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GASIFICATION-BASED ENERGY PRODUCTION SYSTEMS FOR DIFFERENT SIZE CLASSES – POTENTIAL AND STATE OF R&D

Abstract
Different energy production systems based on biomass and waste gasification are being developed in Finland by VTT and it's industrial partners. In 1986-1995 the Finnish gasification R&D activities were almost fully devoted to the development of simplified IGCC power systems suitable to large-scale (>50 MWe) power production based on pressurised fluid-bed gasification, hot gas cleaning and a combined-cycle process. The technical feasibility of this technology was shown in extensive PDU and pilot tests and at the small-scale demonstration plant operating in Värnamo, Sweden. In mid-1990's the atmospheric-pressure gasification activities aiming to small and medium size plants was restarted in Finland. Atmospheric-pressure fixed-bed gasification of wood and peat was commercialised for small-scale (<10 MWth) district heating applications already in 1980's. Today the aim of R&D in this field is to develop a combined heat and power plant based on the use of cleaned product gas in internal combustion engines. Another objective is to enlarge the feedstock basis of fixed-bed gasifiers, which at present are limited to the use piece-shaped fuels such as sod peat and wood chips. Intensive R&D is at present also focused to atmospheric-pressure circulating fluidized-bed gasification of biomass residues and wastes. This gasification technology earlier commercialised for lime-kiln applications is now aiming to co-utilise locally available residues and wastes in existing pulverised coal fired boilers. The first demonstration plant is under construction in Finland and there are several projects under planning or design phase in different parts of Europe. The research at VTT in this field is related to the gasification of biofuels which have problematic ash behaviour and to the gas cleaning from alkali/heavy metals and chlorine.

Background
In the late 1970s, the Energy Department of the Finnish Ministry of Trade and Industry initiated several research and development projects on the gasification of indigenous fuels. The R&D work in the early 1980s was related to simple atmospheric-fuel-gas applications, including a gasification heating plant, lime kilns and other close-coupled end-users, where no specific gas cleaning was required [1]. This development was accomplished in the mid-1980s by commercialisation of two atmospheric gasifiers.

Nine Bioneer updraft gasifiers, originally developed in co-operation by an SME company and VTT, were constructed in 1982 - 1986 with outputs of the order of 5 MWth. These gasifiers are coupled to district heating boilers and drying kilns [2]. The Pyroflow circulating fluidised-bed (CFB) gasifier (developed by A.Ahlstrom Corporation) was also commercialised in the mid-1980s, when four gasifiers in the output range of 15 - 35 MWth were constructed. The product gas from these gasifiers is used for fuelling lime-reburning kilns of pulp factories [3, 4]. Both the Pyroflow and Bioneer gasifiers have been very successful and most of the plants are still in commercial operation.

In the late 1980s, the interest in integrated gasification combined-cycle (IGCC) power plants increased in Finland as in many other countries [5]. The Finnish R&D was mainly focused on the development of simplified IGCC processes based on pressurised air gasification and hot gas cleaning. The main potential of this technology is in medium-scale combined heat and electricity production (from 20 to 150 MWe), and the driving force of this development in Finland was the need for higher power-to-heat ratios in cogeneration, since the heat loads in district heating and process industry are no longer increasing whereas the consumption of electricity still grows.

However, the economic competitiveness of IGCC technology requires so large plant sizes (>30 -50 MWe) that this technology is not feasible in all applications utilising biomass. The conventional fluidised-bed combustion has become commercially available also in a relatively small scale (5 MWe), but this technology has a rather low power-to-heat ratio and consequently its potential is limited to applications with district or process heat as the main product. Thus, there is also a real need to develop more efficient methods for small-scale power production from biomass. one of two alternatives having clearly higher power-to-heat ratios than can be reached in conventional steam cycles [10] is a gasification diesel power plant (the other one is pyrolysis oil based diesel). In the 1980s, gasification diesel power plant technology was developed by Wärtsilä and Ahlstrom Corporations in Finland and by Studsvik Ab in Sweden. The main technical problem of the earlier gasification-diesel R&D activities was gas cleaning from condensable tars. As part of the hot gas cleaning R&D for IGCC applications, VTT has extensively studied catalytic gas cleaning methods, and promising results have been achieved both with a nickel-based monolith catalyst and calcium-based granular bed reactors. the catalytic gas cleaning experience of VTT is presently utilised in developing efficient methods for tar removal in atmospheric-pressure engine applications.

