HARBOORE – WOODCHIPS UPDRAFT GASIFIER AND 1500 KW GAS-ENGINES OPERATING AT 32% POWER EFFICIENCY IN CHP CONFIGURATION

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ABSTRACT
The Harboore updraft wood-chips gasifier was set in operation December 1993, sponsored in part by the Danish Energy Agency. The plant was considered in commercial operation for the provision of district heating for about 650 subscribers at Harboore (North Sea Coast, Denmark) after 3 years of optimisation. Experiments on catalytic cracking of the tar in the product gas were abandoned in 1997 because of insufficient capability and a wet gas cleaning development project proved successful by early 1999. Two gas-engines (from manufacturer Jenbacher, Austria) were set in operation early 2000.
However, the reverse osmosis based water clean-up technology did not operate satisfactorily after up-scaling and a new – Volund developed system was successfully tested early 2001 and set in full scale operation in the spring of 2002. The engines have performed satisfactorily, but because of the waste water problems they were only operated for a total of 2000 hours during the development of the new cleaning technology for tar contaminated water. The water cleaning technology will be optimised during 2002.
Keywords: Combined Heat and Power generation (CHP), Wood chips, Gas Cleaning

1. BACKGROUND

Volund – which is part of the US Company Babcock & Wilcox – has since the early eighties concentrated considerable efforts in conversion of biomass and municipal solid waste into Heat and Power. Babcock & Wilcox Volund employs about 500 and is a major engineering and manufacturing Company within this sector.

With the objective to optimise the power efficiency and environmental impact of the technologies, the Company initiated in the late eighties a development process aimed at including gasification technology into their product portfolio. The main rationale was to change from conversion technologies based on mass combustion into the more versatile product gases available from gasifiers. At the same time it was envisaged that these gases might be used with highly efficient gas-engines and gas-turbines. Very early the development work was focused at technologies for the range 5 – 20 MW fuel input.

Between 1988 and 1992 the experimental work was centred on a MW_{TH} updraft straw gasifier located at the Kyndby Power Plant (Copenhagen area) and based on a design by Dr. Horst Gatzke (Keramische Industrie Bedarfs, Berlin). The work was sponsored in part by ELKRAFT Power Utilities and the Danish Energy Agency. After several attempts to gasify straw for prolonged periods, Volund R&D Centre met the usual problems with high contents of low-melting ashes and had to abandon the work temporarily and concentrate on the gasification of wood-chips – another abundant biomass fuel in Denmark. These experiments, which were quite successful led to continuation of the development program at Harboore from early 1994.

2. THE HARBOORE PROJECT

From 1994 to 1996 several problems – mostly related to maintain stable gasifier operation and keep the product gas system free of deposited tars and particles – were solved. After this period, the gasifier was capable of providing district heating with auxiliary oil firing only for mid-winter peak load district heating demand and the work was now concentrated on cleaning the product gas to a level applicable for gas-engine firing.

Initially, the technology pursued to reduce the product gas tar content from about 80 (g/Nm^3) to levels compatible with the requirements for gas-engines was based on tar cracking using metallic catalysts. However during 1997 this was abandoned for use in prolonged operation and also because the cleaning performance proved inadequate. A system of gas-scrubbers and a wet Electrostatic Precipitator was tested for a prolonged period and by exchanging the gas-scrubbers with district heating cooled heat-exchangers, adequate performance was finally achieved.

In the spring of 2000 two Jenbacher gas-engines (each originally 1000 kW_E natural gas engines modified and down-rated to each 648 kW_E – later increased to each 768 kW_E) were installed at the plant and were soon in satisfactory operation. A system for cleaning the tar contaminated water from the gas cleaning system – based on ultra-filtration and reverse osmosis failed to perform shortly after start up and a new technology had to be developed. In the spring of 2002 – after prolonged pilot scale tests (50 – 60 kg/h of tar-water) – a full scale system (1200 kg/h) were set in operation and has now (Mid-june 2002) operated satisfactorily for one month. This system will be operationally optimised during the next few months.

The various subsystems of the Harboore plant will now be described.

3. OIL/TAR FUELLED DISTRICT HEATING BOILER

To initially provide base-load district heating, an oil/tar fired hot water boiler with a capacity of 4.2 MW_{TH} was included to later be used for peak load district. Originally fuel oil was used, but this fuel has now been substituted by heavy tar from the gasifier product gas clean-up system. The boiler is equipped with a 38 m^3 fuel oil tank, combustion air and exhaust flue gas fans and a 20 meter flue stack.

