Published in: Proceedings of the 17th Biomass Conference, Hamburg, Germany, 29 June - 02 July 2009

RELEVANCE OF FUEL PARAMETERS FOR OPERATION CONDITIONS OF BIOMASS FURNACES

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ABSTRACT: Worldwide biomass ranks fourth as an energy source and over 90% of the generated bio-energy are produced in biomass furnaces. The recent development in biomass combustion technology has led to improvement of efficiency and significant reduction of emissions from modern conversion installations. However, the operation and maintenance of biomass furnaces requires detailed understanding of the complex burning process. There is still a lack of detailed theoretical study and practical experience, which could be used to deal with the difficult combustion characteristic of biomass. Measurements results showed that fuel parameters can vary in a wide range with respect to moisture, heating value, particle size as well as inorganic constituents, which can cause sintering of ash during combustion. Generally the temperature in the grate zone can be defined as the limiting process parameter. Low temperatures causes high emissions of pollutants and lower conversion efficiencies, to high temperatures lead to problems with melting of ash. Recirculation of exhaust fumes is used in the researched furnace for temperature control in the burning chamber.

Keywords: Biomass combustion, environmental impact, organic rankine cycle (ORC)

1 INTRODUCION

Biomass and the resulting forms of bioenergy produced from it are capable to make a large contribution to the future worlds' energy supply. Biomass is by far the most important energy source used to date and large potentials of biomass, which are still available, can enable a relevant increase of sustainable energy utilisation in the future. Traditional biomass utilisation (e.g. cooking stoves, domestic heating appliances) is often not sustainable, has low conversion efficiency and causes high pollutant emissions. The majority of biomass resources are used in traditional applications, but the share of modern bio-energy technologies (advanced combustion systems, gasification, biofuels) is growing [1]. A wide range of conversion technologies are under continuous development that focuses on improving both the efficiency and environmental impact of biomass conversion. The role that biomass will play in the future global energy mix will solely depend upon these technological developments, which can strongly improve the competitiveness and efficiency of modern bio-energy projects.

Among the conversion technologies biomass combustion is the most mature and reliable technology, which provides over 90% of the global bio-energy production [2]. In comparison to other modern bio-chemical and thermo-chemical conversion technologies combustion of biomass has the advantage of non-selective biomass utilisation, which allows burning of a wide variety of biomass fuels [3]. Various furnace technologies are available for the combustion of biomass and grate furnaces are one of the main technologies in biomass conversion for heat and power production. The development of biomass furnace systems has led to deployment of modernised combustion systems, which enable automated operation, have high efficiency and low particle emissions.

Since the biomass potential in Europe is limited, its utilisation has to be characterised by high conversion efficiencies, which means that the importance of decentralised biomass co-generation plants will grow. Such plants are a promising energy supply alternative as they can reduce the energy transmission losses and the fuel transport distances. The most well-proven and commercial available technology for decentralised co-generation based on biomass combustion is the Organic Rankine Cycle with its main advantages, which are excellent part-load operation and reduced operating costs [4]. There are approximately 130 biomass-fired ORC plants installed all over Europe. However, there is still a lack of information on the advantages and disadvantages of the biomass combustion based co-generation plants. The data availability from existing plants is still insufficient for a clear definition of benefits obtained from bio-energy projects. The collection of measurement results from existing plants can serve as a basis for the determination of energy balances, which are important for market analysis and constant development of the conversion equipment. The evaluation of measurement results and practical experience from existing plants is vital for successful development of decentralised biomass combustion in co-generation plants.

Although biomass combustion is the most mature energy conversion technology, innovations are still needed to deal with the complex phenomena involved in this thermo-chemical conversion process. The maintenance and operation of modern biomass furnaces requires detailed understanding of the combustion process. The advanced biomass furnaces systems are complex installations with separated zones, where the main process steps (drying, devolatilisation, gasification, char combustion, and gas-phase oxidation) occur simultaneously at different places [5].

