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ANALYSIS OF THE BIOMASS COGENERATION PLANT FOR DISTRICT HEATING NETWORKS

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ABSTRACT: The CHP plant Scharnhauser Park with a thermal power of 6.3 MWth and 1 MW electrical power output can serve as a practical example for the application of the technology. The installation has a pilot project character and has been used to gather practical experience which should support the deployment of this modern technology. A major challenge is to obtain stable operating conditions of the combustion process with varying biomass quality. The requirements of a district heating system should also be considered during plant operation. Through the modification of the air supply and exhaust system, stable and continuous operation of the furnace can be guaranteed. Additionally a reduction of hard tar depositions in the flue gas heat exchangers was possible. The gathered data material allows analysing the complex biomass combustion process in respect to the variable requirements of the district heating system and varying biomass quality.

1. INTRODUCTION

Modern biomass technologies are anticipated to provide a significant contribution to the global energy supply. Numerous technologies can be used to convert biomass to more convenient energy carriers. The overall global demand for heat and electricity is expected to grow. Biomass offers a good potential to meet this growing energy demand since it is the only carbon based renewable fuel that can directly replace fossil fuels. Although biomass can offer a practical alternative to fossil fuels, it has received relatively low attention. The global potential to increase the use of bioenergy for renewable heating and power generation in CHP plants is therefore large. It is expected that the CHP (combined heat and power) electricity generation will grow, with a comparable increase in available heat towards more efficient bioenergy technologies [1].

Well designed and good quality biomass plants should be installed in order to realise the potential of this energy carrier efficiently. The highest efficiency for the substitution of fossil fuels can be achieved with the energy generation from wood in combined heat and power plants [2]. Decentralised bioenergy plants built reasonably close to the demand load, will reduce transmission losses and improve the energy security by producing additional and alternative resources. Innovative technologies such as the ORC (Organic Rankine Cycle) process represent an economically interesting solution for biomass-fired combined heat and power plants. The paper mainly focuses on the aspects of integration of a CHP plant based on an ORC process into the heat supply system of the area Scharnhauser Park.

The principle of the energy generation by means of an ORC process is similar to the conventional Rankine process with the difference that instead of water an organic working medium is used. The ORC process is connected with a biomass furnace via a thermal oil cycle. Biomass combustion is a fully mature technology and offers an economic option for the production of heat from biomass. Improvements of biomass furnaces with respect to efficiency enhancement and emission reduction have alleviated some of the combustion related problems. However, there is still a potential for further optimisation. Problems occur in relation to changing fuel quality and ineffective combustion control systems.

2. ENERGY SUPPLY SYSTEM

The energy supply system of the area Scharnhauser Park in Ostfildern, near Stuttgart was developed and constructed to ensure an environmentally friendly, sustainable and efficient heat and electricity supply based on renewable energy carriers. The demand for heat and electricity in Scharnhauser Park is provided by a combined heat and power plant. By the combustion of wood, heat and electricity is produced. The plant is operated in heat driven mode. Each year 80% of the heating and approximately 50% of the electrical power for the area Scharnhauser Park are produced CO_2 neutrally in the CHP plant.

