STATE-OF-THE-ART AND FUTURE DEVELOPMENTS REGARDING SMALL-SCALE BIOMASS CHP SYSTEMS WITH A SPECIAL FOCUS ON ORC AND STIRLING ENGINE TECHNOLOGIES

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ABSTRACT: Within the scope of a comprehensive study and two development and demonstration projects, various technologies in the power range of up to 2 MW_{el} for small-scale biomass-fired CHP plants have been investigated, evaluated and compared considering technical as well as economic aspects. Such plants should normally be operated on a heat-controlled basis in order to achieve a high overall efficiency and should run for more than 5,000 annual full load operating hours to ensure economical operation. Two of the technologies examined are very promising and innovative: the *Organic Rankine Cycle* (ORC) process and the *Stirling engine* process.

The ORC process represents an economically interesting technology for small-scale biomass-fired combined heat and power plants in a power range between 400 and 1,500 kW_{el}. A newly developed ORC technology with a nominal electric capacity of 1,000 kW was implemented in the biomass CHP plant Lienz (A) in the framework of an EU demonstration project. This plant was put in operation in February 2001. Stirling engines are a promising solution for installations with nominal electric capacities between 10 and 150 kW. A biomass CHP pilot plant based on a 35 kW_{el}-Stirling engine was developed and put into operation in the end of summer 2002. Up to the end of June 2003 the plant has run for more than 4,300 hours with very promising results.

Keywords: Biomass combustion, combined heat and power (CHP), Organic Rankine Cycle (ORC) process, Stirling engine process.

1 INTRODUCTION AND OBJECTIVES

Some innovative technologies for electricity production in the power range of up to 2 MW_{el} have recently been newly developed or improved, thus rendering them suitable for application in small-scale biomass-fired CHP plants. In a study various CHP technologies have been investigated, evaluated and compared considering technical (technical side constraints, operating characteristics, process control, partial load behaviour, maintenance requirements, environmental aspects, state of development) as well as economic (investment and electricity production costs) aspects [1]. Among them are two innovative technologies based on biomass combustion which are of high interest for small-scale biomass CHP plants. These technologies are the *Organic Rankine Cycle* (ORC) process and the *Stirling engine* process.

The ORC process has attained a high level of development and demonstration units are already in operation. This technology is applicable for small-scale biomass CHP plants with nominal electric capacities between 400 and 1,500 kW.

For small-scale CHP systems using biomass as fuel Stirling engines are a promising solution for installations with nominal electric capacities between 10 and 150 kW.

The objective of this paper is to give an overview about the state-of-development, about the operating experiences already obtained as well as about the future development potential of these two innovative small-scale biomass CHP technologies. Moreover, the paper points out the constraints which have to be considered or which are given when implementing a small-scale biomass CHP plant.

2 TECHNOLOGIES AND CONSTRAINTS FOR THE APPLICATION OF SMALL-SCALE BIOMASS CHP PLANTS

Typical fields of application for small-scale biomass-fired CHP plants are wood-processing industries and sawmills, district heating systems (newly erected or retrofitted systems) as well as industries with a high process heat demand. These applications represent a great market potential in Europe. Due to the relatively low electric efficiency achievable with small-scale CHP plants, a basic requirement for an ecological and cost-effective operation of such plants is that not only the electricity but also the heat produced can be utilised as process or district heat (heat-controlled operation of the overall system).

The following technologies are available for CHP plants based on biomass combustion:

- Steam turbine process
- Steam piston engine process

- Screw-type engine process
- ORC process
- Gas turbine processes
- Stirling engine process

Fixed-bed gasification processes also represent a future potential for small-scale biomass CHP plants but have not yet achieved a level of development which allows commercial application.