4. UPDRAFT WOOD-CHIPS GASIFICATION REACTOR

Based on a moisture content of 42% the reactor will handle about 1880 kg/h of wood-chips fuel corresponding to a loading of 5200 kW_{TH}. The load range for stable operation in engine operation mode is 500 – 6000 kW_{TH} and modulation between these limits takes place within a few minutes. The fuel moisture content may vary between 35% and 55%. However, the Harboore gasifier will handle fuel moisture content down to below 10% and capacities in excess of 7000 kW_{TH} in pure district heating operation mode.

The reactor is equipped with a rotating grate (for ash extraction) and a water-lock and has overall dimensions of about 2.5 meter diameter and a height of about 8 meter. The reactor is further equipped with a top mounted slowly rotating impeller, which acts as fuel leveller and loading control.

The gasifier is using moist air as a gasification agent – initially saturated at about $65^{O}C$ and superheated to about $150^{O}C$ before entering the reactor through the grate. The gasification agents are used for:

- Oxygen from the air is used for burning part of the carbon from the pyrolysis zone of the reactor to provide heat energy (and also CO_2) for the reaction zone
- The water vapour is used to provide steam for the reduction zone, where the steam reacts very quickly with carbon to form H_2 and CO

The humidifier is provided with an air fan and an electric heater (the latter to be used when the plant is operated in pure district heating mode). Further, the scrubber used by the humidifier is heated using district heating water.

5. FUEL AND ASH HANDLING

Using a computer controlled crane system the wood-chip fuel is loaded into a feeding chute, from which it is transported by a system of three screw-feeders to the reactor (to prevent air ingress). Typically, the fuel contains 42% of moisture and have the following (dry) chemical analysis: Carbon 50.00%, Hydrogen 6.17%, Oxygen 42.64%, Nitrogen 0.17% and ash 1.00%.

The ash is falling into the water-lock through the reactor grate, from which is conveyed by screw-feeders to a container. The residual carbon content in the ash is 2 – 3% (dry basis) and the ash may be returned as fertilisers to the plantations, from where the wood-chips originates.

6. WOOD-GAS FIRED DISTRICT HEATING BOILER

The product gas from the reactor is burned in a Low-NO_X burner into a hot-water district heating boiler. Typical temperature levels are $90^{O}/40^{O}C$ and the capacity is about 4.2 MW_{TH}.

The flue gases from the boiler are cooled in a district heating cooled scrubber to about $100^{O}C$ and discharged through a separate tube in the stack provided for the oil/tar boiler. The condensate from the scrubber and the flue gases full-fills the environmental regulations.

7. GAS CLEANING SYSTEM

The product gas from the reactor contains about 80 g/Nm^3 of various tars and acids and also a small amount of tar. The temperature after the reactor is about $75^{O}C$. The product gas is cooled serially through two district heating shell and tube heat exchangers in which a large amount of tar and water is separated together with most of the particles. Following this the gas is cleaned for remaining water/tar aerosols and dust in a wet electrostatic precipitator (ESP).

After these processes the contents of tar and dust are both below 25 mg/Nm^3 – suitable for fuelling gas-engines – and the temperature is about $40^{O}C$. The cleaned gas is fed to the engines by a booster-fan to provide regulation pressure for the "gas train". The gas quality has been verified as follows (dry tar-free volumetric):

H_2	19.0%	($\sigma = 0.4\%$)
CO	22.8%	($\sigma = 1.4\%$)
CH_4	5.3%	($\sigma = 0.1\%$)
CO_2	11.9%	($\sigma = 1.0\%$)
N_2	40.7%	($\sigma = 0.3\%$)

and the net calorific value is: 5.6 MJ/Nm^3 ($\sigma = 0.1$ MJ/Nm^3)

8. HEAVY TAR SEPARATION SYSTEM

The 1200 kg/h tar-contaminated water originating from the two coolers and the ESP is separated in a coalescer into:

- About 100 kg/h of heavy (high molecular) tars having a net calorific value of about 27 MJ/kg. The heavy tar is stored in a 150 m^3 heated tank and part of this tar is used for district heating peak load firing in the oil/tar hot water boiler
- About 1100 kg/h of water contaminated with light (low molecular) tars and acids. This fraction can not be discharged because a typical analysis is: 10 (g/L) phenols, 45 (g/L) total organic carbon (TOC) and acids (mainly acetic and formic acid) causing acidity about pH = 2

9. 2 x 750 kW_E GAS ENGINES

The Harboore plant is equipped with two turbo-charged Jenbacher gas-engines, which are feeding into the electricity grid. The cleaned gas is fed to the engines trough traditional "gas trains". After the engines, air-heaters to replace the electrical heaters of the gasification agent preparation system are located in the engine exhausts. Before discharging the flue gases through the 40 meter flue stack the gases are cooled to about $100^{O}C$ in exhaust boilers.

