EFFICIENT AND ECONOMIC DUST SEPARATION FROM FLUE GAS
BY THE ROTATIONAL PARTICLE SEPARATOR AS AN INNOVATIVE TECHNOLOGY
FOR BIOMASS COMBUSTION AND GASIFICATION PLANTS

*BIOS Bioenergy Systems, Sandgasse 47, A-8010 Graz, Austria
** University of Twente, P.O. Box 217, 7500 AE Enschede, Netherlands
***Kohlbach Ges.m.b.H.&CoKG, Wolfsberg, Austria

ABSTRACT: Due to the fact that fly-ash particles and aerosols formed during biomass combustion and gasification processes are contaminated with a high amount of environmentally harmful heavy metals like zinc, cadmium and lead, efficient dust removal from the flue gas is of great importance. The most common dust separation technology in biomass combustion plants with nominal boiler capacities of between 0.5 and 5 MW\textsubscript{g} is the multi-cyclone with a typical cut diameter of about 5 µm. Since biomass combustion causes not only coarse fly-ash particles (ash entrained from the fuel bed with particle sizes greater 1.0 µm) but also a considerable amount of aerosols (fly-ash with a particle diameter <1.0 µm), the dust emissions can only be reduced to about 100 mg/Nm\textsuperscript{3} (dry flue gas, 13 Vol.% O\textsubscript{2}) with multi-cyclones. Since 1\textsuperscript{st} January 1998 a new dust limiting value of 50 mg/Nm\textsuperscript{3} is valid for biomass combustion units with a nominal boiler capacity of more than 2.0 MW\textsubscript{g} in Austria. To keep this goal advanced dust separation systems like fibrous filters or electrostatic precipitators are necessary. Due to the fact that the costs of these systems are more than twice as high as those of multi-cyclones, a new and innovative dust precipitation technology, the “rotational particle separator” (RPS), which provides for efficient dust separation at comparatively low investment and operating costs, is of great interest for biomass combustion as well as gasification plants. The RPS technology for biomass combustion and gasification plants is developed by BIOS Bioenergy Systems Graz, Austria, in cooperation with the University of Twente, Netherlands, and an Austrian biomass furnace and boiler manufacturer (Kohlbach).

1. TYPICAL PARTICLE SIZE DISTRIBUTIONS OF BIOMASS FLY-ASHES

Comprehensive particle size measurements of biomass fly-ashes were performed with a low-pressure Berner-type cascade impactor. Different combustion technologies and various types of biomass fuels, such as bark, wood chips and straw, were considered. The test runs showed the following generally valid results for biomass fuels:

Two different fly-ash fractions differing in their particle size distribution as well as in their composition have to be distinguished.

The first fly-ash fraction consists of coarse fly-ash particles entrained from the fuel bed. The amount of this ash fraction increases with the boiler load due to higher flue gas velocities and is strongly dependent on the combustion technology, the design of the combustion unit and the process-control technology used. The average particle size of this fly-ash fraction is larger than 5 µm, which means that sufficient flue gas cleaning with multi-cyclones is possible. The second fly-ash fraction consists of aerosols which are formed during the cooling phase of the flue gas in the heat exchanger section by condensation of volatile ash-forming compounds (mainly chlorides and sulfates of alkali compounds). In contrast to the coarse fly-ash fraction this aerosol fraction also contains considerable amounts of environmentally relevant heavy metals like Cd, Zn and Pb, which are also easily volatile. Since biomass fuels differ in their content of ash-forming compounds, the amount and the particle size distribution of the aerosols formed during combustion mainly depend on the fuel fired. In the following a brief summary is given on the mass particle size distributions determined with low-pressure Berner-type impactors in several combustion plants firing different kinds of biomass fuels (see Figure 1–3). To prevent an overflow on the upper impactor stage, coarse fly-ash particles were separated in a pre-cutter cyclone located before the inlet of the impactor. Since the main interest focuses on the formation and concentration of aerosols, the ash fraction collected in the pre-cutter is not regarded in the results presented. The amount of this coarse fly-ash fraction mainly depends on the combustion and process-control technologies used and can vary between 50 and more than 1,000 mg/Nm\textsuperscript{3} (dry flue gas, 13 Vol.% O\textsubscript{2}). Concerning aerosol formation during biomass combustion the following important results were obtained:

- The comparison of the graphs in Figure 1 and 2 with those in Figure 3 reveals a significant difference between the particle size distributions determined for grate combustion and fluidized-bed combustion. Generally, the particle size distribution of aerosols formed during grate combustion is unimodal with one distinct peak in the range <1 µm. For bark, wood chips and sawdust the major amount of aerosols was measured in the range of approximately 0.1 µm. The predominating particle size of aerosols formed during straw combustion is about 0.5 µm. In contrast with that, the particle size distribution of the CFBC concerning particles <5 µm is bimodal. The first peak, which is in the range between 0.02 and 0.1 µm, represents the aerosol fraction, while the second peak is due to small ash particles entrained from the
fluidized bed. In comparison with the results of the grate combustion technology, these particles are far smaller (approximately 4 µm) than fly-ash particles entrained from the grate, and thus cannot be separated with multi-cyclones.

