# WOOD-CHIPS GASIFIER COMBINED HEAT AND POWER

**Dr. Bjorn Teislev**
**Manager, Babcock & Wilcox Volund R&D**
**Babcock & Wilcox Volund R&D Centre, Centervej 2, DK – 6000 Kolding, Denmark**

## 0. SUMMARY

During the recent decade Babcock & Wilcox Volund has devoted considerable efforts into developing a biomass updraft gasification Combined Heat and Power (CHP) technology for industrial application. Today, the Company can competitively offer plants for a fuel input up to about 20 $MW_{TH}$ with power efficiencies in excess of 30% and simultaneous delivery of hot water for district heating.

A significant part of the work has been related to the conditioning of the gasifier product gas for use in gas engines and a reliable solution based on gas cooling, wet electrostatic precipitation and a novel technology for cleaning the resulting tar contaminated water has been demonstrated.

Further, the technology has been automated to a level comparable with more old fashioned technologies for biomass based power generation and the overall environmental performance is significantly improved compared to these steam generation based approaches.

Apart from a minor problem – which is not fully verified for prolonged periods – the Babcock & Wilcox Volund technology must now be considered a fully State of the Art – highly competitive – alternative to older technologies.

Presently the Company is in the process of developing other uses for the technology than CHP application and also for use in connection with other kinds of waste materials.

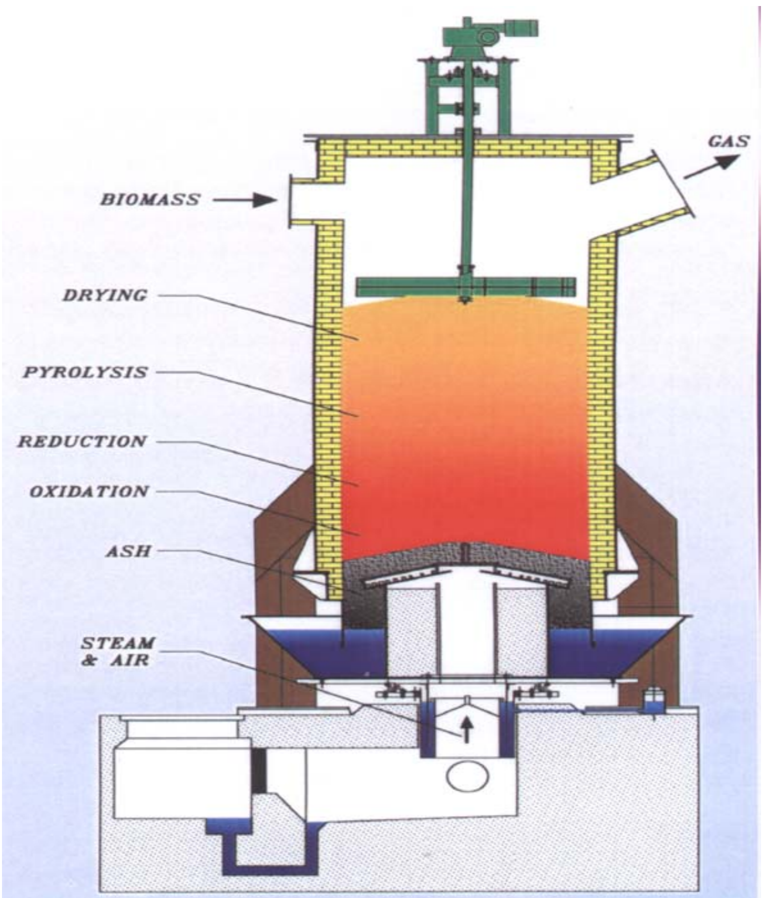
## 1. THE UPDRAFT BIOMASS GASIFIER

### BACKGROUND

In 1987 – in view of the Danish national energy policy – Babcock & Wilcox Volund R&D Centre initiated a program with the aim to develop biomass updraft gasification technology. The main reasons for considering this technology were:

