DEMONSTRATION AND EVALUATION OF AN INNOVATIVE SMALL-SCALE BIOMASS CHP MODULE BASED ON A 730 KW_{EL} SCREW-TYPE STEAM ENGINE

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ABSTRACT: Within the scope of the European 5th Framework Programme, Research Programme EESD, the technical maturity of an innovative small-scale CHP module based on a screw-type steam engine has been demonstrated (project No. NNE5-2000-467). The module with a nominal electric capacity of 730 kW_{el} and a nominal thermal power output of approx. 4,800 kW_{th} has been implemented into the steam cycle of a biomass district and process heating plant in Hartberg, Austria. Commissioning of the plant took place at the end of 2003, comprehensive monitoring work as a basis for further improvements regarding plant design and as a basis for dissemination of the results achieved has been carried out subsequently. The project represents the first large-scale demonstration of the screw-type steam engine technology for small-scale biomass CHP applications at an European level as well as worldwide.
Keywords: combined heat and power generation (CHP), screw-type steam engine, demonstration

1 INTRODUCTION

Small-scale combined heat and power (CHP) plants close to biomass production sites allow efficient utilisation of biomass with a minimum of environmental impact. At present the only useful technologies from a technological and economic point of view for CHP generation based on biomass fuels in the power range between 200 to 1,500 kW_{el} are the screw-type steam engine and the ORC process. The ORC (Organic Rankine Cycle) process is coupled with thermal oil boilers and stronger oriented to district heating and low temperature process heating (e.g. drying chambers in sawmills) whereas the screw-type engine is especially suitable for small-scale applications where steam is necessary as process heating medium [1].

The conventional method of producing electricity from steam are steam turbines or steam engines. Turbines are only economically competitive at power ranges above 1.0 MW_{el}, steam engines are suitable for smaller power ranges. However, their steam and oil cycles are not separated if superheated steam is utilised and therefore deposition of oil traces in the steam cycle occur, which reduces the service life of the plant and increases operating costs.

The screw-type engine cycle is based on the conventional Rankine process. On the contrary to the steam turbine process the steam is expanded in a screw-type engine, which is connected to a generator producing electric power.

The screw-type engine is derived from the screw compressor and is consequently based on comprehensive engine know-how. Screw-type engines are suitable for biomass CHP plants in the range of 200 to 2,500 kW_{el}, where steam parameters can vary, due to variations of the fuel water content and the kind of biomass fuel used, and where a simple and heavy duty design is needed resulting in low operating and maintenance costs.

Screw-type steam engines for small-scale biomass CHP applications in the power range of 200 to 1,000 kW_{el} have a number of advantages compared to steam turbines and conventional steam engines. Screw-type engines show a comparatively high electric efficiency (= electric power produced / steam power input) for small-scale CHP units (about 13 %), which only slightly decreases at partial load operation. Due to the good partial load behaviour in a wide range of load conditions, the whole process can be operated heat controlled and following a high overall efficiency of the biomass CHP plant (between 80 and 90 %) can be achieved.

2 PRINCIPLE OF THE SCREW-TYPE ENGINE TECHNOLOGIE

In co-operation with industrial companies, the university of Dortmund (Germany) has applied the well-proven technology of screw compressors for the development of a screw-type engine. This development has been performed within the 90's and an appropriate screw-type steam engine pilot plant has also been tested at the university for several years [2].

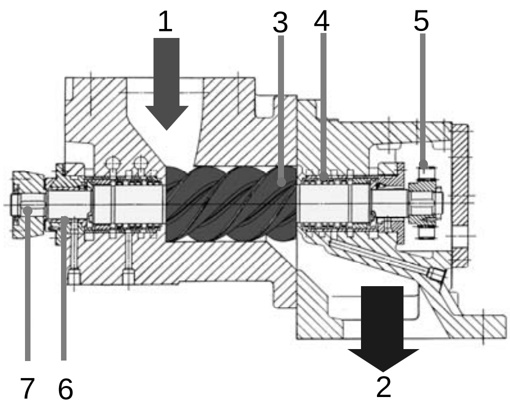

Figure 1: Section drawing of a screw-type engine
Explanations: 1…live steam inlet, 2…exhaust steam outlet, 3…male rotor, 4…shaft seal, 5…synchronisation gearwheels, 6…friction type bearing, 7…output shaft

The screw-type engine is a displacement rotary engine. Similar to piston engines, displacement-type engines are characterised by a closed working chamber. The volume of the working chamber changes cyclically, which leads to a decrease of the energy content of the fluid in the chamber. The main parts of a screw-type engine are the male rotor, the female rotor and a casing, which together form a V-shaped working chamber whose volume depends solely on the angle of rotation. The steam enters the casing through the intake port in the passage formed between the tips of the rotor teeth. During rotation the volume of the chamber increases. Intake is finished when the rotor faces pass the guiding edges and the chamber is separated from the intake port. At this stage steam expansion starts and mechanical power is produced at the output shaft. During expansion the volume of the chamber continues to increase, whereas the energy content of the fluid decreases. This process continues until the exhaust process starts and the steam is extruded. It leaves the machine through the exhaust port. How often this process takes place during one rotation of the male rotor depends on the number of teeth on the male rotor. A detailed section drawing of the screw-type engine can be seen in Figure 1. The expansion process within a screw-type engine is shown in Figure 2.