- The larger diameter of the aerosols determined for straw-fired combustion units in contrast to wood- and bark-fired units is due to the higher number of initially present particles. As aerosol nucleation theory is pointing out, homogenous nucleation is totally suppressed if the initial number of particles is higher than 2*10^4 particles/Nm³ [2]. Upon reaching this critical value the initial and the final number concentrations are equal. Subsequently, volatile compounds condense on the surface of the aerosols present, thus causing particle growth.

- The total amount of aerosols formed during straw combustion can amount to up to 900 mg/Nm³ (dry flue gas, 13 Vol.% O₂), which is about 10 times higher than the emissions of bark- and hardwood-fired combustion units. The lowest aerosol emissions were measured for softwood-fired combustion units. This is due to the varying amounts of alkali compounds, mainly Na and K, in these biomass fuels.

- Furthermore, concerning the combustion of wood and bark, no significant influence of the fuel particle size, the combustion temperature and the boiler load on the size distribution of aerosols was detected [1]. By comparing the particle loads shown in Figures 1 - 3 with the limiting value for dust emissions of 50 mg/Nm³ (dry flue gas, 13 Vol.% O₂) it becomes obvious that not only coarse fly ash particles but also a considerable amount of aerosols smaller than 1 µm must be separated from the flue gas stream. Consequently, more advanced dust precipitation techniques than the multi-cyclone are required, such as electrostatic precipitators, fibrous filters, or, as a new alternative, the rotational particle separator.

2. DESCRIPTION OF THE RPS-TECHNOLOGY

The RPS consists of three main parts, a static body which is designed like a cyclone, a filter element rotating around the vertical axis of the RPS and a cleaning system designed to remove the particles precipitated on the walls of the filter element (see Figure 4). The RPS can be equipped without internal fan or with an impeller fixed at the top of the filter element. The last mentioned option makes it possible to cover the pressure drops of the RPS and the boiler by the internal impeller (no additional draught fan is necessary in this case).

2.1 The cyclone

The flue gas enters the cyclone through a tangential inlet and is then forced into a rotating flow. Due to centrifugal forces coarse fly-ash particles are precipitated along the walls of the cyclone. Depending on the design of the cyclone body, particles with diameters down to about 8 µm can be separated from the flue gas in this way.

2.2 The rotating filter element

The core of the RPS is the filter element (see Figure 5) which consists of a multitude of small parallel channels.
with a diameter of about 1.5 mm, rotating as one body around a common axis. The pre-cleaned flue gas enters the filter element from its bottom and flows through the channels in axial direction to its top. As a result of centrifugal forces particles are moved in radial direction towards the walls of the filter channels and are precipitated there (see Figure 6). The dust collected and agglomerated on the channel walls is removed periodically by injecting pressurized air at high velocity in reverse flow direction through the channels. This is done by a nozzle moving over the rotating filter element at regular intervals without disturbing the operation of the RPS.

Taking into consideration the equilibrium between the centrifugal force and the Stoke’s force, which describes the resistance of a particle due to its relative velocity with respect to the gas, the motion of a particle in a filter channel can be calculated. The residence time in the filter channel of the smallest particle to be separated with 100% probability ($d_{\text{p0, max}}$) is equal to the time required by the particle to move across the radial distance between the channel walls. Consequently the precipitation probability decreases with increasing gas flow and decreasing circumferential speed of the element. Therefore it is possible to adjust the design of the RPS (its cut diameter) to the particle size distribution of the fly-ash to be precipitated and to the specified emission limits. Cut diameters smaller 1.0 µm can be achieved by varying the gas flow and the circumferential speed of the filter element accordingly [4].