Depending on the amount of full-load operating hours, the size of the CHP plant and the biomass fuel price, small-scale biomass-fired CHP plants can produce electricity at costs between 70 and 150 €/MWh$_{el}$ (no investment subsidies considered). The steam processes and the ORC process are presently the best developed and the most economical systems available. The most important influencing variable on electricity production costs are the annual full load operating hours of the CHP plant. For economic operation a minimum value of 5,000 hours can be recommended which shows the importance of an optimal "sizing" of the CHP unit according to the annual heat output line.

3 ORC PROCESS

3.1 Description of technology

The principle of electricity generation by means of an ORC process corresponds to the conventional Rankine process. The substantial difference is that instead of water an organic working medium with favourable thermodynamic properties is used [1,2,3]. The working principle and the different components of the ORC process are shown in Figure 1. The ORC process is connected with the thermal oil boiler via a thermal oil cycle. The ORC unit itself operates as a completely closed process utilising a silicon oil as organic working medium. This pressurised organic working medium is vaporised and slightly superheated by the thermal oil in the evaporator and then expanded in an axial turbine which is directly connected to an asynchronous generator (see Figure 1). Subsequently, the expanded silicon oil passes through a regenerator (where in-cycle heat recuperation takes place) before it enters the condenser. The condensation of the working medium takes place at a temperature level which allows the heat recovered to be utilised as district or process heat (hot water feed temperature about 80 to 100°C). The liquid working medium then passes the feed pumps to again achieve the appropriate pressure level of the hot end of the cycle.

In order to obtain a high electric efficiency (= net electric power produced / thermal power input) of the ORC unit itself, it is necessary to keep the back-pressure of the turbine as low as possible and thus to minimise the necessary temperature for district heat utilisation at the condenser of the ORC plant (approximately 80 °C feed water temperature). This can be achieved by optimising the operation and control of the district heating network in order to keep the necessary feed-water temperature as low as possible as well as by an optimised hydraulic integration of the ORC in the district heating network. In order to achieve this goal, the ORC should be directly connected to the return of the district heating network and the feed water temperature at the ORC outlet should be kept as low as possible by placing the hot water economiser and the hot water boiler downstream of the ORC (see section 3.2, Figure 2 and Figure 3). Following this approach, the ORC can be operated at feed-water temperatures of about 80°C the whole year round, although the feed-water temperature required for the district heating network amounts to 90 to 95 °C in winter. ORC plants are relatively silent (the highest noise emissions occur at the encapsulated generator and amount to about 85 dB(A) at a distance of 1 m.

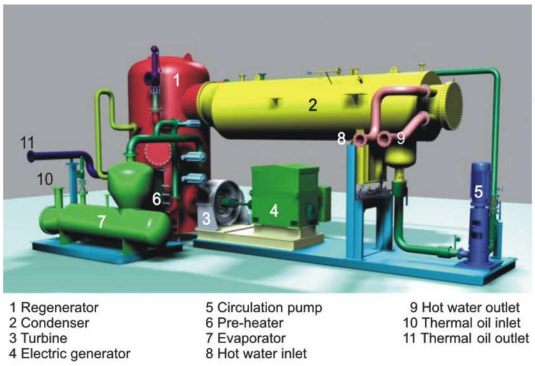

Figure 1. View of an ORC plant. Source: TURBODEN Srl, Brescia, Italy.

Since the cycle of the ORC process is closed and thus no losses of the working medium are possible, the operating costs are low. Only moderate consumption-based costs (lubricants) and maintenance costs are incurred. The usual lifetime of ORC units is greater than twenty years, as has been proven by geothermal applications. The silicone oil used as working medium has the same lifetime as the ORC since it does not undergo any relevant ageing.

3.2 EU demonstration project Lienz with optimised ORC process integration

The biomass CHP plant in Lienz is located in East Tyrol, Austria, and supplies the town of Lienz with district heat (see Figure 2) [4]. It started operation in autumn 2001 and will cover the heat requirement of approximately 70 % of all buildings in the supply area by the end of 2003. The residential and industrial heating systems replaced are mainly oil-fired boilers which results in a considerable CO_2 reduction.