- The inhomogeneous process of mass combustion is changed into the more attractive process of burning a homogeneous gas
- The product gas may – after a modest clean-up – be burned using Low-$NO_X$ gas burner technology in connection with indirectly fired power cycles like the Indirectly Fired Gas Turbine (IFGT) and the Stirling Engine
- After adequate cleaning the product gas may even be used for direct firing of gas-turbines and internal combustion engines

### UPDRAFT GASIFICATION PRINCIPLE



- **DRYING**

Fresh wood-chips (typically 40 – 50% moisture content) is dried in counter-flow with hot rising product gases passing the ”fibre saturation point” (at about 23% moisture) after which changes in wood structure – and also thermophysical properties – appears. At the same time the product gases are cooled to a temperature of 73 – 75$^oC$. The drying process takes place in the temperature range up to about 160$^oC$

- **PYROLYSIS**

The major polymers (Cellulose, Hemicellulose and Lignine) are broken down into typically (dry wood basis, weight): 15% CO, 18% $CO_2$, 6% $CH_4$, 11% $H_2O$ and 30% Tars. A solid – highly reactive – char residue of typically 20% containing some $H_2$ is produced during this process taking place in the temperature range 120$^oC$ to 600$^oC$

- **REDUCTION (GASIFICATION)**

At higher temperatures the char produced in the pyrolysis zone is reacting with $H_2O$ and $CO_2$ to form (mainly) $H_2$, CO and $CO_2$ through several endothermic processes in the temperature range 500$^oC$ to 1100$^oC$

- **OXIDATION (COMBUSTION)**

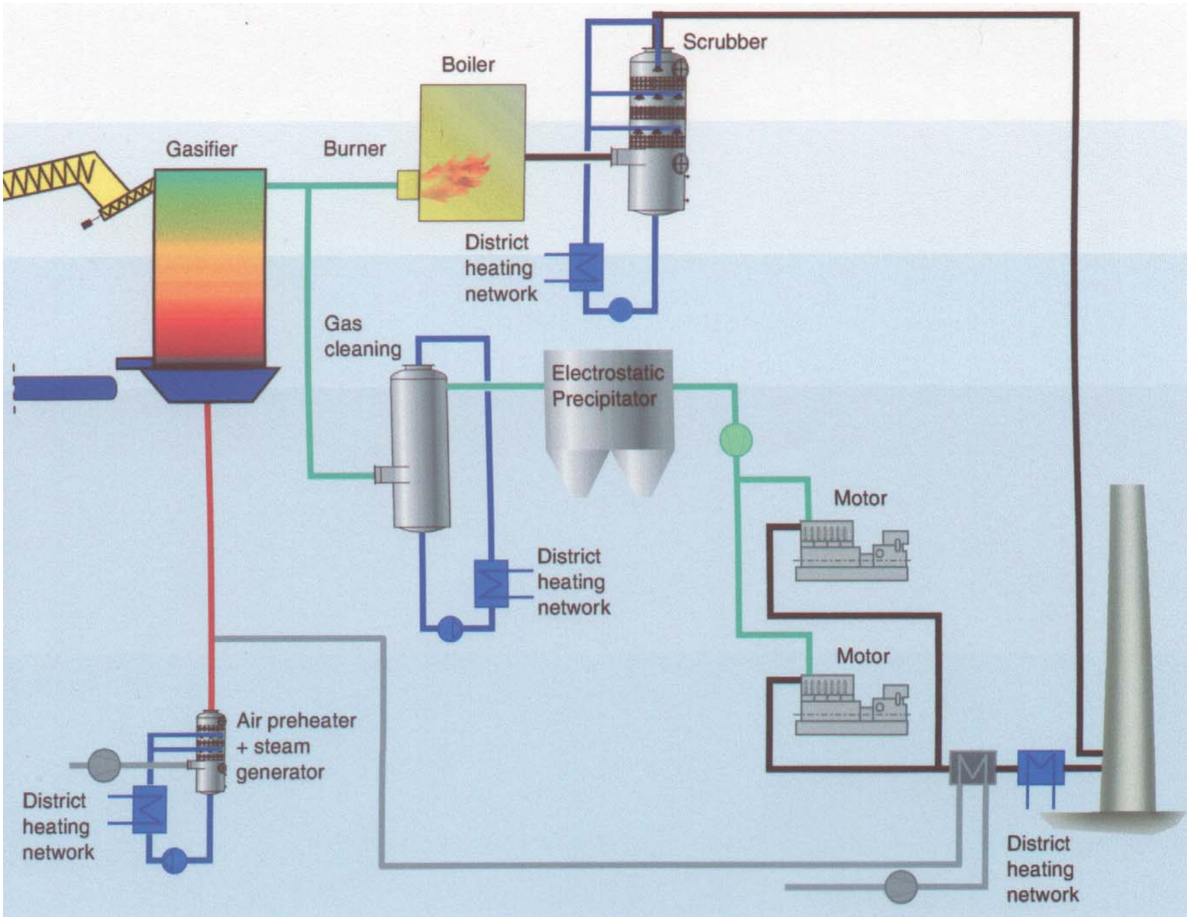
Through the addition of oxygen (typically air) a part of the char descending from above is reacts with $O_2$ (and also through an intermediate stage with CO) to create heat (exothermic processes) at temperatures above 1000$^oC$ for the processes in the previous processes. The amount of combustion typically corresponds to an overall process stoichiometry of 26 – 29%