In addition to the diesel power plants, there are several other interesting applications for atmospheric-pressure gasification technology. One of the most interesting alternatives for cost-effective biomass utilisation is co-firing of biomass-derived product gas in existing pulverised coal fired boilers. This concept is being developed by VTT and Foster Wheeler Energia Oy (former A. Ahlstrom Pyropower) in Finland.

Pressurised fluidized-bed gasification research to support the development of simplified IGCC processes

The main market for biomass-based IGCC plants is in combined heat and electricity production in a medium-size range (30 - 100 MWe). In this size range the IGCC based on oxygen-blown gasification and multistage wet gas cleaning is not economically attractive and, consequently, more simple process configurations are needed to keep the specific investment costs at a reasonable level. The most promising process alternative is the so-called simplified IGCC based on air gasification and subsequent hot gas cleaning.

Several Finnish companies have undertaken significant process development work related to IGCC technology. This development work is supported by research projects conducted at VTT and at Finnish universities.

Enviropower Inc. developed a simplified IGCC process based on the U-GAS coal gasification process, originally developed by the Institute of Gas Technology, USA. The process concept is based on air-blown fluidized-bed gasification and hot gas cleanup and the technology is developed both for biomass and coal feedstocks. The gasification and hot gas cleaning steps of the process were demonstrated during extensive test series carried out at a 15 MWth pressurised pilot plant in 1991 - 1995 [6]. Presently, the process is being further developed and commercialised by Carbona Inc., which is planning to construct a full-scale IGCC demonstration plant in India using Indian lignite as the fuel [7].

Another major IGCC development programme was undertaken by A. Ahlstrom Corporation (presently Foster Wheeler Energia Oy) and the Swedish utility company, Sydkraft. These companies decided in 1991 to start jointly the development of the Bioflow Energy System based on IGCC technology utilising biomass as fuel. The first step in this co-operation was the construction of a small (6 MW electricity and 9 MW district heat) at Värnamo in southern Sweden [8, 9]. This process is based on pressurised air-blown Pyroflow circulating fluidised-bed gasifier and on dry gas cleaning carried out at about 350 °C.

In the most simple case of the IGCC concept [5], biomass is gasified in a bubbling or circulating fluidized-bed at a temperature of 800 - 1 000 °C and at a pressure of 1.8 - 2.5 MPa, and the produced fuel gas is first cooled to 350 - 550 °C and then cleaned from particulates and condensed alkali metals by ceramic filters before leading into the combustion chamber of the gas turbine. Perhaps the most critical technical questions of this process concept are the formation of contaminants (particulates, alkalis, tars and nitrogen-containing compounds) in the gasification of different biomass feedstocks, and the removal of these contaminants in a both environmentally and economically acceptable way. Almost complete removal of particulates and alkalis is required to protect the gas turbine blades from erosion and corrosion. In some operation conditions tars may block gas coolers and ceramic filters due to condensing or polymerising to soot-like deposits. Ammonia and hydrogen cyanide, on the other hand, are potential sources of fuel-bound NOx emissions when the gas is combusted.

Since 1988, different laboratory, bench-scale and PDU test facilities of VTT have been used to study the most critical technical questions of the simplified IGCC processes. However, the most essential part of the work has been carried out at the Process Development Unit (PDU) designed for the R&D of pressurised fluidised-bed gasification and hot gas cleanup for gas turbine applications (Table 1). In the PDU gasifier, the solid feedstock is fed into the bottom part of a bed, which is fluidised by the primary gasification agents, air and a small amount of steam. The product gas after pre-cleaning in the cyclones is first cooled to 350 - 750 °C and then led into the ceramic filter unit, where the particles and condensed alkali metals are removed.

A wide range of feedstocks from hard coals, lignite and peat to different wood-derived fuels and straw have been used in the gasification tests carried out in 1988 - 1996. The main conclusion from this work is that the technical feasibility of the gasification and hot gas cleaning steps of the simplified IGCC process has been demonstrated in a PDU scale with a wide range of biomass, peat and coal feedstocks. The product gas derived from these feedstocks can be cleaned from particulates and alkali metals by ceramic filters operated at an intermediate temperature of 350 - 550 °C. During gas cooling and filtration the volatilised alkali metals react into condensed products, which can be removed together with dust particles to such a degree that the very stringent gas cleaning requirements set by the gas turbines are met.

Table 1. Technical data and operation experience of the PFG test facility of VTT Energy.