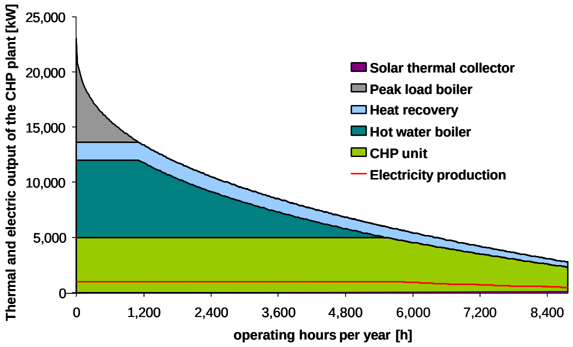

Figure 2. Annual heat and electricity output line for the final stage of development of the district heating network – biomass CHP plant in Lienz

Figure 2 shows the annual heat and electricity output line for the biomass CHP plant in Lienz. The thermal oil boiler with a nominal capacity of 6,000 kW$_{th}$ covers the base load, the hot water boiler with a nominal capacity of 7,000 kW$_{th}$ is additionally in operation for medium load coverage and the peak load is covered by a fuel oil fired boiler with a nominal capacity of 11,000 kW$_{th}$ (see Table 1). The thermal oil boiler supplies the ORC process with heat. The heat recovery unit with a nominal capacity of 2,000 kW$_{th}$ comprises a thermal oil economiser, located downstream of the thermal oil boiler, and a hot water economiser which recovers energy from the flue gases of both biomass-fired boilers. The heat recovery unit increases the overall plant efficiency. The solar collector panel located on the roof of the plant has a surface area of 630 m² and achieves a thermal power of up to 350 kW$_{th}$ (see Table 1).

The main innovative part of the new biomass CHP plant in Lienz is the ORC process with a nominal electric capacity of 1,000 kW$_{el}$ and a nominal thermal capacity of 4,400 kW$_{th}$. The relevant technical data of the ORC process are listed in Table 1. The ORC was manufactured and supplied by TURBODEN Srl, Brescia, Italy.

Table 1. Technical data of the biomass CHP plant Lienz

Technical data of the biomass CHP plant		
Solar thermal collector	630	m^2
Nominal power - thermal oil boiler	6,000	kW
Nominal power - thermal oil economiser	500	kW
Nominal power - hot water boiler	7,000	kW
Nominal power - hot water economiser	1,500	kW
Nominal power - oil boiler (peak load)	11,000	kW
Maximal thermal power - solar collector	350	kW
Production of heat from biomass	60,000	MWh/a
Production of heat from solar energy	250	MWh/a
Production of electricity from biomass	7,200	MWh/a
Technical data of the ORC process		
Thermal power input - ORC at nominal load	5,560	kW
Net electric power output - ORC at nominal load	1,000	kW
Thermal power output - ORC at nominal load	4,440	kW
Net electric efficiency - ORC at nominal load	18	%
Thermal efficiency at nominal load	80	%
Electric and thermal losses	2	%
Heating medium	Thermal oil	
Inlet temperature	300	°C
Outlet temperature	250	°C
Working medium	Silicon oil	
Cooling medium	Water	
Inlet temperature	80	°C
Outlet temperature	60	°C

The overall electric efficiency of the CHP plant (= net electric power produced / fuel power input into the biomass-fired thermal oil boiler [NCV]) has been considerably increased by a new and improved approach of coupling of the thermal oil boiler with a thermal oil economiser and an air preheater (see Figure 3). Using this approach, the thermal efficiency of the biomass-fired thermal oil boiler reaches 82% (= thermal power output / fuel power input [NCV]), which is about 10% higher than corresponding values from conventional biomass-fired thermal oil boilers [5]. This increased thermal efficiency correspondingly also raises the overall electric efficiency of the CHP plant (= net electric power produced / fuel power input into the biomass-fired thermal oil boiler [NCV]) to about 15% (see Figure 4).

