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Low-emission combustion technology for decentral waste treatment in emerging and developing countries

Mohammad Aleysa[1], Souha Meriee[1] and Niro Akbary[1,*]

[1]Department of Combustion Sytems, Fraunhofer-Institute for Building Physics, Germany

Abstract

This study demonstrates an innovative decentralized combustion system for the disposal of biogenic waste, which is called the Low-Emission Combustion System. An adapted combined flue gas cleaning system is set up downstream of an innovative combustion system for the low emission decentralized incineration of different kinds of biogenic waste. The proposed new technology has been tested by preliminary experimental operation for various application scenarios of waste residuals. Meanwhile, the current environmental and health-related aspects are also investigated and experimentally processed. Emissions such as carbon monoxide (CO), total hydrocarbons (C_nH_m), and nitrogen oxides (NO_x) and different parameters have been measured continuously for a precise valuation of the combustion process. The obtained results indicate that the Low-Emission Combustion Concept can maintain stable operation behavior over a long operating time. The half-hour average concentrations of the fine dust are clearly less than 40 [mg / Vm³] [1]. Even more, constant separation efficiency of the particulate matters (> 50 μm) of more than 93% can be achieved without problems. It is also apparent that no exceedance of NO_x – and CO- concentrations has been observed.

Keywords: low emission combustion, air quality control, incineration, biogenic waste, waste disposal

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1. Introduction

Waste disposal is a challenging problem in emerging and developing countries, especially, due to the increasing waste generation and the shortage of appropriate waste management systems [2]. All typical waste treatment methods need a landfill for final disposal [3]. These dumping sites are, on the long term, unstable and so debatable [4]. The increasing energy demand and waste problems, especially, in residential areas, have led to a rising demand for practicable, replicable and scalable technologies [5]. To that regard, waste incineration is an appropriate method for waste disposal, as well as for energy recovery [6], especially, in countries with lacking waste management systems [7] and densely populated areas. In addition, the increasing prices of fossil fuels and the greenhouse gas issue [8] call attention for clean technologies for biomass and solid biogenic waste combustion.

On the other hand, waste incineration has also its drawbacks when the combustion is carried out in an unclean and inefficient manner, due to incorrect operation, deficient construction, and incorrect control. Non- oxidized products that are generated during the combustion process, such as Polycyclic Aromatic Hydrocarbons (PAH), Volatile Organic Compounds (VOCs) and fine dust particles (PM), are considered to be harmful for the environment and human beings [9]. The emissions arising from waste incinerator are of concern, especially, when it comes to decentralize systems and the availability of secondary, expensive cleaning systems.

The Low-Emission Combustion System (LECS) is an efficient and low pollutant technology for the thermal use of biogenic fuels as well as for waste disposal. It is a multiple solid fuels combustion system for the combustion of biomass and co-combustion of biomass and waste. The speciality of this technology is that it is technically robust, cost-effective and user-friendly. In addition, it ensures a stable operation in all operation phases, regardless of the quality of the combustion and the fuel used. This system has been invented and patented by the Department of Combustion and Exhaust Gas Systems in Fraunhofer Institute for Building Physics IBP. Basically, the Low Emission Combustion System, as a multiple solid fuel system, can be implemented as low, medium and high scale worldwide. As a matter of fact, the high replicability and scalability make LECS technology affordable for different applications, as it guarantees an environmental friendly combustion of different standard and non-standard fuels. In addition, LECS have very low dust and gaseous emissions, and cleaning rates over 99% have been achieved with very high repeatability and reproducibility in tested batches. This high combustion efficiency results from the controlled exhaust gas