Bed-I.D.	15 cm	Feedstocks gasified:	
Freeboard-I.D.	25 cm	- Sawdust and wood wastes	
Reactor height	4.2 m	- Straw	
bed	1.2 m	- Different peat products	
freeboard	3.0 m	- Rhenish brown coal	
		- Hard coals: Iowa-Rawhide, Polish coal,	
Operating pressure	2.5 - 10 bar	Illinois No. 6, Colombian coal	
Bed temperature	700 - 1 000 °C	Total gasification test time	2 300 h
Freeboard t (max)	1 100 °C	Number of measured set points	160
Fluidising velocity	0.5 - 1.5 m/s	Amount of gasified fuels	110 ton
Gasification agents	Air, steam	Fuel feed rate (max)	80 kg/h

Detailed results concerning different research topics are available from the following references:

– Fluidized-bed gasification of wood, peat and coal [11 - 14]
– Formation of tars in gasification [12, 15 - 18]
– Fate of fuel nitrogen in gasification processes [12, 18, 44 - 47]
– Hot gas filtration [19 - 23]
– Fate of alkali metals in gasification and gas filtration [12 - 14, 24, 25]
– IGCC system studies [10, 26]
– Fuel feeding and safety issues of pressurised fuel handling [27, 28]

At present the aim of the pressurised gasification R&D work of VTT is to improve further the IGCC process concept. The work comprises the following tasks:

- Cogasification of coal and different biomass fuels: methods for increasing carbon conversion, formation and removal of gas contaminants.
- Further development of hot gas cleaning methods for IGCC applications: development of SCO process for ammonia removal and further activities on the removal of particulates and alkali-metals.
- Experimental research to support the ongoing and planned industrial demonstration projects.
- Special measurements at industrial demonstration and pilot plants.
- Feasibility studies, feedstock characterisation and PDU tests for industrial clients, who are planning new IGCC projects.

Atmospheric-pressure biomass/waste gasification for co-firing in PC-boilers

Atmospheric-pressure gasification of biomass and waste fuels and co-firing of produced gas in large utility boilers is a promising and cost-effective method for reducing the CO_2 emissions of coal-based energy production in short and medium time scale. The commercialisation of cogasification technologies will also promote the development and commercialisation of advanced biomass-based power production systems, such as IGCC, which in the longer run have a key role in the global renewable intensive energy scenarios.

The woody residues of mechanical and chemical wood industry as well as other high quality woody biofuels can be co-combusted with coal in existing fluidised-bed boilers or even in pulverised combustors [29, 30] without major problems. On the other hand, extensive full-scale test programmes carried out with straw in Denmark [31] and with various agrobiofuels in the United States [32] have clearly shown the limitations of this type of co-combustion methods. Many potential biomass feedstocks, such as straw, have a problematic ash melting behaviour, which causes sintering and fouling problems in combustors. Straw and many fast-growing energy crops as well as industrial and municipal waste fuels often contain high amounts of chlorine and alkali metals, which have a tendency to cause severe corrosion problems in coal-fired boilers. This problem can be assumed to be more severe in the modern plants where supercritical steam values are utilised.

Perhaps the most critical factor controlling possibilities for direct co-firing of these problematic biofuels in large PC boilers is the usability of coal ash for cement industry and construction purposes. demolition wood waste is another example of a locally important renewable feedstock, which is difficult to be introduced into ordinary coal-based combustion plants due to the relatively high content of heavy metals (Zn, Pb, Cd) and chlorine.

In principle, there are three main technical solutions to avoid sintering, corrosion and ash problems in co-utilisation of problematic biofuels in large coal-fired power plants:

1. Construction of a smaller separate boiler with low steam values for the biofuels and superheating the steam of the biomass boiler in the coal-fired boiler,
2. Production of pyrolysis oils from the biomass, and
3. Gasification of biomass and combustion of cleaned product gas in the boiler.

The concept based on gasification has several advantages over the other alternatives. First of all the gasification reactor, bubbling or circulating fluidised-bed, is simpler and much cheaper than the complete fluidised-bed boilers with steam cycles or complete pyrolysis oil production plants. Secondly, the product gas can be cleaned from trace metals, chlorine and other harmful contaminants prior to leading into the coal-fired boiler. Depending on the feedstock quality and on the requirements for contaminant control different gas cleaning methods from simple hot cyclones to effective low-temperature filtration can be used. Thirdly, the separation of gasification and gas combustion makes it possible to maintain stable high-temperature combustion in order to minimise risks for the formation of dioxines and other chlorinated organic compounds. Finally, the biomass-derived gas may even have positive effects also on the NOx emissions if it is introduced to the coal-fired boiler as a reburning feedstock [33].