In this paper the results of experimental analysis, which were carried out on a 6.3 MW_{th} feed grate furnace are presented. The researched combustion system serves as a thermal energy source for an ORC module with a capacity of 1 MW_{el}. This installation has a pilot project character and has been used to gather practical experience, which should support the deployment of this modern technology. The practical experience described in the paper can provide information on how to successfully utilise biomass in decentralised combustion plants. The paper should also enable understanding of the difficulties that have to be overcome when operating an ORC plant based on biomass combustion.

2 ENERGY SUPPLY SYSTEM OF THE AREA SCHARNHAUSER PARK

Scharnhauser Park is a community located in Stuttgart-Ostfildern. The 140 ha area consists mainly of residential buildings and has currently 7000 inhabitants. The major portion of the energy supply of the urban area Scharnhauser Park is provided by a biomass co-generation plant with a nominal electric output of 1 MW_{el}. The plant is fired mainly by natural wood scraps and forested wood is burned additionally. The plant is operated in heat driven mode and provides more than 80% of the heating energy for the area. Additional two gas boilers (5 and 10 MW) have been installed to cover the heat demand during peak load periods.

Co-generation of electricity and heat takes place in an ORC (Organic Rankine Cycle) module, where silicone oil is used as working medium. The use of silicone oil as the working fluid has the advantage that electricity can be produced without high temperatures and pressures, which enables a considerable reduction of the investment costs. Additional advantage of the ORC technology is its excellent partial behaviour [6]. The ORC module can operate efficiently in the range between 30 and 100 per cent of full load and therefore it can be seen as a suitable solution for heat driven operation within a heating network. The waste heat from the electricity generation process in Scharnhauser Park is transferred to a district heating network, which spreads over a length of more than 13 km. The feed temperature of the district heating network is controlled by the ambient temperature, which allows an effective operation through a reduction of the heat losses. The good partial load performance of the ORC module enables flexible adaptation of the plant performance to the heating needs of the inhabitants with an almost constant degree of efficiency.

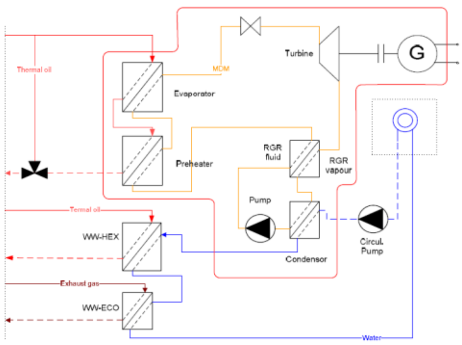

Figure 1: Scheme of the ORC module [7].

The core of the plant is a thermal oil boiler with a nominal capacity of 6.3 MW_{th}. The state of the art biomass grate furnace serves as the thermal energy source for the co-generation process. Thermal oil is utilised as a transport agent between the furnace and the ORC module where electricity is produced.

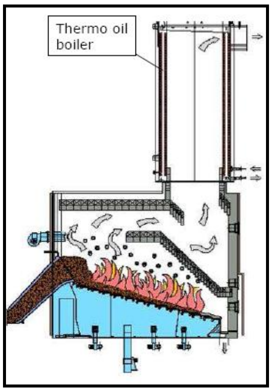

Figure 2: Biomass-fired thermal oil boiler

In modern grate furnaces staged-air combustion is applied in order to make an efficient part-load operation of the combustion system possible. The combustion chamber is divided into primary and secondary combustion zone with separated combustion air supply. The combustion air management system (primary and secondary air) plays a very important role for the emission reduction and efficient operation of biomass furnaces [8]. In the primary combustion zone thermal decomposition of biomass occurs in fuel-rich (under sub-stoichiometrical $\lambda<1$) conditions. During the devolatilisation of biomass in the grate zone NO formed from fuel nitrogen will react with NH_3 and HCN forming N_2. These reactions are used as the primary NO_x-emissions reduction measure [9]. In the secondary combustion zone the gasification products from the primary zone are burned in oxygen reach conditions ($\lambda>1$). If good mixing and high temperatures in the burnout zone are ascertained, the emissions of unburned pollutants (e.g. CO) can be reduced to levels close to zero [2].