*Corresponding author; e-mail: niro.akbary@ibp.fraunhofer.de

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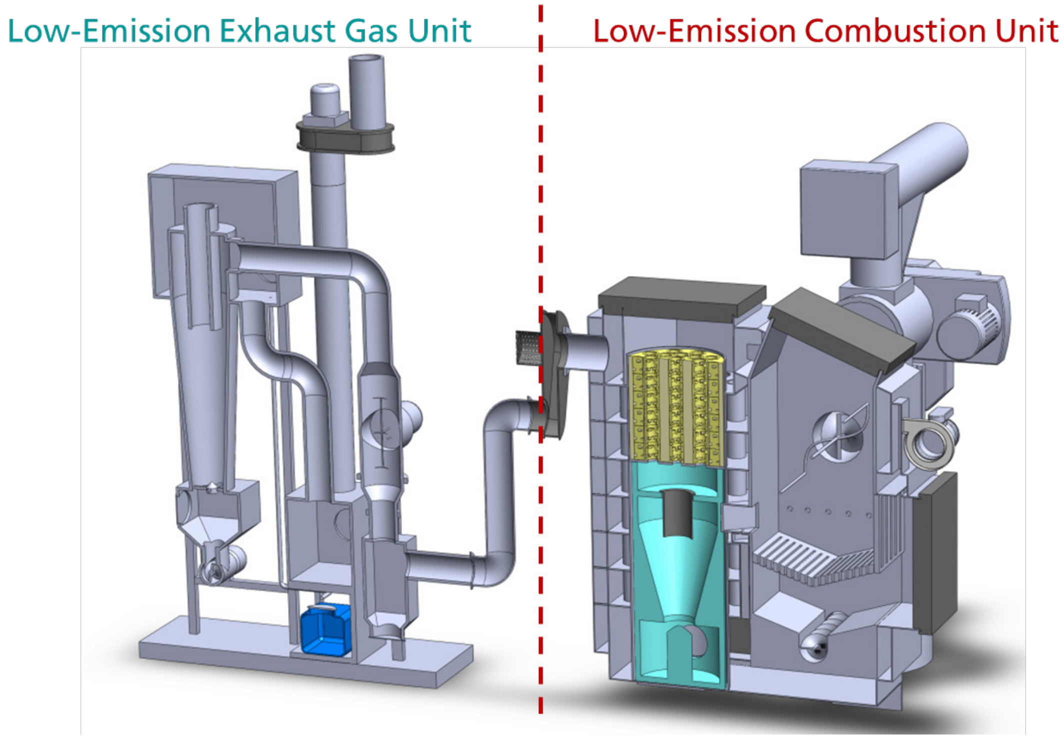

Figure 1 Low-Emission Combustion System (LECS) consisting of two units [12].

temperature and the constantly-clean heat exchanger surfaces, as well as from the minimization of the energy-containing components which ensure a complete combustion [10]. Therefore, a boiler efficiency of more than 91% can be achieved in nominal load operation [11].

2.Material and Methods

2.1 Low-Emission Combustion Concept and Functionality

The Low-Emission Combustion System (LECS) is an innovative combustion technology consisting basically of two processing units, 1) the Low -Emission Combustion Unit and 2) the Low -Emission Exhaust Gas Unit (see **Figure 1**). So far, it has been successfully tested as a multiple solid fuels combustion system for the combustion of biomass and co-combustion of biomass and waste without using expensive exhaust gas cleaning systems, according to the german limit values of 17 BImSchV (Ordinance for waste incineration plants) [1]. Zero concentrations of emissions for carbon monoxide, carbon hydroxides and gravimetric measurable emissions were often achieved in regular operation of the LECS. Additionally, the heat-up phase of the combustion process, during which most of the pollutants are commonly emitted, was reproducibly improved. In the followings sub-sections the specifics of the two units are explained in more detail.

1) Low-Emission Combustion Unit

The Low -Emission Combustion Unit consists of a three-stage combustion unit, supplied with an innovative three-fan-air supply system, as shown in **Figure 2**. In the first combustion chamber, primary air is being supplied understoichiometrically by a pressure fan to adjust the gasification of solid fuels, the generated power, as well as the temperatures of the boiler and the exhaust gases. The generated, burnable gas is led into the second combustion chamber which, due to its shape, is also called the cyclone-combustion chamber. Here, the accruing combustion gas gets burned, depending on the oxygen content inside the exhaust gas, by virtue of the supply of secondary air, using a pressure fan. Moreover, fine particles are agglomerated and separated by centrifugal forces in the cyclone.

