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Research paper

2-Year field operation monitoring of electrostatic precipitators for residential wood heating systems

Thomas Brunner*, Gerald Wuercher, Ingwald Obernberger

Bios Bioenergiesysteme GmbH, Hedwig-Katschinka-Straße 4, 8020 Graz, Austria

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ABSTRACT

To assess the applicability of electrostatic precipitators (ESP) for particulate matter (PM) emission reduction in old residential wood heating appliances comprehensive field tests with accompanying ESP operation monitoring and dedicated emission measurement campaigns have been performed in the region of Graz (AT). Three OekoTube ESPs were thereby tested during the heating seasons 2014/2015 and 2015/2016 at different sites with rather old respectively high-PM-emission wood burning devices. Before installing the ESPs at the field testing sites they were checked in the lab regarding functionality and precipitation efficiency. The evaluation of the plant monitoring data collected during the field tests revealed high seasonal ESP availabilities between 80.2% and 97.7%. Dedicated test runs with emission measurements at the different testing sites showed high precipitation efficiencies which were well comparable with those gained during preceding lab-tests. Based on these results it can be concluded, that ESP models like the OekoTube are suitable as retrofit units in old appliances and have due to their high availability and particle precipitation efficiency the potential to contribute to a significant reduction of particulate matter emissions from old residential wood burning systems.

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1. Introduction and objectives

According to the European Biomass Association (AEBIOM) more than 50% of the bioheat produced in the EU28 is related to residential heating [1]. Logwood stoves, logwood boilers, pellet boilers and wood chip boilers are thereby the most common heating technologies. However, biomass burning in stoves and outdated boiler systems is increasingly criticized as a major source of particulate matter (PM) emissions. With the introduction of the EU directive 1999/30/EC, which limits among others PM_{10} concentrations in the ambient air, it had to be recognised that in many European regions the related limit value is more frequently exceeded than allowed. As the main sources for PM emissions traffic, industry and domestic heating have been identified. It has furthermore been shown that the contribution of residential biomass combustion to the total PM emissions of the residential heating sector exceeds 80% in some European regions.

Previous research projects dealing with this problem have revealed that especially old wood burning appliances are responsible for the high PM emissions of the residential heating sector [2–4]. An appropriate solution to the problem would be to exchange old appliances by modern low-emission systems. However, since owners of outdated heating systems cannot be forced to shift to newer ones and since also incentives for replacing old boilers did up to now often not show the desired effect, the application of precipitators for PM emission reduction seems to be the economically most feasible short-term approach.

The city of Graz (AT) is located in a typical basin-shaped region with a low exchange of air especially during winter time. This leads to accumulation of PM in the ambient air and consequently to more frequent exceedances of the PM concentrations allowed. A broad application of particle precipitators in old wood burning appliances could therefore, among others, be one appropriate countermeasure against air pollution. Recent work has shown that especially electrostatic precipitators (ESPs) are suitable for PM emission reduction from residential biomass combustion appliances [5]. However, former research projects such as the ERA-NET Bioenergy project FutureBioTec [6] have also revealed that many ESPs presently available are not designed for a long-term operation at the harsh operation conditions prevailing in old logwood boilers and stoves which are characterized by a flue gas with insufficient burnout as well as high soot and organic aerosol emissions. The reason

* Corresponding author.
E-mail address: brunner@bios-bioenergy.at (T. Brunner).

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therefore is that presently ESPs are mainly developed with the aim to safeguard the keeping of the stringent dust emission limits for pellet and wood chip combustion defined in the 1. BImSchV in Germany (federal emission control act [7]). Consequently, they are designed for much better burnout conditions than prevailing in old appliances. Moreover, no reliable long-term performance data regarding ESP operation are available.

Thus, the overall objectives of the work presented has been to identify an ESP technology suitable for the application with old high-emission wood burning appliances and to test it over two heating seasons within field tests in the region of Graz. These field tests should be accompanied by a comprehensive monitoring and measurement program.

2. State-of-the-art of particle precipitation devices for small-scale biomass combustion systems

In medium and large-scale biomass combustion processes the application of electrostatic precipitators (ESP) or baghouse filters for fine particulate emission control has been state-of-the-art for many years. With steadily decreasing emission limits regarding dust emissions from small-scale biomass combustion systems also the development of filters for such applications has been intensified during the last decade. In 2011 a comprehensive review on PM emission reduction technologies for small-scale wood burning appliances has been published by IEA Bioenergy Task 32, Biomass combustion and co-firing [8]. According to this study, ESPs represent the most promising options while other dust emission reduction technologies (filtering devices, sprayers, condensers and oxidation catalysts) do not reach the anticipated long term performance and emission reduction efficiency. It is worth to mention that generally two different ESP concepts could be identified. One concept is designed for an application as an add-on at the top of the chimney. This concept bears the big advantage that no space inside the building is needed for the ESP which makes it easier to apply as a retrofit unit. On the other side the filter is exposed to the ambient and therefore a robust design is needed. The second concept foresees an application of the filter between the stove or boiler and the chimney. This concept is more space demanding and, in case of stoves, to be assessed as problematic since the ESP must then be mounted in the room where the stove is located (typically the living room).