The ORC unit in the biomass CHP plant in Lienz has been in successful and almost continuous operation since February 2002. According to operation data already evaluated, the net electric efficiency of the ORC plant amounts to 18% at nominal load and about 16.5% at 50% partial load at feed water temperatures of 85°C (see Figure 7). This underlines the excellent partial load behaviour of this technology.

The internal electric power demand of the ORC for the feed pumps amounts to about 60 kW at nominal load and constitutes the difference between the gross and the net electric power output of the plant. Thus, the gross electric efficiency of the ORC is about 19% at nominal load.

Furthermore, the measurement data already obtained clearly show that the ORC plant can be operated at up to 120% of its nominal electric power, which is an additional advantage during the winter months.

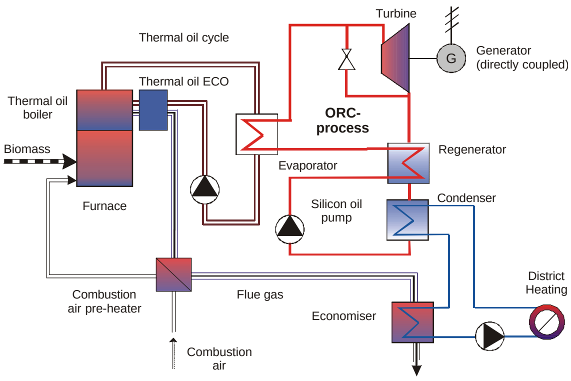

Figure 3. Working principle of the biomass-fired ORC process in Lienz

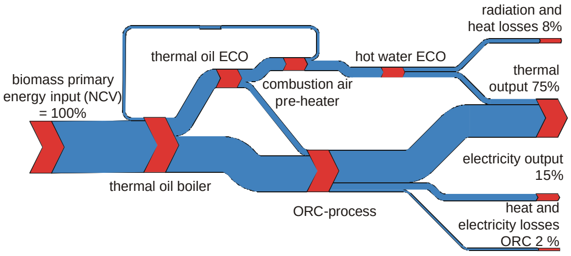

Figure 4. Energy balance of the biomass CHP plant in Lienz

The biomass-fired thermal oil boiler, the thermal oil economiser and the air preheater are equipped with an automatic cleaning system based on pressurised air. This system has already proved its good performance: during the first nine months of operation no manual boiler cleaning was necessary and boiler operation took place without rising flue gas temperatures at the boiler outlet.

Based on the project in Lienz and on experiences with other biomass CHP applications, comprehensive investigations concerning the economy of small-scale biomass CHP plants have been performed. The calculation of the production costs for electricity is based on the VDI guideline 2067. This cost calculation scheme distinguishes four types of costs: capital costs (depreciation, interest costs), consumption based costs (fuel, auxiliary energy, consumables), operation-based costs (personnel costs, costs for maintenance) and other costs (administration, insurance).

The capital costs are based on additional investment costs (about 380 €/kW$_{el}$ for a 1,000 kW$_{el}$ ORC plant) , and consider only the surplus investment costs of a CHP plant in comparison to a conventional biomass combustion plant with a hot water boiler and the same thermal output. The additional investment costs form the correct basis for the calculation of the electricity production costs of a CHP plant. A clear distinction between heat and electricity related costs is also made for all the other types of costs in order to ensure a correct calculation.