The next process step, the so-called Internals Technology, makes up the main difference with other gasification boilers. It is an integrated treatment stage, consisting of ceramic modules for the oxidation of unburned exhaust gas components. The oxidation can be achieved, because the Internals store heat during combustion. The heat is released as soon as the temperature drops below the minimum oxidation temperature. Additionally, the special architecture of the Internals increases the residence time of the exhaust gas by causing turbulent mixing of the latter while at the same time increasing the mixing of combustion air and flue gas which also improves the combustion of unburned components. In the end, the low-emission exhaust gas submits its heat to the heating system and is finally discharged by a fan.

The supply and extraction of the combustion air is realized by two fans that are controlled by a Programmable Logic Controller (PLC). The

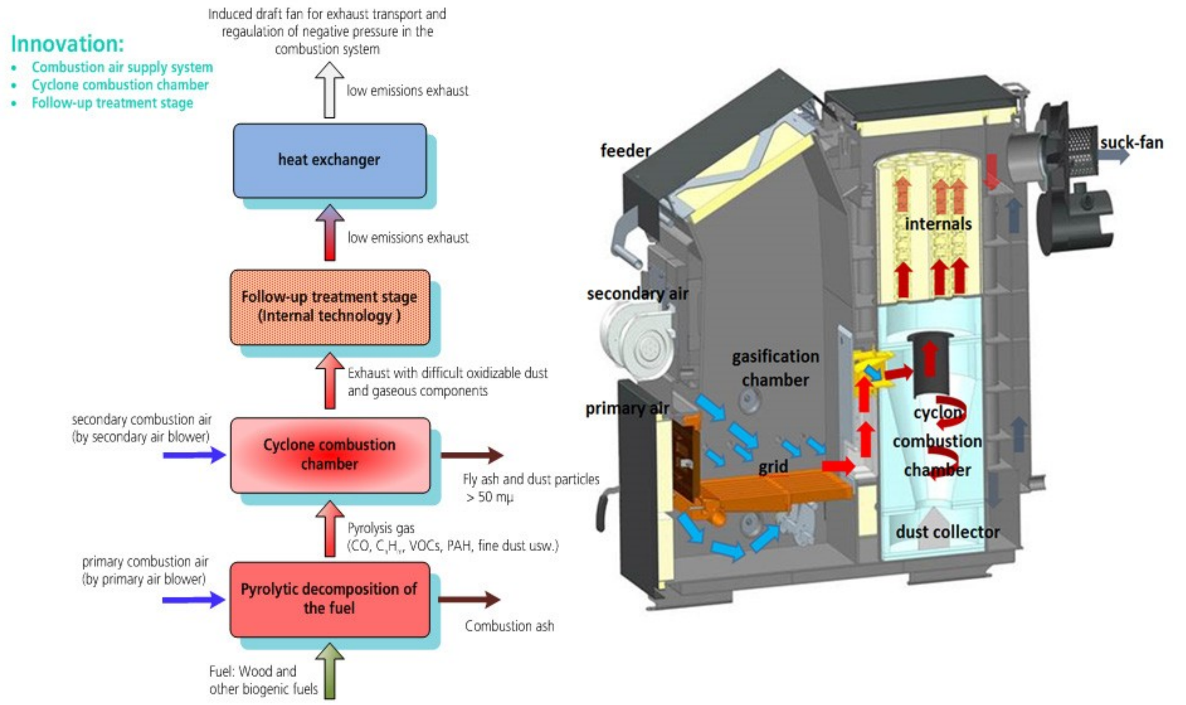

Figure 2 Design and functionality of the Low-Emission Combustion Unit [13]

programming has been invented and improved within the scope of a research project, the so-called LEVS project in the Fraunhofer Institute for Building Physics IBP/ Combustion and Exhaust Gas Systems. The aim of this project was to ensure a significant reduction of gas and dust emissions in all operating phases for the use of small-scaled combustion systems fired by biogenic fuels in residential areas, so that the future technical emission requirements of the 1 st BImSchV (First Federal Pollution Control Ordinance) can be complied with without further secondary measures [13]. The intelligent control can be achieved by a smart interaction between the primary-, secondary- and exhaust-gas fan. Thereby optimized pressures, boiler and exhaust gas temperatures as well as oxygen contents are being adjusted.