## 2. THE DEVELOPMENT PROCESS

The initial work was performed at a – nominally – 1 $MW_{TH}$ updraft gasifier located at the Kyndby Power Plant (Zealand, Denmark) and externally sponsored by ELKRAFT A.m.b.A. power utilities and the Danish Energy Agency.

The reactor was based on a design from the Company Keramische Industrie Bedarfs (Dr. Horst Gatzke, Berlin, Germany) and original the aim was to develop gasification of straw, which is the most abundant biomass in most European countries. However, this was proven quite difficult because of the low ash melting points for this fuel (with associated problems in the reactor reduction zone) and Babcock & Wilcox Volund R&D Centre soon concentrated their efforts on the gasification of wood-chips.

We now – since January 1994 – have a (maximum 6 $MW_{TH}$) wood-chips updraft gasifier in commercial operation at Harboore (Westcoast Jutland, Denmark) for the provision of district heating for the municipality. Since then, the aim has been to convert this plant for Combined Heat and Power (CHP) generation using gas-engines powered by the gasifier product gas.




The main task has been to clean the product gas to a level acceptable to an internal combustion engine and initially Babcock & Wilcox Volund R&D Centre used large efforts to clean the product gas for tars and dust in catalytic tar crackers and candle filters, respectively. The work was done in co-operation with the Danish Technological Institutes and was sponsored externally by the Danish Energy Agency. However, this approach was not successful, and – because in the meantime we optimised the gasifier to produce a gas with a stable tar content and a low dust content – we concentrated on the development of gas scrubbers/coolers and associated waste-water cleaning.

Today, the cleaned gas quality and also the problems connected with effluent waste-water have been verified and 2 gas-engines – each 768 $kW_E$ power (down-rated 1000 $kW_E$ natural gas engines) – are now in more or less continuous operation. An overall power efficiency in excess of 30% (from wood-chips to electricity) has been guaranteed. The engines have been delivered by Austrian manufacturer Jenbacher and the total plant will be optimised during this year.

