built three plants (8 MWth, 9MWth and 11 MWth) in Japan.

The district heating configuration is directly derived from the Harboore plant as it was before the gas engines were added in the year 2000. In most instances the CHP option is more favourable nowadays. This configuration can also be used as a generator for burnable gas substituting natural gas for various purposes

Using the up-draft gasifier as the energy supply for an external superheater utilises the knowledge gained from the Harboore plant as it was before the gas engines were added, the experience achieved from the adiabatic combustion chamber that is included in the present waste water cleaning system and the general boiler knowledge of the company. It has the potential for achieving a power efficiency in excess of 60 % on the gasified fuel. The configuration is advantageous for waste-to-energy boilers, because superheating based on the waste boiler alone is limited by corrosion issues.

The CC-CHP configuration has been developed to achieve maximum power efficiency. The technology is marketed in applications for building with a power production of 5 MWe. In the following section the CC-CHP configuration is described.

5. A combined cycle gasifier-based power plant (CC-CHP)

The CC-CHP configuration is shown on Figure 3.

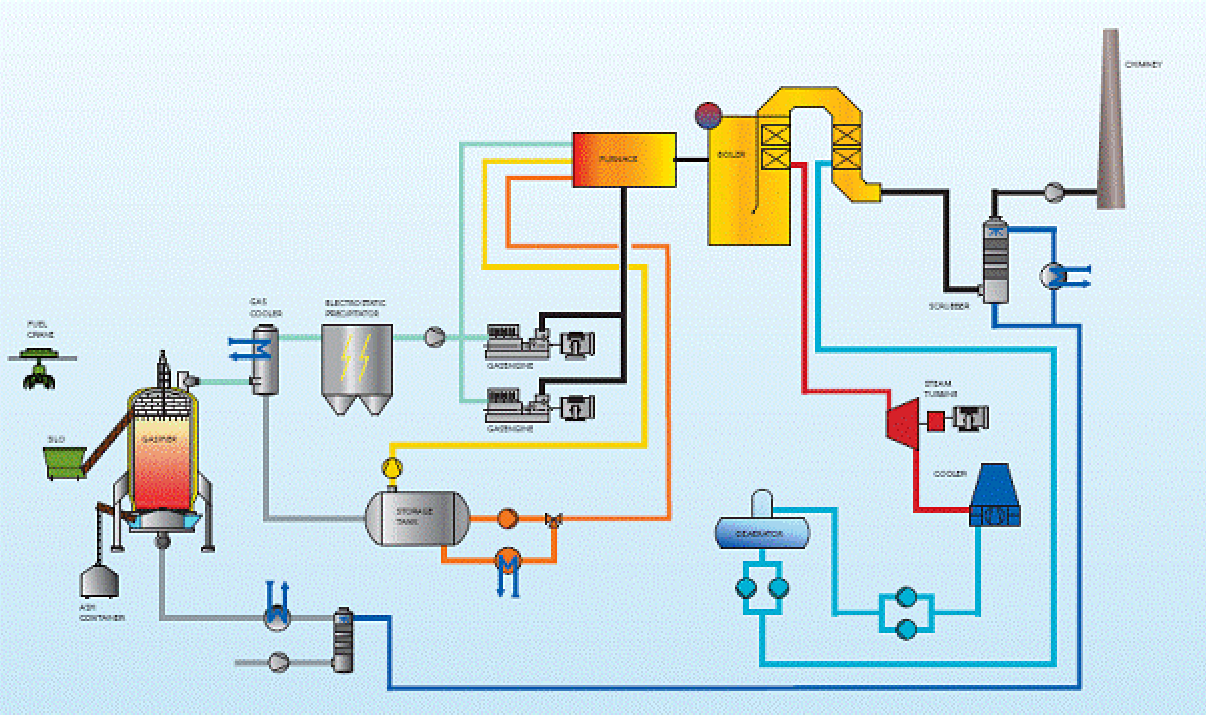

Figure 3: A combined cycle gasifier-based power plant (CC-CHP).

Compared to the Harboore plant the CC-CHP plant the design is identical with respect to the gasifier, fuel feed, ash extraction, product gas cleaning and separation of fluids from the product gas cleaning into an organic phase (tar) and an aqueous phase containing water-soluble organics. In the CC-CHP plant an adiabatic chamber is added, incorporating experience from the adiabatic combustion chamber in the present waste water treatment system at Harboore and the traditional boiler know-how of the company. This chamber has several functions:

Combustion of the tar for subsequent energy recovery

Incineration of the evaporated aqueous phase for waste water cleaning

Addition of the exhaust gas from the gas engines for energy recovery and CO reduction

The energy of the flue gas from the adiabatic chamber is extracted in a boiler producing steam for feeding a steam turbine. Hence, the energy of the gas engine exhaust and tar is utilised for power production which, combined with the power produced by the gas engines, results in high power efficiency.

Approximately 75% of the energy based on the fuel input is present in the cold product gas after cleaning (tar removal and condensation of water), which, with an efficiency of 37% at the gas engine, results in an overall gas engine electrical efficiency of 28% based on the input of fuel as received, similar to the gross efficiency achieved during tests at Harboore. The waste heat recovered from the cooling of the product gas along with the waste heat from the gas engines and the flue gas 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 26% of the fuel heat input to the plant. Along with 33 % of the energy input which comes from the heated heavy tar, water soluble organics from the evaporated aqueous phase, 26%+33%= 59% of the waste energy is led to the heat recovery boiler. Due to the relatively low exit temperature of the adiabatic combustion chamber, the thermal efficiency of the heat recovery boiler is only around 67%, but still allows some 40% 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 the steam consumption for the feed water tank and other minor consumers only around 25-30% of this is expected to be converted to electrical energy (10-12%), thus giving an overall power efficiency of 38-40%$_{gross}$.

For higher steam flows the steam turbine isentropic efficiency will increase, and a dual pressure boiler or reheating of the steam may be applied to improve the steam cycle efficiency, which will increase the overall electrical efficiency to above 40%$_{gross}$.

6. Conclusion

The updraft gasification technology has passed a major milestone R&D-wise as proving full scale CHP operation is done. The present challenge is commercialising the technology on emerging markets by developing matching technologies derived from the accomplished development and experience.