When this co-firing concept is compared to other gasification-based power plant systems, the following conclusions can be drawn: a) Co-firing concept is suitable to a lower size class than simplified IGCC plants based on pressurised gasification. b) Atmospheric-pressure gasification can be utilised and thus, the feeding of low bulk density biofuels is simpler and cheaper than in pressurised gasification processes. c) The heating value of the gas can be lower than in IGCC applications or diesel power plants, since gas combustion is easier to arrange; this gives more freedom in selecting the operation conditions of the gasifier for the problematic biofuels. d) The requirements for gas cleaning are not as stringent as in diesel engines (total tar removal) or in gas turbines (total filtration and alkali removal).

At present, there are a lot of on-going activities in Europe aiming at the demonstration and commercialisation of this promising co-utilisation concept. Almost all activities are based on Circulating Fluidised-Bed gasifiers. Supporting R&D for this co-utilisation method was started at VTT in 1995 by the construction of a PDU-scale CFB gasification and hot gas cleaning test rig (Fig. 1).

There are also several demonstration projects under planning in different parts of Europe. In the Netherlands, the power producing company EPZ is planning to build a 55-80 MWth gasifier to be connected to one of the large coal-fired boilers. This project is also supported by the Thermie Programme of EC. The main feedstock of this plant is contaminated wood waste from demolition activities and the gas contaminants are removed by intermediate temperature filtration prior to leading the gas into the boiler. Another Thermie-supported project is realised in Finland by Lahden Lämpövoima Oy (local energy company) and Foster Wheeler Energia Oy. A wide range of local wood