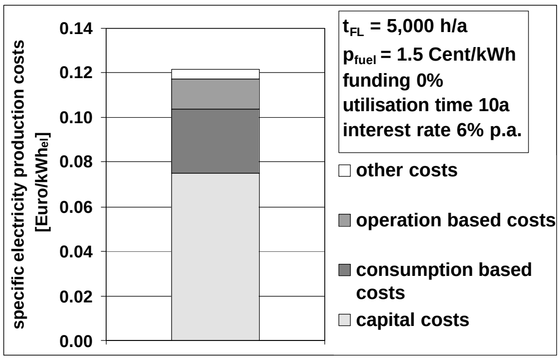

Figure 5. Specific electricity production costs of a biomass-fired CHP plant based on a 1,000 kWel ORC process

As shown in Figure 5 the specific electricity production costs calculated amount to approx. 0.12 €/kWh$_{el}$. For an ORC unit with a nominal electric capacity of 500 kW and the same basic conditions, the specific electricity production costs increase by approximately 15% mainly due to higher specific investment costs (economy-of-scale effect). The most relevant cost factor are the capital costs, representing more than 60% of the overall specific electricity production costs. The fuel costs, the second relevant influencing parameter, account for about 20% of the specific electricity production costs.

3.3 State-of-the-art and future development of the ORC process

The new biomass CHP technology based on the ORC process is an economically and technologically interesting solution for small-scale applications [6, 7].

At present, the ORC technology represents the state-of-the-art and is available on the market. Compact ORC modules are available in container size with nominal capacities between 400 and 1,500 kW$_{el}$.

Further biomass CHP projects based on the ORC technology already implemented or in the implementation stage are located in Fussach (A) (nominal electric capacity 1,100 kW), near Vienna (nominal electric capacity 1,000 kW) and in Toblach (I) (nominal electric capacity 1,500 kW). Future developments focus on a further improvement of the electric efficiency by two-stage ORC cycles as well as by combined hot air turbine - ORC cycles.

4 STIRLING PROCESS

3.1 Description of technology

Stirling engines are based on a closed cycle, where the working gas is alternately compressed in a cold cylinder volume and expanded in a hot cylinder volume. The advantage of the Stirling engine over internal combustion engines is that the heat is not supplied to the cycle by combustion of the fuel inside the cylinder, but transferred from the outside through a heat exchanger in the same way as in a steam boiler. Consequently, the combustion system for a Stirling engine can be based on proven furnace technology, thus reducing combustion related problems typical of solid biomass fuels. The heat input from fuel combustion is transferred to the working gas through a hot heat exchanger at a high temperature typically between 680 °C and 780 °C. The heat that is not converted into work on the shaft is rejected to the cooling water in a cold heat exchanger at 25 °C - 75 °C.

In order to obtain a high overall electric efficiency of the CHP plant, the temperature in the hot heat exchanger should be as high as possible. Therefore, it is necessary to preheat the combustion air with the flue gas leaving the hot heat exchanger by means of an air preheater. Typically the temperature of the combustion air is raised to 500 °C – 600 °C, resulting in very high temperatures in the combustion chamber. This can cause ash slagging and fouling problems in biomass combustion systems and in the hot heat exchanger.

The closed Stirling cycle makes it possible to use a working gas, which is better suited for heat transfer to and from the cycle than air. The use of Helium or Hydrogen is most efficient, but utilisation of these low molecular weight gases makes it difficult to design a piston rod seal, which keeps the working gas inside the cylinder and prevents the lubrication oil from entering the cylinder. Many solutions have been tested, but it is still a delicate component in the engine. An attractive possibility is to bypass the problem by designing the engine as a hermetically sealed unit with the generator incorporated in the pressurised crankcase, just like the electric motor in a hermetically sealed compressor for refrigeration. Only static seals are necessary and the only connections from the inside to the outside of the hermetically sealed crankcase are the cable connections between the generator and the grid.

The problems concerning utilisation of biomass fuels in connection with a Stirling engine are concentrated on transferring the heat from the combustion of the fuel into the working gas. The temperature must be high in order to obtain an acceptable specific power output and efficiency, and the heat exchanger must be designed so that problems with fouling are minimised.

Because of the high temperatures in the combustion chamber and the risk of fouling, it is not possible to utilise a Stirling engine designed for natural gas, as narrow passages in the hot heat exchanger are blocked after less than an hour of operation with biomass fuels. The risk of fouling in biomass combustion processes is mainly due to aerosol formation and condensation of ash vapors when the flue gas gets cooled [8].

