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Electrostatic precipitators for small scale wood furnaces

Small electrostatic precipitators (ESP) can in the future largely contribute to the reduction of fine particle emissions from residential wood furnaces. Therefore three prototypes were tested over a complete heating season in a field testing campaign with a total of 10 ESP's. Long term tests were also performed at a combustion test stand. The measured mean removal efficiencies were inconsistent between 12 and 80 %. Prior to any market implementation several operational and breakdown risks have still to be tackled. Also the test methods for determining the removal efficiency need improvement and standardization.

Keywords
Particle filters, wood furnace, stove, ESP, particle emission

Abstract
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Ultra-fine particles in respiratory air represent a health risk, i.e. particles measuring less than 10 µm and mainly originating from furnaces. Fireplaces and domestic central heating systems using wood fuel carry a high degree of responsibility in such cases. For this reason particle emission restrictions from such furnaces and the monitoring of such emissions in Germany were tightened-up in March 2010. The restrictions are to be further increased in January 2015.

Among methods of complying with these and future treshold values is the application of retrofitted particle filters. A number of European developers and manufacturers recognise hereby an interesting future market. First prototypes already exist and some of these have been investigated and assessed on test stands and in practical trials.

Filter principle and design

Of the three filter concepts investigated, all apply the pipeline electrostatic filter principle. This features the central positioning within an exhaust air pipeline of an electrically-charged (15 to 33 kV) wire or rod (**figure 1**). Particles carried through the resultant electrical field between electrode and pipeline wall become electrically charged. This results in the particles being attracted to the metal pipeline walls where their charge can be released. Some particles then remain attached to the wall and/or cluster with other particles. They can be cleaned from these positions by manual brushing or through mechanical agitation systems. In comparison to barrier filters, the advantages of this principle include the low pressure loss within the exhaust flow and the costefficient construction, the expected cost involved being around 1,500 €.

Three prototypes were investigated (**figure 2**): a multi-pipe precipitator for boilers with active, mechanical agitation, cleaning system („SFF20" or „SFF50" from Spanner RE^2, Neufahrn), a chimney attachment model („APP $R_{esidential}$ ESP" from the Norwegian company APP) and a model for fitting into exhaust gas flues („Zumikron" from Rüegg Cheminée AG in Switzerland).

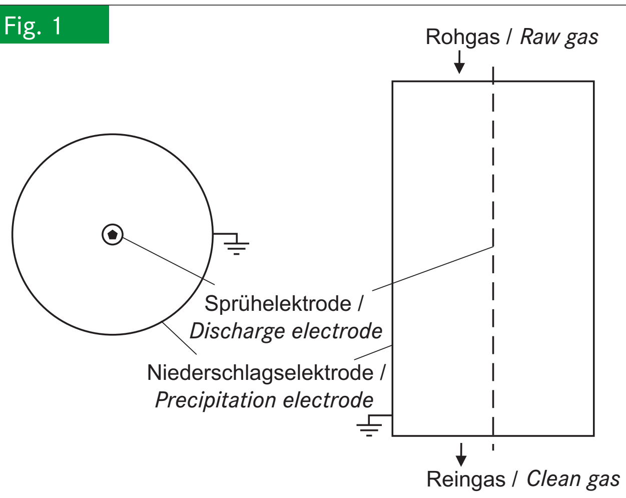
Field trial

Ten private households around Straubing (Bavaria) were selected for a field trial so that in total seven fireplace systems and three central heating boilers could be operated in each case with one of the three precipitator types over a complete heating season. Among the factors recorded were fuel type and particle output. Any malfunctions were recorded and/or corrected as quickly as possible.

Identified under the realistic operational conditions were numerous problem areas and optimisation opportunities. In particular, the following weaknesses or malfunctions – uniformly distributed over the three different precipitator types – were observed (in some cases several times): voltage flashovers, failure of air flow around the electrode, fuse blow-outs, display failure, electrode breakages, attachment failures, sensor defects, high-tension voltage loss, chimney draught problems, rainwater ingress, coordination problems with firing and excess noise generation. Among the more important acceptance problems for users were those arising from installation within the living areas (Zumikron model). Where the device was attached to the chimney-opening, fitting was often obstructed through lack of suitable opportunity for mounting and through lack of access to the roof for the required regular cleaning (APP $R_{esidential}$ ESP).

With all the ESPs the significant amount of dirt collecting on the electrodes and insulation (**figure 3**) led to occasional, or even more than occasional, malfunctions and short-circuits.

Fig. 1



Basic design of a pipe-type electrostatic precipitator (ESP) (cross section and longitudinal cut)

This made it clear that there remains considerable scope for improvement before a problem-free and large-scale practical application becomes reality. However, some solutions were able to be identified during the tests.

Because direct measurement of the particle removal efficiency was not possible during the field tests a highest value for the theoretical maximum particle emission avoided was calculated based on the respective amounts of flue and filter ash collected. In the case of the fireplace systems maximum particle reduction calculated in this way was between 4 and 179 mg/Nm^3 (**table 1**). With pellet-fired boilers particle emission reduction was, as expected, significantly less at 5 mg/Nm^3, whilst for the wood-chip and log-fired boilers remarkable reductions in particle output was recorded with over 100 mg/Nm^3.