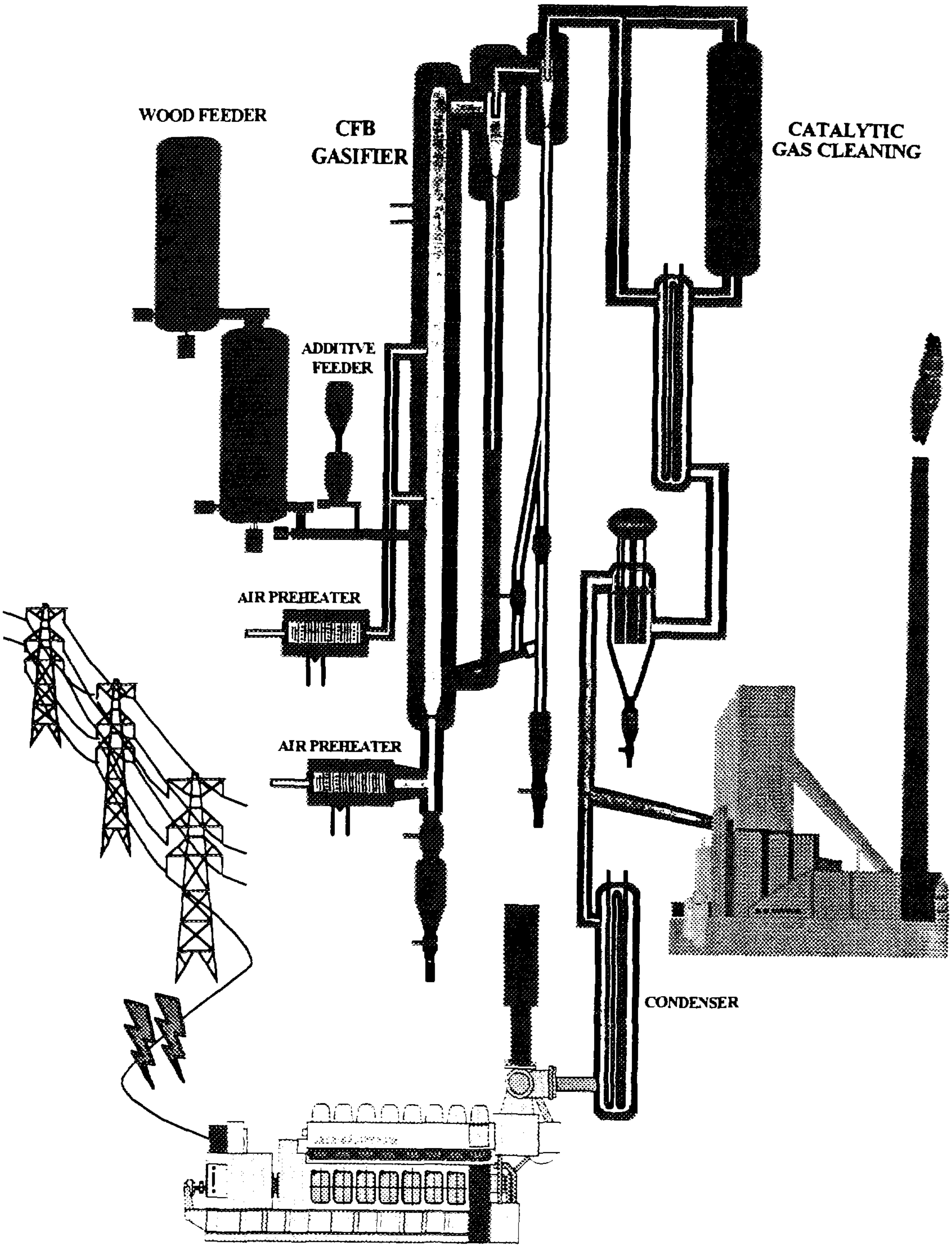

Figure 1. Schematic diagram of the atmospheric-pressure CFB gasification test rig of VTT Energy.

residues and waste materials will be gasified in a CFB reactor and the gas is combusted in an existing coal-fired combined heat and power plant. This plant is under construction and the start-up is scheduled for early 1998.

The ongoing R&D programme of VTT on this co-firing concept includes the following topics:

- CFB gasification of agrobiofuels having a problematic ash sintering behaviour
- CFB gasification of waste fuels (contaminated waste wood, plastics, RDF, etc.)
- Decomposition of tars, which is required if the gas has to be cooled (and filtered) before leading into the boiler
  - Removal of particulates, alkali and heavy metals and chlorine
  - Overall system studies.

Development of small-scale chp systems based on fixed-bed gasification and internal combustion engines

The starting points for the present R&D on small-scale gasifies were the following earlier experiences:

- Reliable commercial operation experiences with Bioneer updraft gasifiers close-coupled to boilers and drying kilns; suitable feedstocks: sod peat and wood chips. This technology is commercially available for heat only production. Combined heat and power production based on small steam cycles could also be realised but is rather expensive and has a low power to heat ratio.
- Unsuccessful experiences with downdarft gasifiers coupled to engines: limitation to high quality wood blocks or charcoal. Severe tar problems and/or ash-related problems with real feedstcoks.
- Very large potential for small-scale chp plants using different kind of wood residues and agrobiofuels.

The present development project is supported by the Joule 3 programme of the European Commission and it has two main goals: a) the development of a new type of gasifier which is suitable also to low-bulk density biofuels which cannot be used in present fixed-bed gasifies, and) the development of catalytic gas cleaning method which produces tar-free gas suitable to engine use.

The role of catalytic tar decomposition is very essential in the engine applications of biomass gasification, because the product gas has to be cooled to about 30-50°C and the tars condensable at this temperature have to be completely removed for avoiding blocking problems in the engine inlet system. Water scrubbing of tarry product gas is not a practical solution at least in the small scale due to the complexity and high costs of waste water treatment.

The catalytic gas cleaning research at VTT was initiated in the mid-1980s and since then the following activities have been carried out:

- Screening of the catalytic activity of cheap bulk materials (limestones, dolomites, iron-based wastes) as well as commercial catalysts: Tests in a portable bench-scale fixed-bed reactor using a slip stream of commercial-scale updraft gasifier [34 - 36].
- Testing of calcium-based materials and nickel catalysts with the product gas of the pressurised fluidised-bed PDU [17,18].
- Fundamental studies on catalytic tar decomposition and on poisoning of the catalysts [37, 38]
- Development and slip stream testing of a nickel monolith catalyst in pressurised gasification applications [39, 40]
- Techno-economic studies of catalytic gas cleaning in IGCC and engine applications [40].
- Design and construction of two different full-scale catalyst reactors (nickel monoliths and a calcium-based reactor) for the atmospheric-pressure CFB gasification PDU facility (1996 - 1997).

In the present project the catalytic gas cleaning expertise of VTT is used for the development of the tar removal process for fixed-bed gasifiers. The work will be carried out in 1997-99 using a new pilot plant to be operated at VTT in Espoo. If the goals of the project will be reached, the system will be ready for demonstration in early 1999.

Feedstock characterisation for gasification

In addition to actual gasification and gas cleaning R&D VTT is also carrying out feedstock characterisation work using different laboratory and bench-scale test facilities. The main topics of this work have been the following:

- Reactivity and pyrolysis behaviour of biofuels and coals in gasification conditions [41, 42]
- Ash behaviour in fluidised-bed gasification and combustion [43, 44]
- Development of analysis and characterisation methods for biomass feedstocks and collection of data base for biofuels [48].

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