3. PILOT PLANT AND RESULTS OF TEST RUNS

The first RPS designed for a biomass combustion plant was installed in the district heating plant Feldbach (Styria/Austria). The technical data of the combustion unit are:

- fuel: wood chips (water content: 15 – 25 wt.% w.b.)
- combustion technology: underfeed stoker
- nominal boiler capacity: 1.4 MW

Data of the RPS:

- nominal gas flow: 9,000 m³/h at 260°C
- nominal number of revolutions: 1,500 rpm

This RPS has been in continuous operation at loads of between 30 and 120% of its nominal capacity without any serious problems for more than a year. Several dust emission measurements with softwood, hardwood and bark were performed during test runs from February to April 1997 as well as in December 1997. The results show that the dust emissions of the plant were reduced to 40 – 90 mg/Nm³ (dry flue gas, 13.0 Vol% O₂) [5] depending on the biomass fuel used. The dust concentrations in the purified flue gas were below 50 mg/Nm³ for softwood, and between 70 and 90 m/Nm³ for hardwood and bark. These results are due to the higher aerosol amount caused by higher alkali concentrations in these fuels (see section 1).

Comparing these dust concentrations with typical emissions of biomass combustion units equipped with multi-cyclones (between 80 and 150 mg/Nm³), the improvement achieved with the RPS becomes obvious. Hence, the first large-scale RPS proved the suitability of this technology for biomass combustion units.

The next step of development focused on the optimization of the particle separation efficiency in order to obtain dust emission reductions below 50 mg/Nm³ for all biomass fuels. To achieve this aim further detailed information concerning the relations between gas flow, circumferential speed and particle separation efficiency were needed. This led to the design of a pilot RPS, which can easily be transported, assembled and dismantled to carry out test runs in several heating plants equipped with different combustion technologies and using various fuels. Moreover, this pilot unit, in contrast with the first large-scale RPS mentioned above, is not equipped with an impeller. Hence, the number of revolutions of the filter element can be varied independently of the gas throughput. The technical data of the RPS are:

- nominal gas flow: 800 m³/h at 200°C
nominal number of revolutions 3,000 rpm
Furthermore, by taking a side stream from the flue gas of a combustion unit and passing it through the pilot RPS with an external flue gas fan, it is possible to change the operating parameters of the RPS without influencing the combustion process. Several test runs under the following conditions in a hardwood-fired combustion plant (underfeed stoker) were performed:

gas flow: 500 – 1,000 m³/h
number of revolutions: 2,200 – 3,300 rpm
For each test run performed the diameter of the particle which is separated with 100% probability \(d_{\text{max}}\) was calculated by a mathematical model specially developed for the design of RPS units.

Figure 7 shows the evaluated results for an inlet flow of 540 m³/h (160°C) and 2,500 rpm \(d_{\text{max}}=1.14 \mu m\), 2,750 rpm \(d_{\text{max}}=1.04 \mu m\) and 3,000 rpm \(d_{\text{max}}=0.96 \mu m\). Total dust emissions between 34 and 38 mg/Nm³ (dry flue gas, 13 Vol.% \(O_2\)) were determined at the RPS outlet.

The concentration of size-qualified particle concentrations in the flue gas at the RPS inlet and outlet. Flue gas flow: 540 m³/h at 160°C.

In Figure 7 the results for an inlet flow of 930 m³/h (160°C) are shown. The \(d_{\text{max}}\) varied between 1.10 \(\mu m\) and 1.64 \(\mu m\). Total dust emissions of between 44 and 64 mg/Nm³ (dry flue gas, 13 Vol.% \(O_2\)) were determined.

Since particle separation in the range <1 \(\mu m\) during all test runs was better than initially expected according to theoretical calculations, it can be assumed that agglomeration effects in the RPS additionally support dust precipitation in the submicron range.

Due to the results of the test runs and according to economic considerations, small RPS units connected in parallel with a \(d_{\text{max}}\) of approximately 1.1 \(\mu m\) seem to be the most efficient solution for a further optimization of this dust separation technique in order to guarantee dust emissions lower than 50 mg/Nm³. This approach is called “multi-RPS” system.

4. ECONOMIC ASPECTS

In most cases, conventional efficient dust precipitation technologies, like electrostatic precipitators or fibrous filters, are too expensive to be installed in biomass combustion plants with nominal boiler capacities of between 0.5 and 5.0 MWth. The investment costs of a RPS amount only to about 50 to 70% of the costs of conventional technologies. Moreover, the pressure drop of a RPS is similar to that of a multi-cyclone and consequently, the operating costs are about the same (this also applies to electrostatic precipitators). Among the further advantages of the RPS are its small space requirements. It needs about the same space as a multi-cyclone but significantly less than electrostatic precipitators or fibrous filters. Taking into consideration these cost factors and the dust precipitation efficiency of the RPS shown in section 3, the economic as well as ecological advantages of RPS in comparison to conventional dust precipitation technologies for biomass combustion plants are considerable. Future development also focuses on the application of RPS for biomass gasification units for dust as well as tar separation from the gas produced.

REFERENCES