2) Low-Emission Exhaust Gas Cleaning Unit

The Low-Emission Exhaust Gas Cleaning Unit is an innovative exhaust gas treatment system for the cleanup of dust and gaseous emissions during the combustion of biogenic fuels in domestic boilers, according to DIN EN 303-5. This system is a combination of a fine dust agglomeration unit with a downstream centrifugal separator. The agglomeration can be done electrostatically, acoustically and through wet processes, as well as by a combination of these methods. The agglomerated particulate matters are deposited in a downstream centrifugal separator. In order to achieve an efficient separation-performance in the cyclone, independently of the fluctuations in the thermal boiler output and the generated exhaust gas volume flow, a partial flow is taken from the main exhaust gas flow behind the cyclone and fed back at the entrance of the cyclone. When using wet processes, the system can be quasi- or fully-wet operated. In both operating variants, a high constant deposition of fine dust particles and the treatment of acidic pollutant components, such as sulfur dioxide, hydrogen chloride, hydrogen fluoride and nitrogen dioxide, can be achieved. A significant reduction in these components can be obtained by using a solution of potassium hydroxide or other detergents.

3. Innovations

The biogenic solid fuel is gasified under stoichiometrically in the gasification chamber, due to the supply of primary air and heat [14]. In the subsequent cyclone combustion chamber, this produced gas is then completely oxidized, by virtue of the supply of secondary air [15]. The removal of particles (> 50 μm) is also ensured by the centrifugal power of the special cyclone-combustion chamber. An integrated burn-out stage is the “Internals” Technology, which is a unit of ceramic modules with the task to oxidize the difficult-to-oxidize exhaust gas components. The “Internals” store heat during combustion and then release it, as soon as the temperature drops below the minimum oxidation temperature. Due to the long oxidation path in both the cyclone and the “Internals”, an increase of the residence time of the exhaust gas in a high-temperature environment can be achieved. In addition, the turbulences that result from the centrifugal flows in the cyclone as well as turbulences in the internals enhance the mixing of the combustion air and the flue gas in the high temperature zone. As a result, only low concentrations of hazardous emissions (CO, C_nH_m, particulate matters and others) are released. Furthermore, zero concentration of carbon monoxide is often achieved. At the end, the low-emission exhaust gas submits its heat to the heating system and is then discharged by a fan to the outside environment (**Figure 2**).

The advantages of each component of the Low-Emission Combustion System can be summarized as follows:

3.1 Low-Emission Combustion Unit

Innovative air supply system:

1) no flow dependencies and separate control algorithms for primary air, secondary air and exhaust gas fans;

2) no influence of changing weather conditions or exhaust gas parameters on the supply of the combustion air;

3) no influence on the air distribution.

Cyclone-combustion chamber:

4) pre-separation of coarse dust particles (> 50 µm,) with efficiencies of 95 %, because of the centrifugal forces in the cyclone as well as an intensive separation of fine dust particles (< 50 µm) due to the agglomeration effect during the circulation of the particles;

5) intensive mixing and extension of retention time;

6) higher modulation capability;

7) avoidance of short-circuit currents in the combustion chamber area due to smaller gas volumes;

8) no mechanical cleaning required, since it is a self-cleaning system;

9) cyclone technology uses no moving parts, so no aging with operating time will occur.

Post treatment step:

10) internals act as a reactor that ensures a complete combustion, apart from the dynamics of the gasification process;

11) enlargement of the active reaction surface (intensification of mixing, homogenization and stabilization of the temperature);

12) separation and thermal treatment of combustibles ;

13) maintaining of low emissions during burn-out.

