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# Survey on the present state of particle precipitation devices for residential biomass combustion with a nominal capacity up to 50 kW in IEA Bioenergy Task32 member countries

## Final version

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IEA Bioenergy

# Preface

This report is the result of an IEA Bioenergy Task32 project. It has been coordinated and prepared by BIOS BIOENERGIESYSTEME GmbH in cooperation with the Graz University of Technology, Institute for Process and Particle Engineering, Austria. The following Task member states have actively contributed to this report:

- Canada / Department of Natural Resources (Sebnem Madrali)
- Denmark / Force Technology (Anders Evald/Ole Schleicher)
- Finland / Technical Research Centre of Finland (Jorma Jokiniemi)
- Germany / Technologie- und Forderzentrum Straubing (Hans Hartmann)
- Ireland / Teagasc (John Finnan)
- Netherlands / Procede Biomass BV (Jaap Koppejan)
- Sweden / SP Technical Research Institute of Sweden (Linda Bäfver)
- Switzerland / Verenum (Thomas Nussbaumer)

In addition, relevant findings of the ongoing ERA-NET project “FutureBioTec” which also deals with filters for residential biomass heating systems have been considered.

The co-ordinator thanks all contributing institutions for their support.

Ingwald Obernberger

Project Co-ordinator

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# Abstract

Solid biomass combustion is increasingly criticised as a major source of PM emissions. With the introduction of the EU directive 1999/30/EC, which limits $PM_{10}$ concentrations in the ambient air, it had to be recognised that in many European regions these limiting values are frequently exceeded. As the main sources for PM emissions traffic, industry and domestic heating have been identified. The contribution of residential biomass combustion to the total PM emissions of the residential heating sector exceeds in some European countries 80%. Significant differences exist regarding the present dust emission limit values for small-scale combustion systems in the IEA Bioenergy Task32 member countries. This is of great relevance as stricter emission limits accelerate the technological development and the market introduction of particle precipitation devices. Intense R&D activities regarding the development of particle precipitation devices are especially ongoing in Austria, Germany and Switzerland as in these countries the strictest dust emission limits exist.

The scope of this survey is to compile the present state-of-the-art of particle precipitation devices for residential biomass combustion systems (nominal boiler capacity <50 kW) in the IEA Bioenergy Task32 member countries. The work mainly focused on technologies which are already available on the market or which are close to market introduction with an emphasis on ESP systems. The survey involved the evaluation of 13 electrostatic precipitators, 2 catalytic converters, two ceramic filters, three condensing heat exchangers and one additional device. Subsidies or incentives for small-scale particle precipitation devices are only available in Germany. There are no certificates for particle precipitation devices foreseen in the IEA Bioenergy Task32 member countries at present.

The ESP technology seems to be the most promising technological approach for small-scale biomass combustion. Till 2011 3 ESPs for residential biomass combustion systems have been introduced into the market. 4 ESPs for residential biomass combustion systems can be expected to enter the market soon. A considerable number of devices is presently under development and can be expected to be demonstrated within the next years.

Most of the ESPs have been developed and tested under good or acceptable combustion conditions at test stands. Furthermore, up to now only a few long term field test runs have been performed. Therefore, sufficient data concerning the applicability and availability of the investigated devices are not available. Moreover, the influence of condensable and sticky particles, which result from poor combustion conditions (typical for old stoves/boilers as well as start-up conditions) on the efficiency and availability of ESPs is still not sufficiently clarified. Ongoing and future projects are focusing on these issues as they will be crucial for a broad market introduction of a specific technology.

Up to now no promising results have been achieved with catalytic converters for wood boilers/stoves. Due to the required high flue gas temperatures for catalytic oxidation, these devices are not available during start-up and phases of incomplete burnout of the flue gas due to low temperatures. A specially developed high temperature condensing heat exchanger could achieve satisfying particle precipitation efficiency as based on theoretical calculations. The technology has potential, but needs further research on practical needs. The precipitation efficiency of conventional condensing heat exchangers is rather low. The main application of

these systems is to increase the thermal efficiency of the boiler rather than to reduce particulate emissions.

In general particle precipitation devices are secondary measures and therefore could especially be attractive for old systems which show the highest particulate emissions. For these conditions the filters must really show a robust behaviour and must also be equipped with an efficient and automatic cleaning system. Therefore, the applicability of filters for old systems where really great particle reduction potentials are given should be a special focus of future work. For modern biomass boilers the main focus should be on the reduction of particulate emissions by primary measures and filters should only be applied if additionally necessary.

There is no common international approach regarding PM emission measurements and a common European method to determine PM emissions is urgently needed. Moreover, also for the determination of filter efficiencies so far no common international approach exists. Regarding these future standards for filter testing relevant points such as the influence of the condensation of volatile organic compounds in and downstream the filter, aspects regarding the positioning of the filter Indirectly downstream boiler/stove outlet or on roof top as well as the monitoring of filter parameters relevant for the filter performance must be considered.