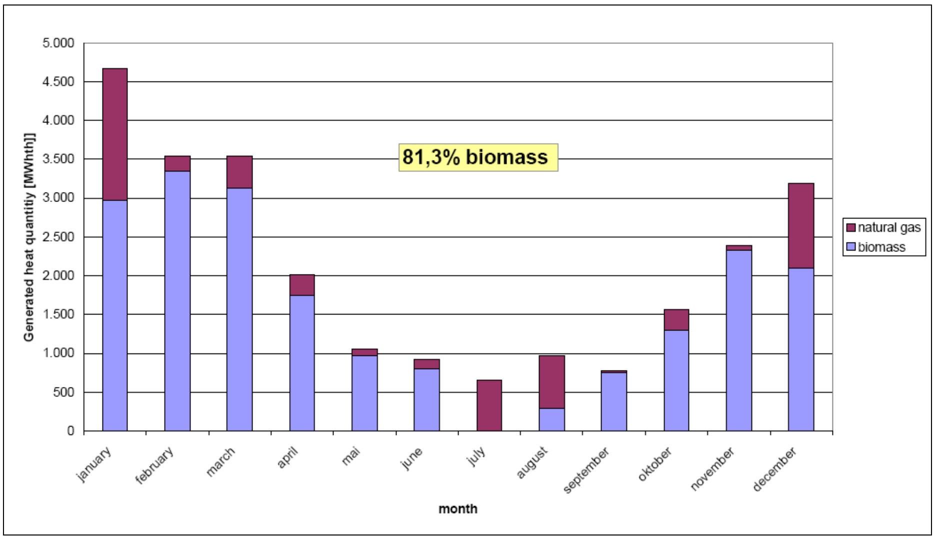

Fig.1. Heat generation 2006

Wood chips are used as combustible at the CHP plant. The plant is equipped with a firewood bunker with a holding capacity of 1000 m^3. The fuel is carried by a crane to a daily storage and transported hydraulically to the burner. The heat produced in the biomass furnace is released to the thermal oil. Thermal oil carries the heat energy from the wood burner to the evaporator of the ORC cycle, where the working medium is vaporised. Silicon oil is used as the working medium at the CHP plant. The steam is guided into the turbine which is directly connected to a generator. After leaving the turbine, the silicone oil vapour passes through a regenerator and flows to the condenser. During the condensation of the working medium the residual heat from the electricity generation process is transferred to the district heating network. The electric efficiency of the ORC (= net electric power output / power input with the thermal oil) at nominal load is about 18% which is a quite high value for small-scale-

CHP-plants. This high net electricity efficiency can also be kept at partial load operation, which is very important for CHP plants in heat controlled operation [3].

The core of the plant is the 6.3 MW_{th} biomass furnace. The modern grate firing including exhaust gas heat recovery and a fully automated combustion control system ensures a complete combustion and a minimum appearance of the pollutant emissions. The burning chamber of the furnace is constructed as a counter flow chamber especially suitable for the burning of wet material. The combustion chamber is separated into two different zones (primary and secondary) in order to optimise the process of thermal utilisation of wood. In the primary combustion zone the wood chips are gasified under sub-strochiometrical ($\lambda<1$) conditions. The main process steps of thermal decomposition in the primary combustion zone are drying, devolatilisation, gasification and char combustion. The gasification products from the primary combustion zone are transferred to the secondary zone where they are burned under over-stochiometrical conditions. The flue gases from biomass combustion enter an exhaust heat recovery system. The installation of a complex exhaust gas cleaning system at the plant contributes to a significant reduction of dust particles from the combustion chamber. Additionally a permanent emission monitoring system was installed at the plant in order to control the emissions of pollutants from the combustion process.

The residual heat from the CHP module is transferred to the customers via a district heating system with a length of 13.5 km. An connection to the district heating network is obligatory for apartments and houses in Scharnhauser Park, which ensures high heat demand. The feed temperature of the district heating net is controlled by the ambient temperature. This allows an effective operation of the system through a reduction of heat losses in summertime due to the decreasing feed temperatures.

Due to the fact that in summertime there is only a demand for hot water, the amount of produced heat decreases significantly. A high efficiency of the biomass utilisation can be achieved only if the energy is demanded the whole year round and at a high capacity. A possible solution is the production of cold through absorption cooling driven by heat from district heating network. The possibility to combine heat power production with the supply of cooling energy will be realised in the course of planning for a new office building. The cold production system is planned to be a pilot installation implementing thermal cooling for air condition of offices and IT structure. The cooling process is realised by lithium bromine based absorption chillier with a cooling power of 105 kW which will be installed in the basement of the building. The supply with cooling energy seems to be a good alternative to reach a sufficient workload and the yearly operation hours with biomass can be higher.

3. PRACTICAL EXPERIENCE

The information availability for decentralised CHP plants based on biomass combustion is generally limited due to the relatively low practical experience of this innovative technology. Many problems that usually arise when building a plant can be avoided when building a second plant. Understanding of technical, economical and environmental plant behaviour will have a positive impact on deployment of modern bioenergy technologies. The analysis of measurement results, information on project circumstances should help to install good quality, well designed bioenergy plants. Information publishing aims to enhance the awareness of bioenergy technologies could also convince the consumers of the benefits that the bioenergy applications might have.

While ORC-modules have been used for producing electricity via geothermal energy for a long time, it can be seen as a new technology in connection with biomass combustion. Therefore missing operational experiences can be considered as one major disadvantage [4]. The publication of information on project circumstances, project success (or otherwise) could help to build professional support for the development of new bioenergy projects. In this context the practical experiences from Scharnhauser Park can serve as a basis for the analysis of the reliability of decentralised CHP plants based on biomass combustion and can provide useful knowledge and information for the development of modern energy supply systems.