In general, the incineration of waste should be followed by flue gas cleaning steps [9]. The Low-Emission Combustion Unit ensures the reduction of dust and gaseous emissions by primary measures. Low emissions of CO and PMs are guaranteed due to the particular structure of the cyclone-combustion chamber and the internals technology. Other gas emissions are also of concern, such as nitrogen oxides, sulfur dioxides and hydrochloric acids in the case of biogenic waste incineration.

Low-Emission Exhaust Gas Treatment Unit

The Low-Emission Exhaust Gas Treatment Unit is integrated to ensure an efficient and stable separation of dust and gaseous emissions in continuous practical operation. The functional principle of each part of the flue gas cleaning system can be described as follows:

Ionization chamber:

1) negative charging of the dust particles in the ionization chamber to improve the agglomeration behavior of the fine dust particles which leads to a mass and volume increase by the formation of agglomerates,

2) operates in wet as well as in quasi-dry operation by adding fine water drops to support the agglomeration process.

Cyclone:

3) the already agglomerated dusts and water droplets are separated due to the centrifugal forces in the downstream cyclone.

Exhaust Gas recirculation:

4) prevention of condensation.

Draft fan

5) collecting the cleaned exhaust gas.

The main characters of the innovative flue gas system can be distinguished by the following technical features and advantages:

6) continuous operation with high separation efficiency, independent of the exhaust gas parameters, such as: speed, temperature, pressure, exhaust composition and dust load;

7) particularly suitable for waste gas deducting or exhaust gas cleaning in the combustion of problematic fuels, such as biogenic or medical waste;

8) high operating modulation capability and flexibility against changes in exhaust gas parameters, thanks to the combination of electric agglomeration and centrifugal separator;

9) due to the compact design, up to 600 m^3 of flue gas, which corresponds to a thermal output of approximately 150 kW, can be treated smoothly;

10) safe disposal of the separated dust, thanks to a modern dust container system;

11) wet operation of the system is particularly suitable for the deposition of sticky dusts which often result from biogenic fuels;

12) no mechanical device needed to clean the precipitation electrode. The cleaning takes place continuously and pneumatically, because of the turbulent flow in the cyclone.

4. Experimental Investigation

In the frame of a research project in the Department of Combustion and Exhaust Gas Systems in Fraunhofer Institute for Building Physics IBP, preliminary experimental investigations are performed on a prototype of the concept, with a thermal capacity of the test incineration plant of approx. 65 kW, to assess the suitability of the Low-Emission Concept for the combustion of biogenic waste. In this experimental