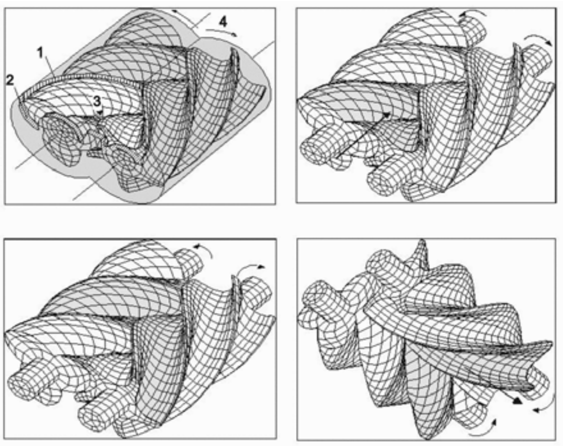

Figure 2: Expansion process within a screw-type engine
Explanations: 1…radial guiding edge, 2…axial guiding edge, 3…flow direction, 4…direction of rotation

After leaving the screw-type engine, the exhaust steam (parameters: e.g. 1 bar_a, 100°C) enters the condenser where the heat of condensation is transferred to the hot-water cycle which is used as process and district heat.

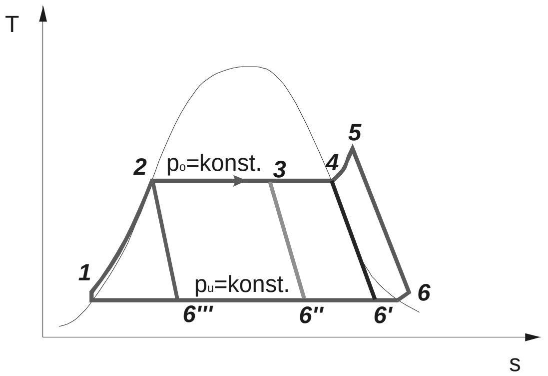

Figure 3: Possible cycles of operation of the screw-type engine process
Explanations: 5-6…superheated steam, 4-6'…saturated steam, 3-6''…wet steam, 2-6'''…pressurised hot water

The screw-type engine is a very compact machine with a long life time and low maintenance costs. It is insensitive to steam quality fluctuations and can be operated with superheated steam, saturated steam, wet steam and pressurised hot water (see Figure 3).

Screw-type steam engines for small-scale biomass CHP applications have a number of advantages compared to conventional steam turbines and steam engines:

- Comparatively high electric efficiency for small-scale CHP units (< 1,000 kW_{el}).
- The screw-type engine has a good partial-load efficiency over a wide range of load conditions.
- Load fluctuations between 30 and 100 % of nominal electric power production are no problem.
- The screw-type engine is insensitive to steam quality fluctuations. Even water droplets in steam, which can occur in a small-scale steam boiler due to malfunction or changes of biomass fuel quality or load, do not cause any problems in screw-type engines.
- The steam cycle and the oil cycle are completely separated by an air-lock system.
- The fully automatic operation and easy handling save personal costs.
- The screw-type engine is a very compact and robust machine with low maintenance costs.

3 TECHNICAL DESCRIPTION OF THE BIOMASS-FIRED CHP PLANT IN HARTBERG (AUSTRIA)

The biomass district heating plant Hartberg (see Figure 4) is located in Styria, Austria, and started its operation in 1987. The heating plant is equipped with a water tube steam boiler and supplies process and district heat consumers via a steam and a hot water network of pipes.

Figure 4: View of the biomass CHP plant in Hartberg (Austria)

In order to obtain a more efficient utilisation of the biomass fuels (bark, wood chips, sawdust etc.) used by producing not only heat but also electricity, a steam superheater and a screw-type engine were implemented into the heating plant at the end of 2003.

Due to the innovative nature of this project (demonstration of the first biomass-fired CHP plant based on a screw-type steam engine), the design, manufacture, installation and monitoring of the CHP module were funded by the European Commission within the scope of the European 5th Framework Programme, Research Programme EESD (project No. NNE5-2000-467) [3].