A summary of typical gas quality data is presented below:

| **DATE: 07-03-2000** | H2% | CO% | CO2% | O2% | CH4% | N2% | Hn(MJ/Nm3) |
|---|---|---|---|---|---|---|---|
| *12:00-13:00* | 19,30 | 21,80 | 12,80 | 0,15 | 5,50 | 40,45 | 6,56 |
| *13:00-14:00* | 19,20 | 20,50 | 13,50 | 0,15 | 5,50 | 41,15 | 6,37 |
| *14:00-15:00* | 19,20 | 22,80 | 11,90 | 0,18 | 5,20 | 40,72 | 6,56 |
| *15:00-16:00* | 18,70 | 23,00 | 11,70 | 0,20 | 5,40 | 41,00 | 6,59 |
| *16:00-17:00* | 19,00 | 23,70 | 11,40 | 0,18 | 5,40 | 40,32 | 6,70 |
| *17:00-18:00* | 19,40 | 23,20 | 11,60 | 0,17 | 5,20 | 40,43 | 6,66 |
| *18:00-19:00* | 18,30 | 24,80 | 10,50 | 0,19 | 5,20 | 41,01 | 6,72 |
| Mean value | 19,01 | 22,83 | 11,91 | 0,17 | 5,34 | 40,73 | 6,59 |
| Standard deviation | 0,39 | 1,37 | 0,98 | 0,02 | 0,14 | 0,33 | 0,12 |

| **DATE: 08-03-2000** | H2% | CO% | CO2% | O2% | CH4% | N2% | Hn(MJ/Nm3) |
|---|---|---|---|---|---|---|---|
| *10:00-11:00* | 18,20 | 21,60 | 11,80 | 0,26 | 5,10 | 43,04 | 6,28 |
| *11:00-12:00* | 19,10 | 21,70 | 12,60 | 0,18 | 5,60 | 40,82 | 6,55 |
| *12:00-13:00* | 18,20 | 24,80 | 10,70 | 0,20 | 5,60 | 40,50 | 6,84 |
| *13:00-14:00* | 17,10 | 25,90 | 9,70 | 0,19 | 5,40 | 41,71 | 6,80 |
| *14:00-15:00* | 18,10 | 28,00 | 8,40 | 0,22 | 5,10 | 40,18 | 7,06 |
| *15:00-16:00* | 18,60 | 26,90 | 9,40 | 0,18 | 5,60 | 39,32 | 7,15 |
| *16:00-17:00* | 17,20 | 27,60 | 8,70 | 0,24 | 5,20 | 41,06 | 6,95 |
| Mean value | 18,07 | 25,21 | 10,19 | 0,21 | 5,37 | 40,95 | 6,80 |
| Standard deviation | 0,72 | 2,66 | 1,58 | 0,03 | 0,24 | 1,19 | 0,30 |

**Representative dry and tar-free product gas composition at Harboøre plant**
*(Danish Technological Institute report May 5th, 2000)*

Babcock & Wilcox Volund now considers the gasifier combined heat and power (CHP) process – for wood-chips and similar fuels and in the range up to about 20 $MW_{TH}$ fuel input – fully commercial.

## 3. BABCOCK & WILCOX VOLUND GAS CLEAN-UP TECHNOLOGY

**Overall description of the technology used by Babcock & Wilcox Volund (BWV)**

The raw gas derived from the BWV updraft gasifier is available (water-saturated) at a temperature of about 75$^{o}$C and has a composition as reported above. In addition to this the raw gas has a tar-content of 0.060 – 0.080 kg/Nm$^3$ .

The gas conditioning system involves:

- The product gas is cooled – using the district heating grid – to about 45$^{o}$C, during which a considerable amount of water/tar condensate and also aerosols (microscopic water/tar droplets) is released
- The aerosols are subsequently removed from the gas stream by means of a wet electrostatic precipitator
- After this treatment the gas is clean and applicable for the gas-engines (both tar and dust contents are below 25 mg/Nm$^3$)
- The gas is boosted to a slightly higher pressure to accomplish engine inlet pressure regulation – by means of a traditional "gas train" – to slightly below atmospheric pressure

At full engine output, the amount of tar contaminated waste water from the Harboore gasifier amounts to about 1200 litres/hour containing about 18% of various organic acids and tars.