3.2 Biomass CHP plant based on a 35 kW$_{el}$ Stirling engine

A Stirling engine especially designed for CHP plants using biomass fuels has been developed at the Technical University of Denmark. The design of the Stirling engine is based on numerical optimisation of more than 20 parameters describing cylinders, heat exchangers, regenerators etc. [9]. The engine, which is designed for a nominal electric capacity of 35 kW, has four cylinders arranged in a square with the cylinders parallel to each other. Helium is used as working gas at a maximum mean pressure of 4.5 MPa. The four hot heat exchangers (one for each cylinder) are designed as panels forming a square combustion chamber, where radiation from the combustion is transferred directly to the panels. Narrow passages in the hot heat exchanger sections are avoided in order to adapt the system to flue gases from combustion systems fired with solid fuels.

The engine is designed as a hermetically sealed unit. The built-in asynchronous generator, which is also used as starter motor, has 6 poles corresponding to an engine speed of approximately 1000 rpm when coupled directly to the power grid (50 Hz AC).

The design of the SM3C Stirling engine for the plant described here is based on experiences from a first and a second prototype, which have already been tested. The first prototype, SM3A, was tested for more than 1,400 hours with wood chips as fuel, before the tests had to be stopped due to mechanical problems [10]. The second engine, SM3B, was improved considerably compared to the first engine, and the test results were very satisfactory [11].

Table 2. Specifications of the 35 kW$_{el}$ Stirling engine

Nominal electric power	kW	35
Bore	mm	142
Stroke	mm	76
Number of cylinders		4
Speed	rpm	1,010
Mean pressure	Mpa	5
Working gas		Helium
Heater temperature	K	1,020
Engine weight		1,600

The specifications of the new Stirling engine are shown in Table 2. The improvements of this engine compared to the first and the second prototype are improved reliability of the crank mechanism, improved cooling of the piston rod seals and a new design of the hot heat exchanger.

The dimensions of the yokes in the patented crank mechanism were increased in order to improve rupture strength. Furthermore, several bearings were replaced with a larger type, thus improving the lifetime of the engine.

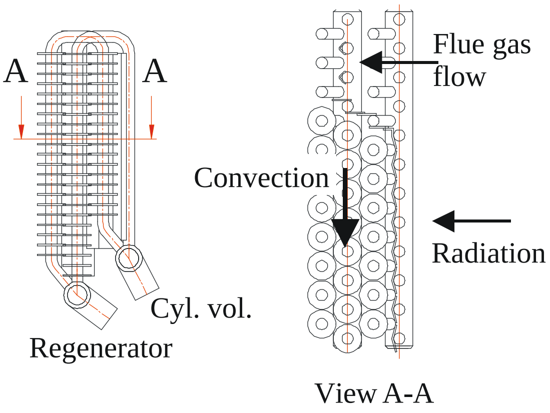

Figure 6. Sketch of hot heat exchanger panel

A new piston rod cooling system was tested on engine No. 2 (SM3B), but the design was very complicated. Cooling of the piston rod improves the lifetime of the seal and considerably extends service intervals, as the piston rod seal is a dynamic seal and thus subjected to the highest load. The new engine is also provided with piston rod coolers, but the system has been considerably improved and the results have been very satisfactory. The objective is to obtain replacement intervals of 15,000 hours of operation.

The new design of the hot heat exchanger was necessary in order to adapt it to a maximum flue gas temperature in the combustion chamber of 1,300°C (the first and the second prototype were designed for flue gas temperatures of 1,600 °C). As a consequence of the reduction of the maximum temperature in the combustion chamber, the mass flow of flue gas had to be increased. Furthermore, less heat is transferred as radiation compared to the previous design.