Typical emissions at the flue stack are (reference 5% O_2): CO 1500 mg/Nm^3, NO_X 400 mg/Nm^3 and UHC 6 $\mu g/Nm^3$

10. TARWATC – FINAL WATER CLEAN-UP

The dirty water from the heavy tar separation system is cleaned before discharge using the Babcock & Wilcox Volund developed TARWATC system:

Using hot water from the engine exhaust boilers the contaminated water is evaporated and the light tars (having a net calorific value about 14 MJ/kg) are separated. The slightly contaminated steam is heated in counter-flow with clean steam from the TARWATC reactor to a high temperature before entering the reactor. The temperature is further increased by burning part of the light tars inside the reactor. The clean steam is condensed in a district heating cooled condenser and the inert gases are discharged through the engine flue stack.

The condensate from the clean steam full-fills the environmental regulations for discharge into municipal systems (verified emission levels are: Phenols below 0.15 mg/L, TOC below 15 mg/L and an acidity of pH = 6.9 – 7.0).

11. PLANT OPTIMISATION

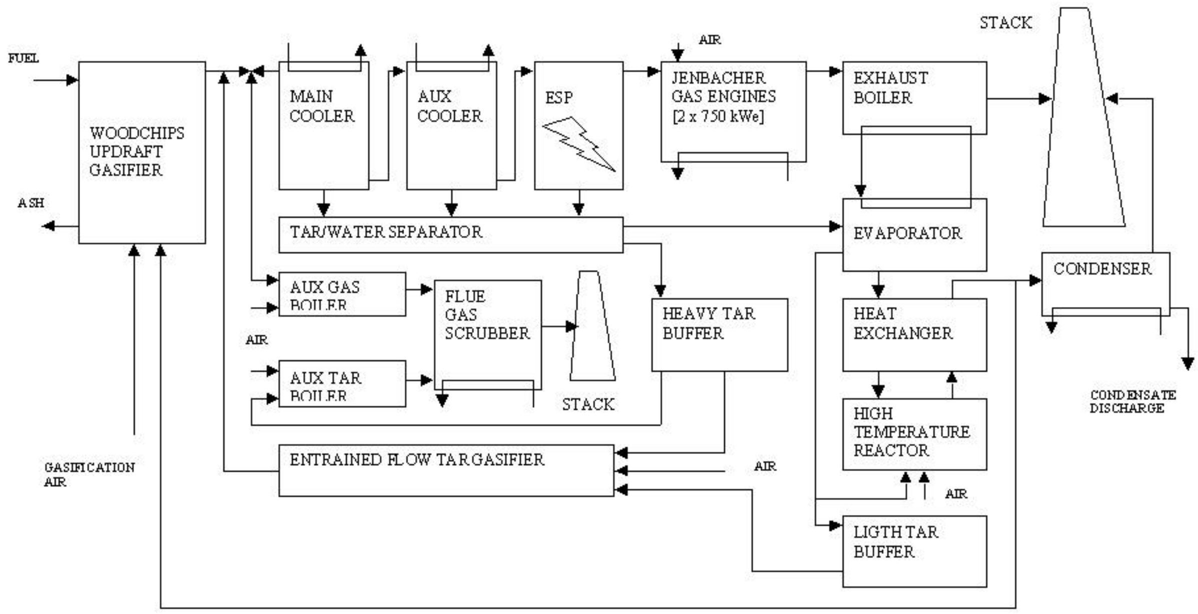
The wet gas cleaning system used at the Harboore CHP plant leaves about 50 kg/h of heavy tars and about 100 kg/h of light tars after part of these residues are used for operating the TARWATC process and for district heating peak load firing.

These low-grade fuels may be used for district heating, but a more attractive solution would be to return the tars to the gasification reactor to release part of the carbon burned to maintain reactor heat supply for gasification. An alternative solution would be to gasify the tars and join the gas produced with the main gasifier product gas flow.

A re-introduction of the tars into the gasifier will improve the plant power efficiency and will especially be important at markets, where use of district heating is of secondary importance.

Early 2002, Babcock & Wilcox Volund R&D Centre successfully gasified these residuals on a (8 kg/h) laboratory scale entrained flow gasifier and are now in the process of preparing a full-scale project to be implemented at the Harboore gasifier within a few months.

Based on the experiences with the pilot scale gasifier it is anticipated, that the overall power efficiency may be improved by possibly 3% (point).



GENERAL LAYOUT HARBOORE WOODCHIPS FIRED CHP-PLANT