Table I shows the schedule of the project. The CHP module was delivered to the heating plant in September 2003 (see Figure 5). Commissioning was carried out in November 2003 and subsequently the monitoring phase started with the objective to achieve a comprehensive evaluation of the innovative CHP module.

Table I: Project planning and time table

	Start	End
overall design of the CHP plant	09/2001	10/2001
design of the CHP module	11/2001	07/2002
manufacture of the CHP module	08/2002	06/2003
installation of the CHP module	07/2003	11/2003
commissioning of the CHP module	-	11/2003
monitoring phase	12/2003	04/2004

Figure 5: Unloading of the screw-type engine module

Figure 6 shows the annual heat output line of the district heating network loco heating plant, which formed the basis for a correct design of the CHP module. In this heat output line only the district heat supply of the system is considered. The process heat (steam) needed is directly extracted from the steam drum and is therefore not relevant for the CHP unit (see also Figure 7). As the existing biomass steam boiler has a nominal capacity of 18 MW also the peak load of district heat can be covered.

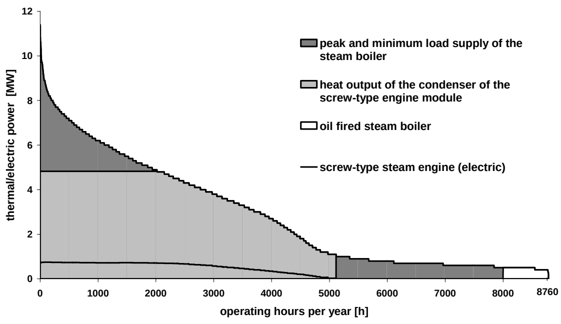

Figure 6: Annual heat output line of the district heating network loco heating plant in Hartberg

Based on this curve and economic calculations, the biomass CHP plant was designed for basic and medium load operation in heat controlled mode. The CHP size selected ensures a high number of full load operating hours (about 4,000 h/a) as well as a high overall annual efficiency of the CHP plant (about 80%).

In Figure 7 the process flow diagram of the biomass CHP plant in Hartberg (Austria) is shown.

The main parts of the process are the biomass-fired steam boiler (steam parameters: saturated steam of 26 bar_a, 225°C), the superheater (steam parameters: 25 bar_a, 255°C), the spray cooler behind the superheater as well as the screw-type engine utilising the steam for electricity production. After passing the screw-type engine the exhaust steam (parameters: 0.5-1.5 bar_a, 80-110°C) enters the condenser where the heat of condensation is transferred to the hot-water cycle to be utilised as district heat.

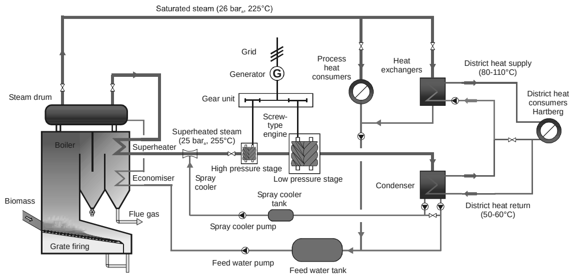

Figure 7: Process flow diagram of the biomass CHP plant in Hartberg

The screw-type engine in Hartberg is designed as a two-stage unit. The steam passes first through the smaller high-pressure stage, and then through the larger low-pressure stage (see Figure 8). Each stage is equipped with separate bearings and seals. Because of the high rotational speed of the screw-type engines, a gear unit is installed, which powers the asynchronous generator. The gross nominal capacity of the screw-type engine in Hartberg amounts to 730 kW_{el}. The auxiliary electric power of the CHP module is about 20 kW_{el} which results in a net electric capacity of the system of 710 kW_{el}.

Figure 8: Screw-type steam engine of the biomass CHP plant in Hartberg (net nominal electric capacity: 710 kW_{el})
Explanations: 1…low-pressure stage, 2…high-pressure stage, 3…gear unit, 4…generator

The screw-type steam engine works in grid connected operation. Plant operation and start up are controlled fully automatically by an electronic control system and do not require additional staff.

To make sure that the oil in the bearings and the synchronisation gear is separated from the steam in the working chamber, shaft sealings (designed as labyrinth seals) are provided on both the inlet and discharge sides of the engine. In addition the screw-type engine is equipped with a purge gas system (air is injected into the labyrinth packing under slight pressure) to ensure a complete separation between the steam and the oil section.

In Table II the technical data of the CHP plant in Hartberg are specified.