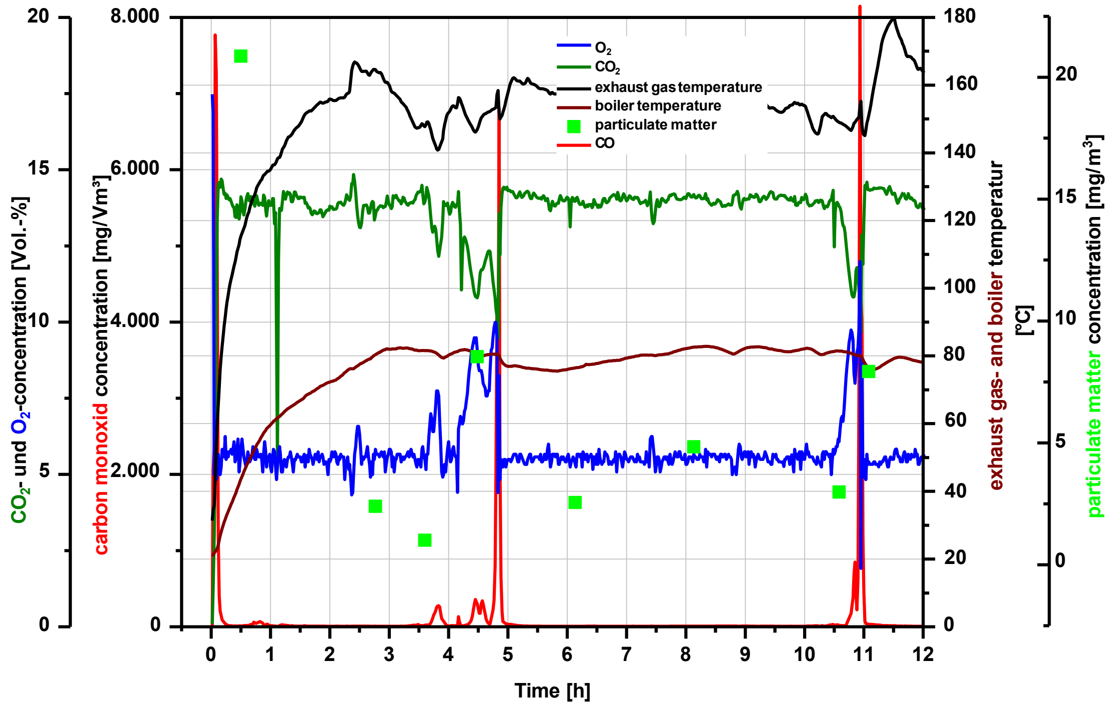

Figure 3 Results of preliminary experimental emission concentrations measurements (left axis) and separation behavior for different raw gas dust concentrations as well as O_2 and CO_2 content (left axis) of the Low-Emission Combustion System.

Table 1 Mean values of emissions reached during operation phases

categories	**start-up**	**regular operation**	**burn-up**
duration as a proportion of the total period of combustion [%]	2-4	85-95	3-5
CO-mean [mg/Vm^3]	2000-8000	50-150	3000-10000
dust according to VDI 2066 [mg/Vm^3]	< 100	< 10	< 50

study, the combustion behavior of the fuel, the generated flue gas and the flow-related parameters have been determined. A wide range of measurements with different operating parameters and several fuel charges have been carried out on a prototype of Low-Emission Combustion Concept. This system has been successfully tested with different kinds of solid biogenic fuels and waste.

Comprehensive measurements on dust and gaseous pollutant (total and fine dust, NO_x and SO_2), the stability and efficiency of dust separation in continuous operation are carried out in practice using various kinds of biogenic fuels. **Figure 3** illustrates the stable combustion of solid biomass fuels in a Low Emission Combustion System. Here, carbon monoxide is less than 50 mg/Vm³ and dust emissions are less than 7 mg/Vm³. Furthermore, the start-up and feeding phases, where most of the pollutions are commonly generated, are reduced, which has a great positive influence on the significant reduction of hazardous emissions.

Mean values of CO and dust emissions according to VDI 2066 standard as a proportion of the total combustion period are shown in **Table 1** [16]**.** These emissions are measured in the different operation phases of waste combustion in LECS**.** Zero concentrations of emissions for carbon monoxide, carbon hydroxides and gravimetric measurable emissions were oft achieved in the regular operation of the LECS.

5. Discussion and conclusions

On the basis of the achieved results, the technology can maintain stable operation behaviour over a long operating time. Low emissions of hazardous exhaust gas compounds during the experimental measurements in laboratory and practice and, particularly, with regard to the satisfaction of the required limit values of 17st BImSchV have been achieved. It should be kept in mind that the German laws are in fact among the strictest environmental laws in Europe. In addition, the half-hour average