In the primary combustion zone thermal decomposition of the fuel occurs on inclined moving grate. Counter-current system of operation is applied on the co-generation plant in Scharnhauser Park, because it is suitable for burning of wet fuels with relatively low heating value. In this mode of operation the fuel moisture evaporation is increased by the hot flue gas, which passes over the wet combustible. The grate transports the biomass in the combustion chamber and distributes the primary air across the fuel bed. In order to protect the grate from negative influence of high temperatures, the grate is cooled by water from district heating network. The grate is separated into sections according to the individual steps of thermal decomposition of biomass on the grate, which are drying, pyrolysis and charcoal oxidation. After the biomass enters the hot combustion chamber, the fuel moisture will be evaporated. As the evaporation effect the temperature in the combustion chamber decreases and the combustion process slows down. Therefore the water content is an important combustible parameter, which has a strong influence on the combustion behaviour of biomass. After the moisture is evaporated the devolatilisation (pyrolysis) of biomass under absence of oxygen occurs. When the volatile substances are released from the combustible, approximately 20% of the fuel mass will remain as charcoal. The charcoal is then oxidised at the end of the grate in the presence of externally supplied combustion air. The primary air supply consists of separate combustion air fans for each step of the thermal decomposition of the fuel in order to meet the requirements of the zones where drying, pyrolysis and char oxidation occur.

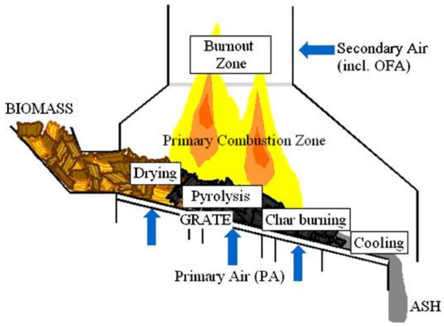

Figure 3: Scheme of a grate furnace [8]

In the furnace of the co-generation plant in Scharnhauser Park, park waste wood is mainly used as the combustible. This kind of biomass is often contaminated with sand and soil, which have become mixed during the harvesting of the wood. The impurities in the fuel, such as dirt lower the ash melting temperature and therefore lead to several operational problems in biomass furnaces. It was observed in Scharnhauser Park that excessive sintering and fusion of the ash in the fuel bed will occur if the temperatures in the grate zone are higher than 900°C. Flue gas recirculation is applied in the analysed combustion system in order to enable efficient temperature control in the combustion chamber.

3 ENVIRONMENTAL IMPACT OF THE ENERGY GENERATION PROCESS

Biomass combustion offers several advantages and combustion based co-generation plants allow an efficient utilisation of biomass potential. However, there are still some technical challenges related to the complex combustion behaviour of biomass, which include pollutants emitted as the result of incomplete combustion and particle emissions. Varying output performance of the combustion system, inefficient combustion air management system and changing fuel parameters can lead to unfavourable burning conditions and therefore higher pollutant emissions. Biomass combustion in low efficient furnaces is an important source of air pollution which can cause several health problems. For that reason the measurement and control of these emissions is of high importance when the combustion plant is used for decentralised production of energy in an urban area. The co-generation plant in Scharnhauser Park is equipped with an emission monitoring system, which allows to analyse and to control the environmental performance of the plant on a regular basis.

3.1 Carbon monoxide emissions

Carbon monoxide (CO) is one of the main air pollutants produced by incomplete combustion. The formation of pollutants from incomplete combustion can be reduced by high temperatures in the combustion chamber, sufficient residence time of the combustible gases in the combustion zone and adequate mixing of combustion air and fuel [10]. To achieve complete combustion of solid biomass a relatively long residence time is needed because of the high volatile content of the combustible. Additionally the furnace design should ensure that the temperature of the combustible gases will not be reduced by heat exchangers until CO converts to CO_2.