Test stand measurements and long-term trials

Long-term trials were carried out with the three ESPs featuring in each case around six weeks of practice-typical operation on the test stand. Each of the three ESP types was operated with a „modern“ and a „simple“ chimney furnace, or on an older log-fired central heating boiler. The degree of filtration was determined on a weekly basis through gravimetric particle sampling via a dilution tunnel after the ESP and through a regulated partial flow dilution carried out before the ESP. The latter method was specially developed for the trials.

The results show a tendencially reduced filtration effect with high particle emissions in the raw gas (**figure 4**)). With the APP Residential ESP used with woodstoves an average separation of over 60 % could be achieved while the Zumikron system proved to have hardly any effect with a separation degree of less than 20 % within the trial design selected in this case (i.e. approx. 1.5 m separation pipeline after the spray electrode. However, in practice this value could lie higher as shown by field trial results (**table 1**).

Particle separation degrees as low as this are always accompanied by very high fluctuations of recorded values (with a coefficient of variation (CV) here of around 200 %) and some individual recordings even indicated a negative separation value with the Zumikron equipment. This allows the conclusion that particle-sampling results can be significantly influenced by electrostatic-charged particles able to be redirected at the sampling nozzle which leads to the possibility that their concentration could be overestimated. With higher-efficiency filter systems this error is not so marked. For example, measuring fluctuations with the Spanner-SFF20 lay in the normal range of particle measurements with CV = 22 % and the average separation degree was also highest here at 80 %.

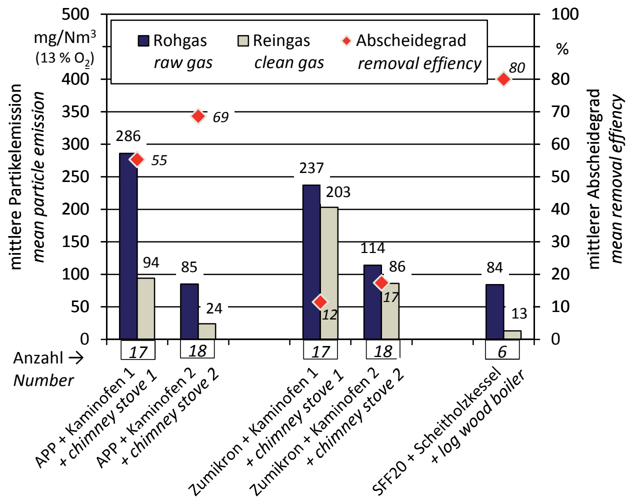
Fig. 2

Examples of precipitators used in field tests; left: Zumikron in flue gas pipe of a stove; middle: APP R$_{esidential}$ ESP in chimney top; right: Spanner SFF20 with pellet boiler. Photos: TFZ

Fig. 3

Electrode clamp of the Zumikron ESP, demounted for cleaning after use

Fig. 4



Mean and number of single measurements for raw- and clean gas particle concentration and mean of all measured removal efficiencies in several long term trials with 3 ESP's

Conclusions

Small electrostatic precipitators currently represent for domestic wood-fired systems a very promising technological option for reducing fine particle emissions. Concepts featuring active cleaning of the precipitation electrode for automatic particle extraction appear especially promising. However, before suitability for long-term operation considerable further development and optimisation will be required. Improvements are also re-

Table 1

Ash separated during the field tests, calculated as particle emission reduction in the flue gas based on 13 % O_2 content

Praxisfall *Practise case*	**Brennstoffverbrauch** *Fuel consumption* (kg/a)	**Maximal mögliche vermiedene Staubemission** *Max. possible dust emission prevention* (mg/Nm^3, 13 % O_2)
APP $R_{esidential}$ mit Kaminofen, 6 kW *APP $R_{esidential}$ and chimney stove, 6 kW*	2000	15
APP $R_{esidential}$ mit 2 Kaminöfen, 7 bzw. 5 kW *APP $R_{esidential}$ and 2 chimney stoves, 7 and 5 kW*	780	44
APP $R_{esidential}$ mit Grundofen, 5 kW *APP $R_{esidential}$ and tiled stove, 5 kW*	3740	22
Zumikron mit Kaminofen, 12 kW *Zumikron and chimney stove, 12 kW*	2380	7
Zumikron mit Kaminofen, 8 KW *Zumikron and chimney stove, 8 KW*	5100	46
Zumikron mit Kachelofen, 9 kW *Zumikron and tiled stove, 9 kW*	1140	179
Zumikron mit Küchenherd, 6 kW *Zumikron and cooker, 6 kW*	1530	4
Spanner SFF20 mit Scheitholzkessel, 15 kW *Spanner SFF20 and log wood boiler, 15 kW*	3400	103
Spanner SFF20 mit Pelletkessel, 15 kW *Spanner SFF20 and pellet boiler, 15 kW*	2800	5
Spanner SFF50 mit Hackgutkessel, 45 kW *Spanner SFF50 and wood chip boiler, 45 kW*	15180	137

quired in testing and measuring methods for such ESPs or these methods should be extended, as well as standardised, using other principles, like those based on particle counting.

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Peter Turowski and **Susanne Kiener** are members of the scientific staff within this department.

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