3.1 COMBUSTION AIR MANAGEMENT

Through control of the amount of wood scraps fed to the combustion chamber the output performance of the furnace can be adjusted to the actual heat demand. For an efficient operation of the furnace and low emissions an advanced combustion air management is required. The combustion of biomass is a complex process with simultaneously occurring consecutive reactions. The main biomass combustion steps are drying of fuel, pyrolisis/gasification, charcoal oxidation and gas phase oxidation. In order to achieve higher efficiency of the process the combustion stages have been separated into different locations in the furnace. State of the art furnaces are equipped with separate combustion air fans according to the process steps of thermal utilisation of biomass. Additionally the installation of a flue gas suction fan offers more flexibility to provide optimised process conditions. However, the combined arrangements of fans for combustion air and flue gases fans are often insufficiently controllable by standard control systems, which lead to unsteady combustion.

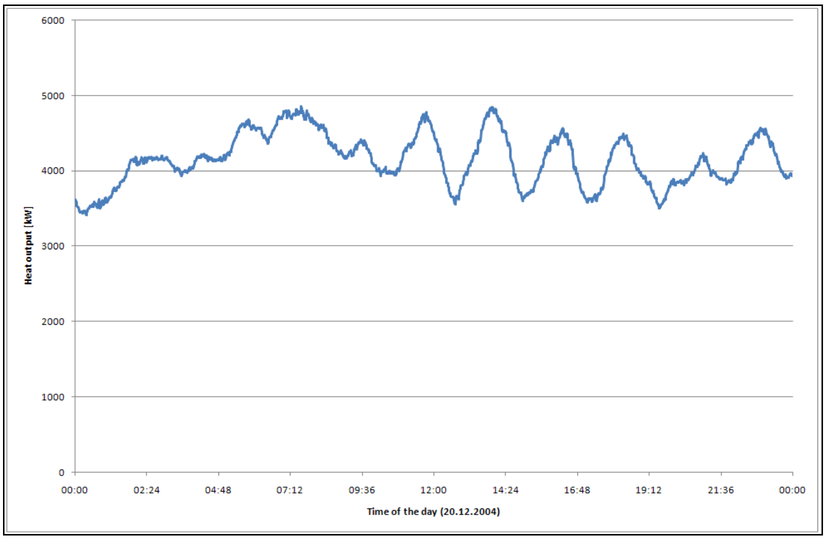

Fig.2. Unsteady combustion

The optimisation of the combustion air management system was necessary to guarantee a stable combustion. The response time of the combustion air fans and the flue gas fan was changed in order to operate the furnace efficiently at partial load. The combustion air fans reaction time was modified to ensure an adequate excess air ratio for each step of the combustion process. The response time of the flue gas fan which secures the transport of the exhaust fumes to the stack was increased to adjust the specific combustion air amounts to the requirements of the combustion process. After the interaction between the combustion air fans and the flue gas fan was considered within the combustion control system, stable combustion was achieved.

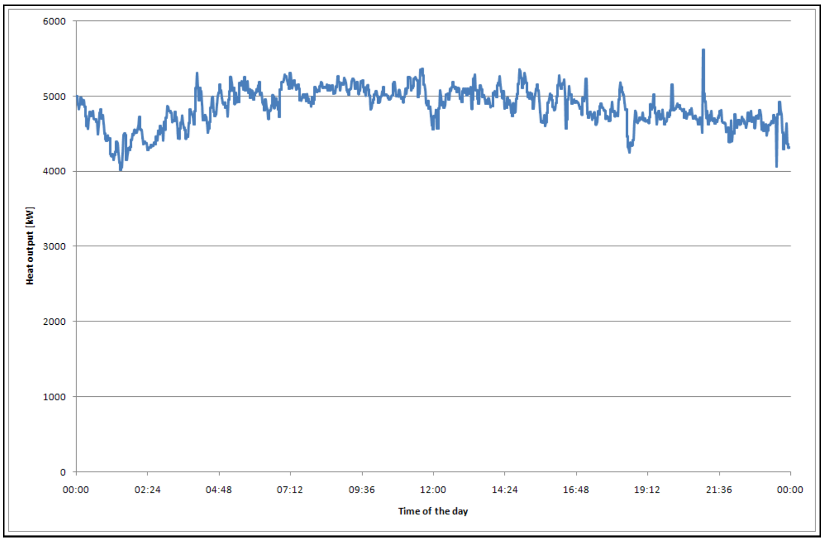

Fig.3. – Stable combustion

3.2 EFFECT OF FUEL PROPERTIES

The properties of biomass relevant for the combustion process can vary in a relatively wide range. Unsuitable parameters of solid biofuels can lead to operational problems during combustion. The burning process of woody biomass is mostly influenced by the particle size, moisture and caloric value. The nominal values of process parameters cannot be achieved if the fuel properties do not match the process requirements.