Figure 7. 35 kW Stirling engine before installation in the furnace

The hot heat exchanger consists of 23 tubes with an outside diameter of 13.7 mm. The tubes are U-formed connecting the cylinder manifold with the regenerator manifold. In the old design, half of these tubes formed the radiation panel of the hot heat exchanger, while the other half were responsible for the convective heat transfer. As shown in Figure 6 the new design has only 12 half-tubes for the radiation part, while the remaining 36 half-tubes are used for convective heat transfer. Fins are used for enhancing the heat transfer area. Figure 7 shows the engine with the hot heat exchanger ready for installation in the furnace. The water-cooled generator, which is part of the hermetically sealed design, can be seen in front.

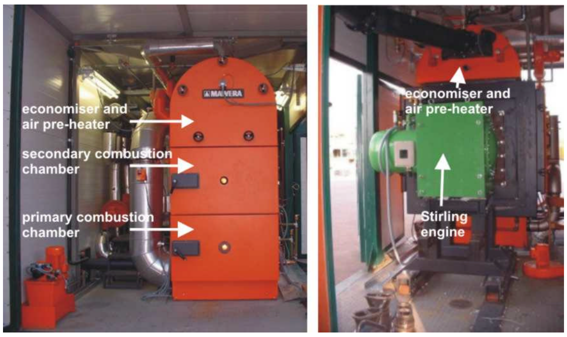

Figure 8: Pictures of the small-scale CHP pilot plant with a 35 kW$_{el}$ Stirling engine

A small-scale CHP plant for biomass fuels based on the Stirling engine described above was developed and designed in cooperation between MAWERA Holzfeuerungsanlagen GmbH, an Austrian Biomass furnace and boiler manufacturer, the Technical University of Denmark and BIOS BIOENERGIESYSTEME GmbH, an Austrian development and engineering company. The design of the furnace and its adaptation to the specific requirements of the 35 $\mathrm{kW_{el}}$ Stirling engine was an important and difficult task. The plant should operate at a high temperature level to increase the electric efficiency of the Stirling engine but temperature peaks in the furnace should be impeded in order to reduce ash slagging and fouling. The new combustion system was developed and optimised using CFD simulations of gas phase combustion.

Figure 8 shows a picture of the new CHP pilot plant. The furnace is equipped with underfeed stoker technology. The Stirling engine is mounted in a horizontal position downstream of the secondary combustion chamber for convenient maintenance (see Figure 8). The air preheater and the economiser are placed on top of the furnace in order to achieve a compact design of the plant. The CHP plant should not require substantially more space than a normal biomass combustion plant with the same heat output. To remove fly ash particles from the hot gas heat exchanger, a pneumatic and fully automatic cleaning system was developed and installed.

To keep the operating costs to a minimum, small-scale plants will have to run in unmanned operation for days or weeks. The system has therefore been fully automated. Any engine failure will be detected and the combustion system will immediately be shut down.

The plant was put into operation at the end of summer 2002 and has been running fully automatically since autumn 2002. The engine has run for more than 4,300 hours until the end of June 2003 and for more than 2,900 hours from the beginning of February to the end of June 2003 at a high load level. In this period, the average availability of the pilot plant was more than 80% , in May and June 2003 even more than 92%.

Table 3. Average results of test runs performed at the 35 $\mathrm{kW_{el}}$ pilot plant compared to design targets

		Design target	Obtained during test runs
Temperature of the preheated air	°C	550	360
Temperature of the cooling water at Stirling cooler inlet	°C	55	61
Electric power output	kW	35	31
Thermal power output - Stirling engine	kW	105	124
Thermal power output - CHP plant	kW	215	272
Fuel power input	kW	291	337
Fuel consumption (w.b.) (water content approx. 30 wt%)	kg/h	85	96
Electric efficiency - Stirling engine	%	25.0	20.0
Overall electric efficiency - CHP plant	%	12.0	9.2
Overall efficiency - CHP plant	%	85.9	90.0