Table II: Technical data of the CHP plant in Hartberg
Explanations: g…gauge, a…absolute, electric efficiency…net electric power produced / steam power input

Nominal data of the biomass boiler unit		
Nominal power of the steam boiler	18	MW
Boiler pressure (approved)	32	bar_g
Steam parameters	225°C / 26	bar_a
Nominal data of the CHP module		
Steam power input	5,640	kW
Steam flow rate	8.1	t/h
Steam parameters inlet	255°C / 25	bar_a
Gross nominal electric power	730	kW
Net nominal electric power	710	kW
Thermal power of the condenser	4,800	kW
Steam parameters outlet (nominal conditions)	100°C / 1	bar_a
El. efficiency at nominal load operation	12.6	%

4 TECHNOLOGICAL EVALUATION OF THE SCREW-TYPE STEAM ENGINE PROCESS

The screw-type steam engine in the biomass CHP plant in Hartberg has been in successful and almost continuous operation since November 2003.

In order to evaluate and optimise the CHP plant, all relevant operating data of the screw-type steam process are recorded by the installed data acquisition system.

In Figure 9 relevant data of the screw-type steam engine process in Hartberg are shown. The diagram illustrates the steady and continuous operation of the screw-type engine during a representative period of about 3 weeks.

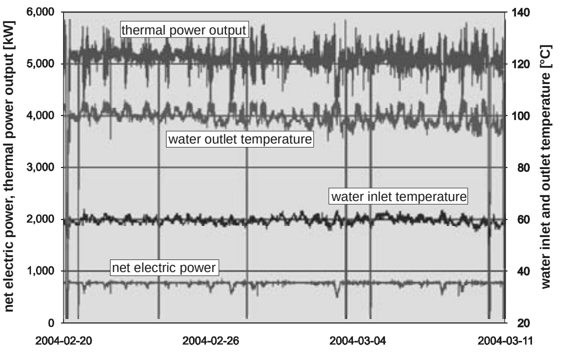

Figure 9: Relevant operating data of the biomass CHP module in Hartberg measured during the monitoring period
Explanations: thermal power output related to the condenser, water inlet and outlet related to the district heating network

Figure 10 shows the annual energy flow chart of the biomass CHP plant in Hartberg for nominal load (see Table II) and the ratio of energy output flows in relation to the net calorific value of the biomass fuel (NCV). The overall net electric efficiency of the CHP plant amounts to about 10% (related to the net calorific value of the biomass fuel), which relates to a net electric efficiency of the screw-type steam engine of 12.3%.

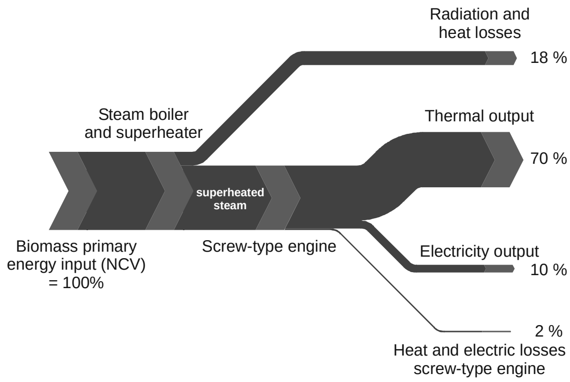

Figure 10: Energy flow chart of the biomass CHP module in Hartberg

5 SUMMARY AND OUTLOOK

The technical maturity of the screw-type steam engine has been demonstrated in the biomass CHP plant in Hartberg.

Due to the high stage of development of the screw-type steam engine achieved and the numerous advantages compared to conventional steam-based small-scale CHP technologies, a quick market introduction is anticipated in short term.

The great potential and large demand for decentralised biomass fired CHP plants in the power range up to 2 MW_{el} represents a large potential for further implementations of screw-type steam engines and increased and more efficient thermal biomass utilisation in small-scale CHP units within Europe.

6 REFERENCES

[1] OBERNBERGER I., HAMMERSCHMID A., 1999: Dezentrale Biomasse-Kraft-Wärme-Kopplungstechnologien, Schriftenreihe "Thermische Biomassenutzung", Band 4, dbv-Verlag der Technischen Universität Graz, Graz, Österreich.

[2] PIATKOWSKI R., KAUDER K., 1996: Schraubenmotor zur Wärmekraftkopplung: Stand der Technik. In: Tagungsband zum 4. Holzenergie-Symposium, Oktober 1996, Zürich, Bundesamt für Energiewirtschaft (Hrsg.), Bern, Schweiz.

[3] OBERNBERGER I., HAMMERSCHMID A., STALLINGER A., 2004: Biomass-fired CHP plant based on a screw-type engine cycle. Final publishable report of the EU demonstration project No. NNE5-2000-467, European Commission, DG Energy-Transport (ed.), Brussels, Belgium, 2004 – in preparation.