Grate furnaces are manufactured in two basic configurations depending on the fuel moisture: co-current and counter-current. The biomass furnace at the CHP plant Scharnhauser Park was constructed as a counter-current combustion unit. This type of furnace is suitable for burning of freshly harvested biomass with a moisture content of up to 65%. However, depending on the biomass source and storage time the moisture of the delivered wood chips can vary widely. Dryer fuel has a higher burning rate and therefore makes the combustion more intense and hence the temperatures in the combustion zone would increase. Higher temperatures in the grate zone lead to melting of ash which can cause slag and deposit formation in the furnace and boiler. Therefore the temperatures in the grate zone should not exceed the value of 850°C.

An additional humidifier was installed within the fuel supply system in order to achieve suitable moisture of the wood scraps according to the requirements of the combustion unit. Higher moisture of the fuel ensures that the temperatures in the grate zone do not exceed the critical values and therefore prevent the sintering of ash during combustion.

The burning rate is mostly influenced by fuel size and smaller fuel particles results in a higher combustion rate. Generally, larger-size particles result in a higher air-to-fuel stoichiometric ratio or less fuel rich combustion [5]. Due to the lower combustion rate of larger particles the required output performance of the furnace cannot always be achieved, which leads to several operational problems. In order to ensure efficient operation of the CHP plant a compromise must be found between the requirements of the district heating network and optimal process parameters which are necessary for clean and complete combustion. The practical experience helps the plant operator to predict the burning characteristics of a new fuel. Nevertheless additional studies on the effect of fuel particle sizes on biomass combustion will carried out in Scharnhauser Park to make the utilisation of biomass more effective and environmental friendly.

The combustion behaviour of biomass is also influenced by the fuel caloric value, which can range from 15 to 22 MJ/kg. The energy density of biomass has an impact on the burning rate and the adiabate temperature of combustion. The lower net caloric value of fuel results in a higher amount of fuel which has to be fed into the burner. Consequently the net caloric value of biomass must be taken into consideration in order to adjust the control system of the furnace properly and to ensure optimal performance and complete combustion.

3.3 FLY ASH

Higher ash contents and high quantity of ash-forming elements in the fuel can cause the forming of hard agglomerates in the grate zone. The fuel also contains herbaceous biomass which leads to a decreasing ash melting point. Agglomeration, slagging and fouling can occur if herbaceous biomass is burned with wood scraps. Problems still unsolved, that need comprehensive research and development, are reactions taking place in the hot flue gas, causing corrosion and fouling in furnaces and boilers (especially when K-, S- and CL-rich biomass such as straw, cereals and grass are used). Research on possibilities to prevent them (by material selection or appropriate technologies) is of great importance [6].
A number of problems that occurred during the plant operation in Scharnhauser Park are related to ash depositions and fouling. Practical experience gained during the CHP plant operation can be used as a basis for understanding and solving of these ash fouling related problems.

Fig.4. Manual boiler cleaning

Ash fouling on the surface of heat exchangers affects the heat exchange rate in a negative way. An increase of the thickness of the ash depositions makes the heat transfer between the flue gases and heat carrier inefficient and hence the exhaust gases temperature after the furnace would increase. The thermal oil boiler was equipped with an automatic cleaning system based on pressurised air in order to prevent ash fouling on the heat exchanger surface. This system allows the reduction of the ash depositions related problems. However, the functionality of the nozzles for pressured air has to be controlled systematically. If the system does not work correctly the heat exchanger tubes can be damaged, which leads to a high thermal oil fire danger. Additional manual cleaning of boiler tubes is necessary every six months when the flue gas temperature at the boiler outlet increases significantly. The heat exchanger pipes are then cleaned with dry ice blowing in order to reduce the heat losses.

Ash depositions can cumulate in the exhaust heat recovery system and clog the pipes of the heat exchangers. Flue gas condensate in the blocked channels of water economiser and air pre-heater and can cause corrosion on the heat exchanger tubes. After several operational problems caused by ash depositions in the exhaust heat recovery systems the plant operator decided to upgrade the water economiser and air pre-heater by the installation of an additional automatic pressured air cleaning system.

Although the problems were solved, the water economiser was damaged and had to be put out of operation. Due to the fact that the water economiser is now bypassed the whole potential of the combustion unit cannot be used. To prevent corrosion of the exhaust heat recovery system each flue gas heat exchanger of a biomass furnace in Scharnhauser Park has to be equipped with a separate cleaning system.