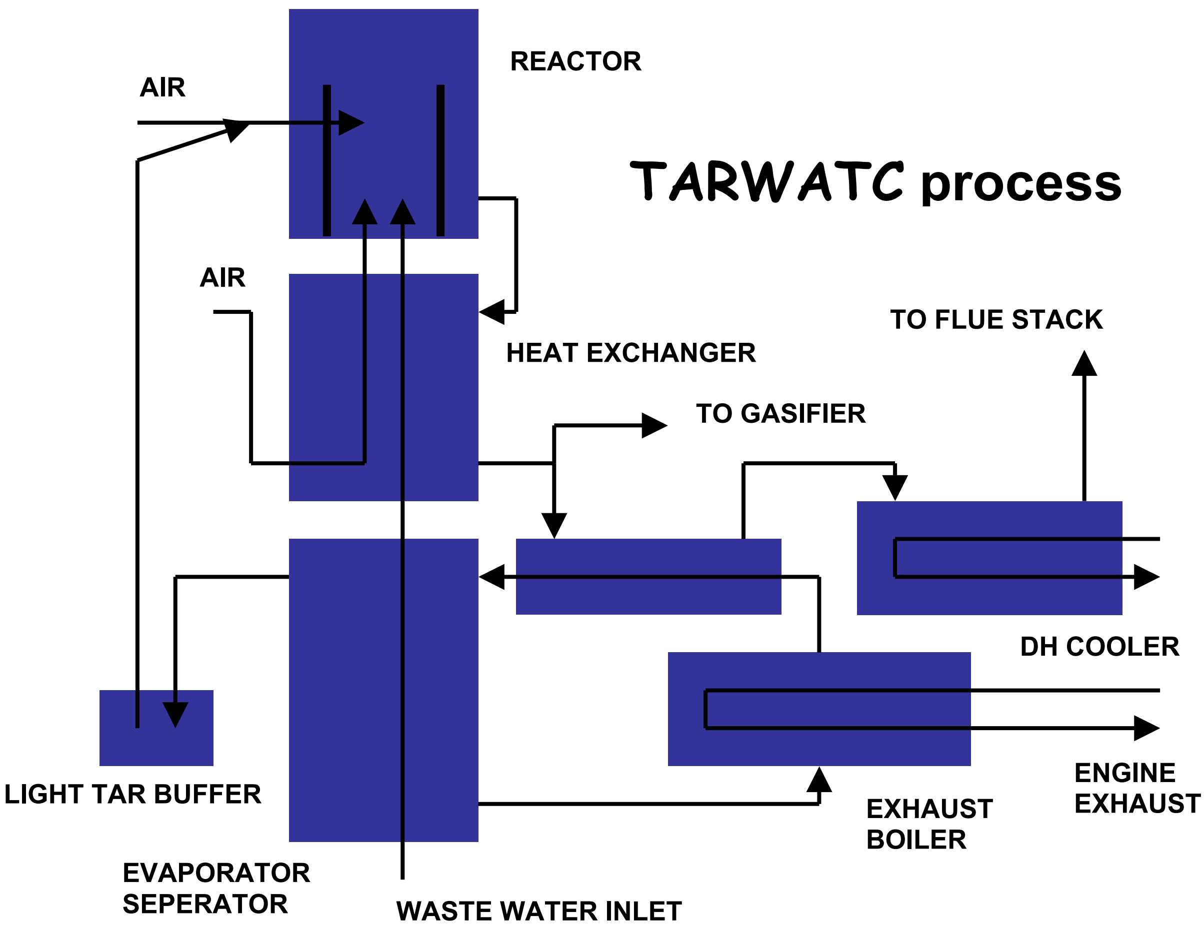
The waste water clean-up system comprises:

- In a separator (a so-called coalescer) about 80 litres/h of heavy (high molecular) tars are separated from the waste water. This tar has a gross calorific value of 26 – 28 MJ/kg and is used for:
    1. District heating peak load firing
    2. Re-injection into the gasifier reaction zones
    3. Gasification in a small separate gasifier (see below)