According to the IEA survey three ESP technologies, the ESPs Zumikon (from Rüegg Cheminée AG, Switzerland), the Airbox ESP (from Spartherm Feuerungstechnik GmbH, Germany) and the ESP Oekotube (from the company OekoSolve, Liechtenstein) have already been in the market in 2011.

At the same time a Danish study [9] evaluated the application of particle precipitation devices in connection with old-technology (high emission) stoves. Five technologies were tested under controlled conditions in the laboratory and subsequently by mounting them on appropriate stoves in private homes. The technologies were the ESPs Zumikon, Airbox and CleanAir ESP (from Applied Plasma Physics AS, Norway) as well as oxidation catalyst technologies from MoreCat GmbH, Germany and ECOXY AS, Norway. The main conclusion of this study was that all the technologies had a reducing effect on the emissions, but their efficiencies were low. The authors concluded that it seems to be much more environmentally sustainable to work for a replacement of old wood stoves and boilers with new low-emission systems.

In a German study [10], multi-pipe electrostatic precipitators for boilers from Spanner RE^2, Germany (type "SFF20" or SFF50″), a chimney-top model from the Norwegian company APP and a Zumikon ESP fitted into flue the gas duct between furnace and chimney were tested over a complete heating season in a field trial. Long-term combustion test stand trials were additionally conducted. Average particle precipitation rates between 12 and 80% were achieved and the authors of the study pointed out that before practical application, some operational problems and malfunction risks of the prototypes have to be solved to make their operation robust enough for a broad market application.

One general finding of all studies performed at this time was that additional R&D was needed to make the different ESP systems more reliable and especially also applicable for old residential wood heating appliances.

In Germany, the Technology and Support Centre in the Centre of Excellence for Renewable Resources (TFZ) and the Deutsches Biomasseforschungszentrum (DBFZ) jointly organize an annual expert meeting regarding dust precipitation devices for small-scale biomass appliances ("Abscheider Fachgespräch") at which an international update on actual filter technologies as well as current developments is provided. In 2015 and 2016 [11,12] these events have shown that especially ESPs are presently under development or already offered on the market by a number of manufacturers. Most of the applications are mounted in between the boiler and the chimney and generally the target application of the filters are modern wood chip, pellet and logwood boilers and not old wood burning appliances characterized by very high emissions of soot and organic particles. Moreover, R&D on some other concepts (filtering precipitators, oxidation catalysts for stoves) is ongoing but these systems are still in the development stage.

3. Approach

3.1. Selection and description of the ESP technology

At first, an appropriate ESP technology, which is capable to operate at the harsh conditions of old biomass burning appliances had to be identified. Test runs with four different ESPs performed within the former Austrian R&D project BM-PM-Filtertest (funded by the Austrian Climate and Energy Fund) have shown that the availability and precipitation efficiency of ESPs may significantly suffer from high concentrations of organic aerosols and soot in the raw gas which lead to problems and failures with ESP operation. In this project, the ESP OekoTube of the company OekoSolve (CH) has been identified as reliable ESP, which can, due to its specific design concept regarding isolator and electrode operate at poor burnout conditions of the biomass boiler resp. stove to which it is connected and achieves very good precipitation efficiencies. Moreover, the OekoTube at this time was the only reliable system, which can easily be applied as retrofit unit, since it is mounted at the top of the chimney. For these reasons, the OekoTube technology was selected for the field tests.

The OekoTube is a typical tube-type electrostatic precipitator. The unit consist of a T-fitting (9 in Fig. 1) and a metal tube which are mounted on top of the chimney (chimney-top application). It uses the inner surface of the chimney or in case of a non-metallic chimney an extended metal tube (as shown in Fig. 1) as precipitation electrode. A 1.6 m long electrode (10) thereby extends downwards in the chimney and is connected with an insulator (5) positioned outside the flue gas stream. The electronic circuit and the control unit (2) are mounted outside and protected with a cover (4) against weathering. The power consumption of the ESP amounts to 20–30 W during operation and the high-voltage power applied is usually in the range of 15–30 kV. The OekoTube is applicable for biomass combustion systems up to 40 kW.

The OekoTube is equipped with a temperature sensor (7 in Fig. 1) which measures the flue gas temperature. Based on the exceedance of a predefined temperature the control system identifies the start-up phase of the heating system and automatically

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