During thermal decomposition of biomass in the primary combustion zone a fraction of ash is related to the gas phase. Solid phase sub-micron particles together with volatilised ash forming compounds from the fuel form fly ash particles. These particles get entrained with flue gases and cause depositions at the bottom of the secondary combustion chamber. The ash depositions have to be systematically removed, usually once per week to ensure regular operation of the furnace. This fact has to be considered concerning the necessary maintenance effort of modern biomass furnaces which strongly depends on fuel properties.

The development of a reliable fuel supply chain has proved to be difficult in Scharnhauser Park. It was found that the fuel properties change depending on the time of the year. The wood chips produced in spring and autumn contain a high amount of waste due to the seasonal cleanup works. The general trend observed during the plant operation shows that higher waste fractions in the combustible negatively influence the plant operation. The amount of produced heat and electricity decrease seasonally, which can be related to the worsening of fuel quality. The construction of additional large fuel storage is currently under consideration. This additional fuel silo should secure reliable biomass supply all-year-round. The seasonable fluctuations of fuel properties have to be considered by plant operators in order to develop their own fuel supply chain specific to local conditions.

4. CONCLUSIONS

Decentralised bioenergy CHP plants based on biomass combustion offer a good potential to meet the growing energy demand. Although biomass combustion is a mature technology problems still occur due to the changing fuel quality and ineffective combustion control systems. The data on operation circumstances at the CHP plant Scharnhauser Park can provide useful information for efficient deployment of modern biomass technologies.

Combustion air management systems of modern biomass furnaces often work inefficiently. The combined arrangements of the combustion air and flue gas fans have to be efficiently coordinated to provide optimial process conditions.

The properties of the biomass fuel are of great importance for a reliable plant operation. Combustible parameters including particle size, moisture and caloric value have a strong effect on the burning characteristics. Larger fuel particles have a lower burning rate, which can lead to problems to achieve the nominal output performance of the furnace. Moisture content of the combustible influences the adiabate burning temperature. Due to the design parameters the wood chips in Scharnhauser Park have to be humidified before combustion in order to avoid ash melting in the grate zone. The caloric value of the fuel should also be considered as a relevant process parameter, which affects the amount of fuel transported to the burning chamber.

Ash depositions and fouling caused several problems during the plant operation. Ash fouling on the heat exchanger surfaces affects the heat exchange rate in a negative way. Therefore regular manual cleaning of the tube surfaces is necessary. Additional automatic cleaning systems have been installed on the heat exchangers of the exhaust heat recovery system. Ash depositions have to be removed from the bottom of the secondary combustion chamber systematically to ensure stable operation of the furnace.

The practical experience described in the paper can provide information on how to successfully deploy biomass in ORC plants. The paper should enable understanding of the difficulties that have to be overcome when operating an ORC plant based on biomass combustion. Through a description of the issues involved in operating a CHP plant, a guideline for the successful development of similar bioenergy projects should be created.

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INTEGRATION VON BIOMASSE-KWK-ANLAGEN IN WÄRMEVERSORGUNGSYSTEME VON STADTGEBIETEN

ZUSAMMENFASSUNG: Die Energieerzeugung in Heizkraftwerken auf Basis der ORC Technologie bietet aufgrund ihrer ökonomischen Vorteile eine interessante Alternative zur Verstromung von Biomasse. Bei der Verwendung einer Biomassefeuerung als Energielieferant für das ORC Modul fehlt es jedoch an Praxiserfahrungen. Vor allem die Anpassung der Betriebsparameter der Feuerung an die Anforderungen des ORC Prozesses und der Wärmeabnehmer im KWK-Betrieb stellt aufgrund der vielen Einflussfaktoren eine komplexe Aufgabe dar.

Anhand der Betriebserfahrungen und Langzeitmessungen aus dem Heizkraftwerk Scharnhauser Park wurde ein deutlicher Einfluss der Brennstoffparameter auf die Effizienz des Energieerzeugungsprozesses ermittelt. Die Publikation beschreibt die Auswirkungen der Brennstoffparameter wie Feuchte, Stückigkeit und Heizwert auf den Verbrennungsprozess. Weiter werden Lösungen beschrieben, die in Scharnhauser Park eingesetzt wurden, um eine effiziente Biomassenutzung mit Berücksichtigung ihrer spezifischen Eigenschaften, wie z.B. die relativ niedrige Ascheschmelztemperatur zu ermöglichen.

Fehlende Praxiserfahrungen aus bestehenden Anlagen werden als einer der größten Nachteile der Verwendung von ORC Technologie zur Biomasseverstromung angegeben. Somit können die in der Publikation beschriebenen Betriebserfahrungen einen wichtigen Beitrag zur Bewertung der Praxistauglichkeit dieser Technologie leisten.