- In a special process developed by Volund the remaining waste water is cleaned to a level suitable for discharge into the sewerage system. During this process about 100 litres/h of light (low molecular) tars are separated. This novel waste water clean-up process – TARWATC (patents pending) – will be described in the following paragraph. The light tar separated has a gross calorific value of 13 – 15 MJ/kg and is used for:
    1. Re-injection into the gasifier gasification agent preparation system
    2. Gasification in a small entrained flow gasifier – which has been successfully tested at pilot scale by Volund R&D Centre , and is presently in the process of being developed for full scale implementation at the Harboore plant

The re-introduction of tar is important for the overall plant energetic economy and by re-introducing the tar into the gas producing process and joining this additional gas production with the main product gas stream before the main gas coolers, this can indeed be achieved.

## 4. A NOVEL TAR WATER CLEAN-UP PROCESS



- Engine exhaust heat is transferred to the evaporator using a hot-water loop
- The tar-water is evaporated partly and separated into a combustible liquid – highly contaminated phase – and a (more or less) clean steam phase
- The tar remaining in the steam phase is thermally cracked in the reactor at a high temperature using heat derived from the combustible fraction
- The reactor may be operated in oxidation mode (resulting in flue gases) or in reduction mode (combustible gases). The oxidation mode is the preferred solution
- A mixture of clean steam and gases – combustible or inert depending on the operational mode – leaves the reactor
- A part of the hot exit gases are used as gasification agent for the associated gasification process
- However, the major part of the hot exit gases can be used for district heating (by means of a steam condenser) or vented through a flue stack

The contaminated waste water inlet may contain 15 – 20 g/litre of organic acids (causing an acidity about pH = 2), 5 – 10 g/litre of phenols (and similar compounds) and a total organic carbon content (TOC) of 40 – 50 g/litre. A typical analysis of the waste water to be treated may be:

- Acetic acid 14200 mg/litre
- Formic acid 1900 mg/litre

causing an acidity of pH=2.03

- Phenol 730 mg/litre
- Guaiacol 1030 mg/litre
- Dihydroxy-benzene 1400 mg/litre
- Other phenols 2840 mg/litre

and further specific PAH's:

- Naphtalene 0.45 mg/litre
- Antracene/Phenanthrene < 0.005 mg/litre

The total organic carbon content (TOC) is 45900 mg/litre

The original tar-contaminated waste water is separated into 2 streams:

- A heavily contaminated fraction (about 10%) with a TOC of about 300000 mg/litre and a gross calorific value of about 13 MJ/kg (part of this will be re-used internally in the TARWATC process – the rest may be burned in the plant auxiliary boilers during district heating peak loads) or gasified in a small entrained flow gasifier to improve gas production

- A clean condensate with a TOC below 15 mg/litre, a total phenol content below 0.15 mg/litre and an acidity of pH = 6.90 – 7.10 (thereby eliminating need of neutralisation before discharge)

Babcock & Wilcox Volund R&D Centre has made several small-scale experiments with the process – first on a laboratory scale system with a capacity of 2 kg/h waste water and during the early Winter 2001/2002 on a pilot scale system with a capacity of about 50 kg/h was operated for a prolonged period. All experiments have proven successful (regarding environmental performance, corrosion and fouling) and BWV is presently in the process of designing and installing a full scale implementation at the Harboore gasifier (Denmark), capable of handling about 1200 litres/h of tar contaminated water from the product gas clean-up system.

## 5. PLANT PERFORMANCE, CAPITAL COST, ETC.

At nominal conditions the wood-chips fuel input is 4800 $kW_{TH}$, which is transformed into 1500 $kW_E$ power and 3200 $kW_{TH}$ district heating (operated at forward temperature 90$^o$C and return temperature 40$^o$C). Therefore, the power efficiency (from wood-chips to electricity) is about 31%. The wood-chips have a typical “particle diameter” of 10 to 80 mm (however, through a special design of the fuel feeding system much larger particles can be handled) and particles less than 10 mm can be accepted if this fraction is less than 10%. For the operation with engines it is further required, that the fuel humidity must be in the range 30 – 55% to avoid fouling problems in the gas clean-up system (however, the gasifier itself can handle fuel moisture down to practically zero).