The smoke from small scale units with poor process control equipment can contain relatively high amounts of carbon monoxide. CO emissions can be influenced mainly by the excess air ratio during combustion in a given furnace. To low excess air ratio will result in insufficient mixing and lead to incomplete combustion, while to high excess air ratios cools the system and result in decreased combustion temperature [11]. The measured CO emissions can serve as a benchmark of combustion efficiency.

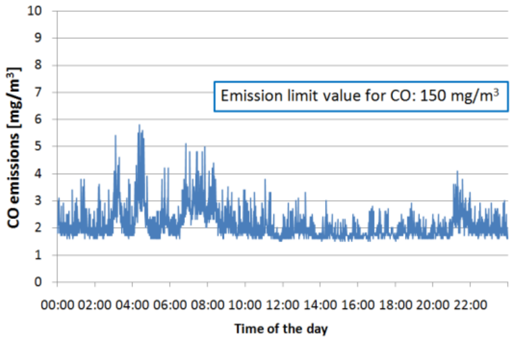

Figure 4: Measured CO emissions

Low emission values measured in Scharnhauser Park indicate that sufficient mixing and combustion temperatures have been achieved in the burnout zone. In large biomass furnaces staged-air combustion can be efficiently utilised to reduce carbon monoxide emissions. Additionally efficient process control in large furnaces enables operation of the system at adequate oxygen concentrations and therefore favourable combustion conditions can be obtained. As the result of good air-fuel mixing and high temperatures in the burnout zones the measured CO emissions are close to zero in comparison to the emission limit values.

3.2 Particulate emissions

Particulate emissions from biomass combustion are one of the main environmental issues related to the utilisation of biomass as energy source. Fine particles (PM 10) have negative health effects as they can be retained deep in the lungs. Small domestic heating appliances, which often operate under part load conditions with lower load, lower excess air ratio and low quality fuel lead to increased particle emissions.

Particles can be emitted as the effect of incomplete combustion and formed from inorganic material in the fuel-ash. Modern grate furnaces with improved combustion control achieve high carbon burnout efficiency [12]. Therefore the particles emissions from incomplete combustion are negligible or none in case of the state of the art large biomass furnaces. Particle emissions from the inorganic material, which are critically related to the fuel properties originate from complete combustion and are the major concern for biomass combustion.

Part of the mineral fraction of the fuel (alkali compounds) devolatalise during combustion and is transported with the flue gas as volatile ash compounds. When the exhaust fumes cool down as they reach the heat exchangers, fine particles can be formed through condensation and nucleation of these vapours. The particle emissions can be affected by excess air ratio, combustion temperature and fuel moisture. However, primary particle emissions reduction measures seems to have only small influence on the amount of emitted particles in large biomass combustion appliances.

Mass concentrations of fine particles in the exhaust fumes may vary between 60 and 2100 mg/m^3 dependent on the biomass fuel and the combustion appliance used [13]. The strict emission limits for fine particles in Scharnhauser Park can only be achieved when the furnace is equipped with dust separation devices.

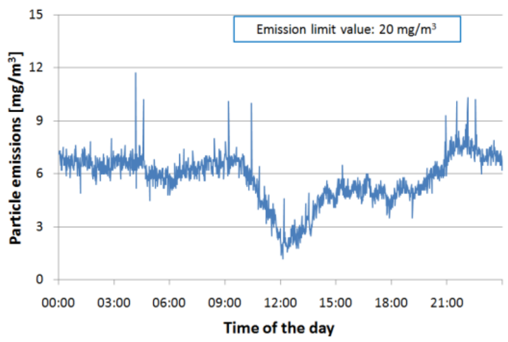

Figure 5: Measured particulate emissions

The mass concentration of fine particles can be efficiently reduced by dust separation devices before the gas is emitted to the ambient. Due to the economy of scale installation of dust separation devices is only economically feasible at large plants and consequently only these units allow achieving of strict emission limit values. The PM emissions measured in Scharnhauser Park are very low in comparison to the emission limit values. Because of the low particulate emissions the deployment of decentralised biomass plants for urban areas is an adequate solution for environmentally friendly utilisation of biomass potentials.