In spring 2003 comprehensive test runs were performed. Table 3 shows the results of the test runs compared to design targets. The average electric power output of 31 $\mathrm{kW_{el}}$ is less than the expected nominal output of 35 $\mathrm{kW_{el}}$ achieved in tests with natural gas. The decrease in power is partly due to a lower efficiency of the hot heat exchanger with wood chip fuel compared to natural gas. Furthermore, the temperature of the cooling water at the cold heat exchanger inlet of the Stirling engine was higher than initially foreseen, which also results in a reduced electric power output. The electric efficiency of the Stirling engine is also lower than expected (20 instead of 25%), which is mainly due to the fact that the Stirling engine is significantly less efficient at partial load than at full load operation. Furthermore, the air preheater does not work satisfactorily. The test runs performed show that the temperature of the preheated combustion air is about 190 °C lower than initially foreseen (see Table 3). This is due to high heat losses to the water cooled walls enclosing the air preheater. The overall electric efficiency of the CHP plant measured during the test runs amounts to approx. 9.2 %, which is about 25% less than expected. The overall efficiency of the CHP plant (electric + thermal) is higher than the design target, which shows that the economiser works very satisfactorily.

During the test runs different wood chip qualities were used, and the plant was running well with water contents ranging from 10 to 55 wt.% (w.b.).

The automatic cleaning system was improved several times during the test period. At the moment, manual cleaning of the hot heat exchanger is necessary after more than one month of operation. It is expected that further improvements of the automatic cleaning system will increase these intervals to 2 - 3 months.

3.3 State of development of the Stirling process

Several research teams in Europe and the USA are working on the development of Stirling engines for CHP, and some of those are also working with biomass fuels.

With more than 4,300 hours of successful operation the pilot plant described above can be considered as a breakthrough in the utilisation of Stirling engines for small-scale CHP plants utilising wood chip fuels. At the moment, the plant works fully automatically and the development of the control system is almost completed. But there are several problems to be addressed in future, primarily regarding enhanced electric efficiency. In this context, major emphasis should be placed on improving the efficiencies of the hot heat exchanger, of the air preheater and of the entire combustion system. Furthermore, the optimisation of the pneumatic cleaning system to reduce ash deposition in the hot heat exchanger and thus to achieve a higher availability of the whole system is of great relevance.

In addition to these development goals, future activities should further prove the reliability and low service demand of the plant. Furthermore, the specific price of the plant has to be decreased by implementing serial production on a stage-by-stage basis in order to make the technology competitive.

Small series production of Stirling engines is planned to be launched in 2004, and it is expected that the price of manufacture can be considerably reduced, once the first two or three small series have been built.

In an ongoing EU research project (project “BIO-STIRLING”; project No. NNE5-1999-00097) a CHP plant with a 75 $\mathrm{kW_{el}}$ eight cylinder Stirling engine has been developed. This plant will be put into operation in summer 2003.

4 CONCLUSIONS AND RECOMMENDATIONS FOR SMALL-SCALE BIOMASS CHP PLANTS

Several technical side constraints are of great importance for decentralised biomass CHP plants. The technology must be robust and highly available and plants must be designed to run in unmanned operation. Therefore, a high level of process control and process automation is necessary. Other important factors are good partial load behaviour and the ability to handle quick load changes. Overall electric plant efficiency should be between 12 and 20%.

A high number of full load operation hours and high overall efficiency are crucial factors for economical performance. Appropriate feed-in tariffs for electricity from biomass as well as a certain period of time over which these tariffs are guaranteed (at least 10 years) are essential in order to drive market introduction of small-scale biomass CHP technologies forward. These framework conditions are crucial for initiating serial production of such CHP systems, which is the most important factor for cost reduction, as capital costs account for about 60% of total electricity production costs.

The ORC and the Stirling engine technologies described in this paper have proven their applicability for small-scale biomass CHP plants and represent an interesting future potential in this field.

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