The total capital investment for the 1500 $kW_E$ Harboore plant is about 5.5 mio. US$ and in addition to this about 2.0 mio. US$ of specific R&D has been spent. About 3.5 mio. US$ has been subsidised by the Danish Energy Agency.

The annual operation of the Harboore plant amounts to more than 8000 hours and is handled by two persons (which are also responsible for managing the district heating grid – about 750 subscribers)

## 6. ENVIRONMENTAL ISSUES, ETC.

In 2001, the Danish Technological Institute analysed the exhaust from the engines and the following results were achieved under full operational load (two measurement sessions – each one day) – referred to a flue gas $O_2$ of 5%:

| | |
|---|---|
| ▪ CO (mg/$Nm^3$,dry) | 1500 – 1800 |
| ▪ NO (mg $NO_2$/$Nm^3$,dry) | 400 – 500 |
| ▪ UHC ($CH_4$) (mg C/$Nm^3$,dry) | 50 – 60 |
| ▪ Naphtalene ($\mu$g/$Nm^3$,dry) | 3 – 5 |
| ▪ Other PAH's ($\mu$g/$Nm^3$,dry) | 1 - 2 |

The present Danish regulations requires a CO-emission not exceeding 500 (mg/$Nm^3$,dry) and therefore the reduction of this emission is presently being addressed by the engine manufacturer (Jenbacher, Austria). Using a catalyst system for a prolonged period, they have achieved a reduction to 500 – 700 (mg/$Nm^3$,dry). Being the first biomass-gasifier based CHP plant in Denmark, it is anticipated, that the national regulations will be modified to reflect these results.

Concerning the ash from the Harboore plant, the wood-chips (which is harvested from near-coastal plantations) has an inherent ash content of about 0.6%. The ash leaving the gasifier has been analysed having a carbon content of about 3%. Based on this the "carbon loss" can be estimated to about 0.02%. The ash – which has further been tested negative for dioxin and PAH's – is returned to the plantations as a fertiliser.

## 7. FURTHER DEVELOPMENT

However, a minor problem still remains: The lubricating oil for the engines must be changed twice as often than when the same engines are operated on natural gas. The problem is related to a peculiarity of the updraft gasification technology which has not been seen in connection with downdraft and fluidised bed gasifiers where the product gas passes through a very hot zone before leaving the reactor.

In the updraft gasifier the product gas leaves at about 75$^{o}$C and because of this the methyl-chloride formed in the pyrolysis zone of the reactor will pass unrestricted to the engines (it will not be absorbed in a wet gas clean-up system). However, when this contaminant reaches the engine combustion chambers it will be de-composed into Hydrochloric Acid, which will contaminate the engine lubrication oil. A study on oil additives is underway aimed at counteracting the influence of high chlorine contents on the lubricating performance.

Parallel to the updraft gasifier CHP technology being successfully commercially proven over an extended period and remaining minor problems solved, the development of several other applications for the BWV gasifier are in progress in Babcock & Wilcox Volund R&D Centre:

- Use of gasifier product gas for external steam superheating in e.g. Municipal Solid Waste plants
- Use of the product gas for reburning in connection with $NO_x$ reduction technologies
- Use of the technology for selective treatment of hazardous waste materials
- Use of a wood-chips gasifier to power an externally fired Stirling Engine

The two first applications are presently being studied for the preparation of demonstration in full scale. The third application has been demonstrated at 700 $kW_{TH}$ fuel input for Refuse Derived Fuel (RDF) pellets and for creosoted construction waste wood and railroad tiers – these are presently in the process of being demonstrated in industrial scale. The fourth application is presently in the process of being optimised in connection with a 40 $kW_E$ Stirling Engine Combined Heat and Power system (Ansager, Jutland, Denmark).