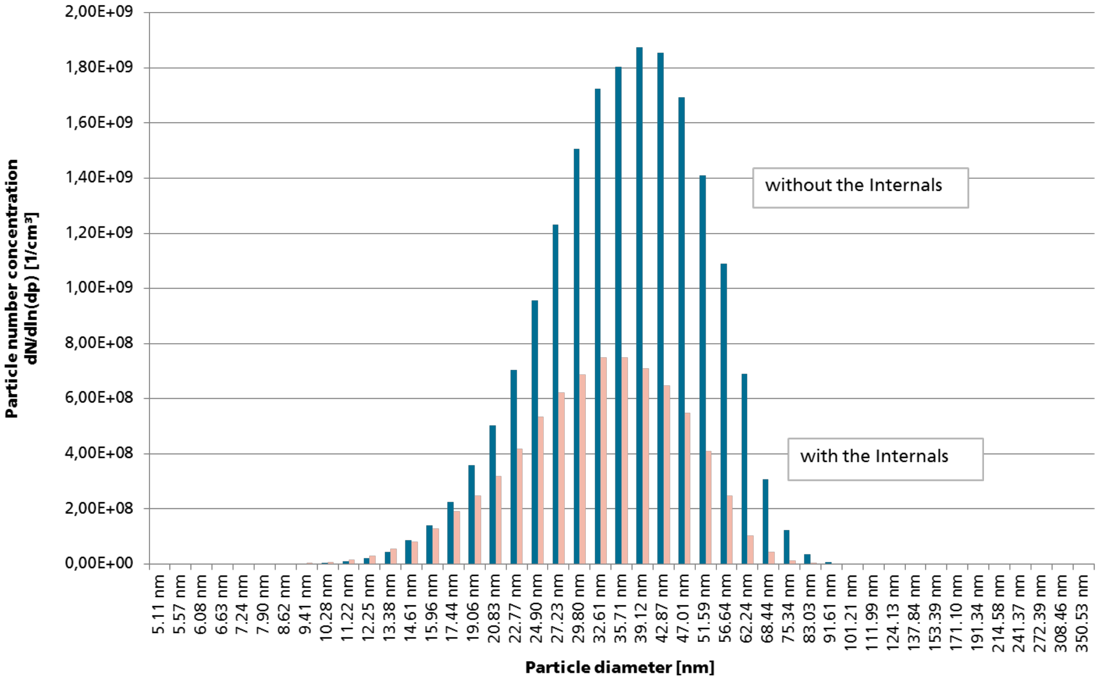

Figure 4 Histogram of fine dust concentrations as a function of the particle diameter without and with "Internals" Technology

concentrations of the fine dust are clearly below the required limit value of 20 [mg / Vm³], required by the 17 th German Federal Pollution Control Ordinance [1].

The good separation effect of the Internals on the particulate matters (< 400 nm) can be clearly seen in **Figure 4**. A constant separation efficiency of more than 93% can be achieved without problems for particulate matters > 50 µm. It is also apparent that the system was able to guarantee very high separation rates over a wide range of particle diameters. In addition, no half-hour average of CO- measurements exceeds the regulation limit, owing to the special innovative construction of the cyclone and the Internals (**Figure 3**). No exceedance of NO_x - concentrations has been observed.

The use of the integrated primary measures (cyclone-combustion chamber and the internals) not only ensures the fulfilling of the regulation limit values of the 17st BImSchV in continuous operation by drastically reducing the concentrations of fine dust and carbon monoxide, but they also offer cost-effective and competitive combustion technologies for the thermal utilization of biomass and other biogenic fuels.

In addition, the manufacturing of the Low Emission Combustion technology can be easily realized, since it does not require specific materials and the required materials are all at hand. This fact makes it very easy for series production. The economic advantages of this concept can be clearly demonstrated in automatically fed boilers with thermal capacities underneath 100 kW, in which a well-functioning and cost-effective filter system cannot economically be implemented.

As a further implementation, the development of this combustion technology will be carried out in Egypt for the safe disposal of medical waste. This project is funded by the Federal Ministry of Education and Research (BMBF), which promotes research projects in the field of applied environmental research in emerging and poor countries, will be implemented by the Fraunhofer Institute for Building Physics IBP and the Suez Canal University SCU. This innovative combustion concept will lead to low-emissions combustion and inert the waste materials, due to its internal high temperatures (above 800°C), by using primary measures and cheap secondary measures. All these properties make the Low-Emission Combustion System very valuable for the safe disposal of medical waste.

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