4 TEMPERATURE CONTROL

Measurement results showed that the water content of the combustible can vary widely, which has a strong influence on the adiabatic combustion temperature. On the basis of calculation results it can be stated that the decrease of the fuel moisture in case of the controlled fuel samples can cause a temperature increase of about 200°C.

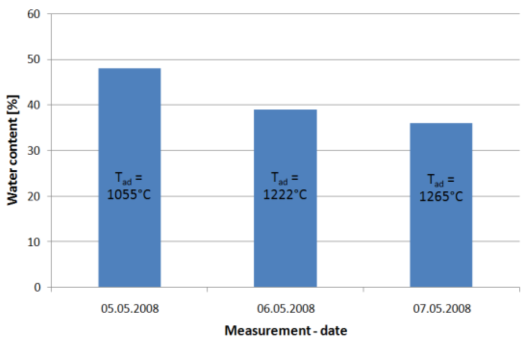

Figure 6: Moisture content and adiabatic temperature fluctuations

Generally the temperature in the grate zone can be defined as the limiting process parameter. Low temperatures causes high emissions of pollutants and lower conversion efficiencies, to high temperatures lead to problems with melting of ash. In the researched furnace changing fuel parameters cause strong fluctuations of the temperature in the grate zone, which cause several operational problems related mainly to ash sintering during combustion.

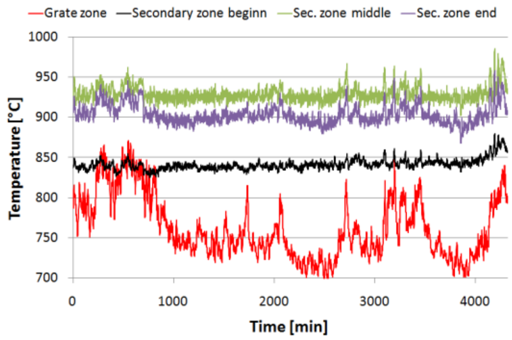

Figure 7: Temperature levels in the combustion chamber

Combustion temperature is the most important process parameter due to its exponential influence on the burning rate. The relation between the adiabatic combustion temperature and the excess air ratio can be estimated on the basis of energy calculations. The optimisation of these variables can contribute to increased efficiency of the combustion process.

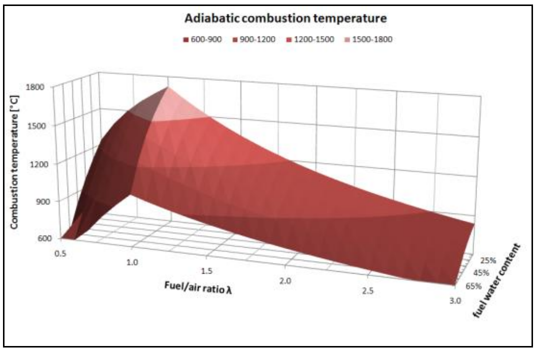

Figure 8: Adiabatic combustion temperature

5 CONCLUSIONS

- The CHP plant can be characterised by an efficient part load operation
- Emissions of pollutants from incomplete combustion are very low or even close to zero
- Problems occur due to changing fuel parameters and temperature fluctuations in the grate zone
- Combustion temperature is the most important process parameter due to its exponential influence on the burning rate

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7 ACKNOWLEDGEMENT

The research work was financially supported by the European Commission within the 6th Framework Programme for research, technological development and demonstration. The authors would like to thank for the financial support within the Marie Curie Research Training Networks (contract number: MRTN-CT-2006-033489, CITYNET).