In order to seriously introduce new small-scale filters in the market, the filters must be well tested and reliable. Furthermore, the filters must operate automatically over a whole heating period and must work efficiently. Besides the technological requirements, which still have to be proven for most applications, also legal and financial incentives will be needed to really achieve an effective market introduction which should, according to the present state of development, take place within the next 5 years in mid Europe (Germany and Austria).

# 1 Introduction

Particle precipitation devices for medium and large-scale biomass combustion plants are already state-of-the-art. During last years strong interest has arisen in the use of filters for small-scale biomass combustion systems, especially for residential biomass boilers and stoves, as it is already well known that in many European countries residential biomass combustion contributes with more than 80% to the total PM emissions of the residential heating sector [30]. Up to now only a small number of particle precipitation devices (e.g. ESP) for small-scale biomass combustion systems has been introduced into the market. A considerable number of devices is presently under development and is expected to be demonstrated within the next years.

Common disadvantages of these systems are:

- investment costs are relatively high compared to the costs of furnaces/stoves
- most of the filters are developed and tested under good or acceptable combustion conditions
- the operation behaviour of filters under poor combustion conditions is not sufficiently tested
- no reliable information about long-term reliability and efficiency is available

Up to now detailed studies concerning applications of different particle precipitation devices in small-scale combustion systems are scarce.

# 2 Objectives

The scope of this survey is to compile the present state-of-the-art of particle precipitation devices for residential biomass combustion systems (nominal boiler capacity <50 kW) in the IEA Bioenergy Task32 member countries. The work mainly focused on technologies which are already available on the market or which are close to market introduction with an emphasis on dry and wet ESP systems or a combination of ESP with scrubber/condensing systems. Ceramic filters and catalytic converters have also been investigated but are of minor relevance.

The main objectives were:

- collection and compilation of data concerning the technological performance (applicability for different combustion systems, availability and precipitation efficiency) as well as collection and compilation of economic data
- technological evaluation of technologies

A literature survey as well as data available from filter manufacturers, data from national projects of the project partners, especially also information and results from the ongoing ERANET project “Future Biotec”, formed the basis of this survey.

In addition, the situation of particulate emissions in general as well as of dust emission limits for residential biomass combustion in the IEA Bioenergy Task32 member countries is summarised. Furthermore, information concerning ongoing R&D projects, subsidies and necessary certificates for particle precipitation devices in the IEA Bioenergy Task32 member countries are given.

# 3 Background in the IEA Bioenergy Task32 member countries

The situation of particulate emissions in general as well as dust emission limits for residential biomass combustion in the IEA Bioenergy Task32 member countries is summarised. Furthermore, information concerning ongoing R&D projects, subsidies and necessary certificates for particle precipitation devices in the partner countries are given.

## 3.1 Description of the present situation of particle emissions in IEA Bioenergy Task32 member countries

### 3.1.1 Description of the present situation of particle emissions in Austria

With the introduction of the EU directive 1999/30/EC, which limits $PM_{10}$ concentrations in the ambient air, it had to be recognised that in many Austrian regions these limiting values are frequently exceeded. Therefore, the public debate concerning particulate emissions automatically led to the discussion of particulate emissions from biomass combustion. As the main sources for PM emissions traffic, industry and small consumers have been identified (see Figure 1). In Austria wood combustion has been the source of more than 85% of the $PM_{10}$ (particulate matter with a diameter <10 μm) emissions from residential heating (see Figure 2) [63].

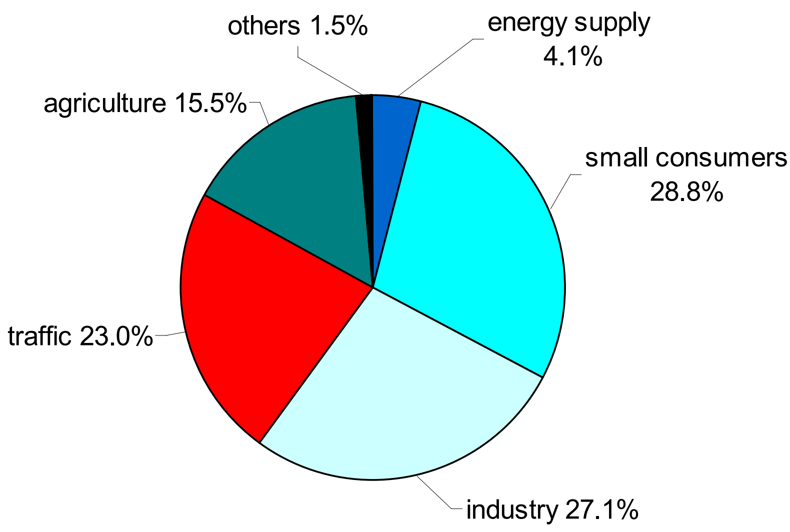



**Figure 1:** Sources of particulate emissions in Austria (2008)

Explanations: source [64]

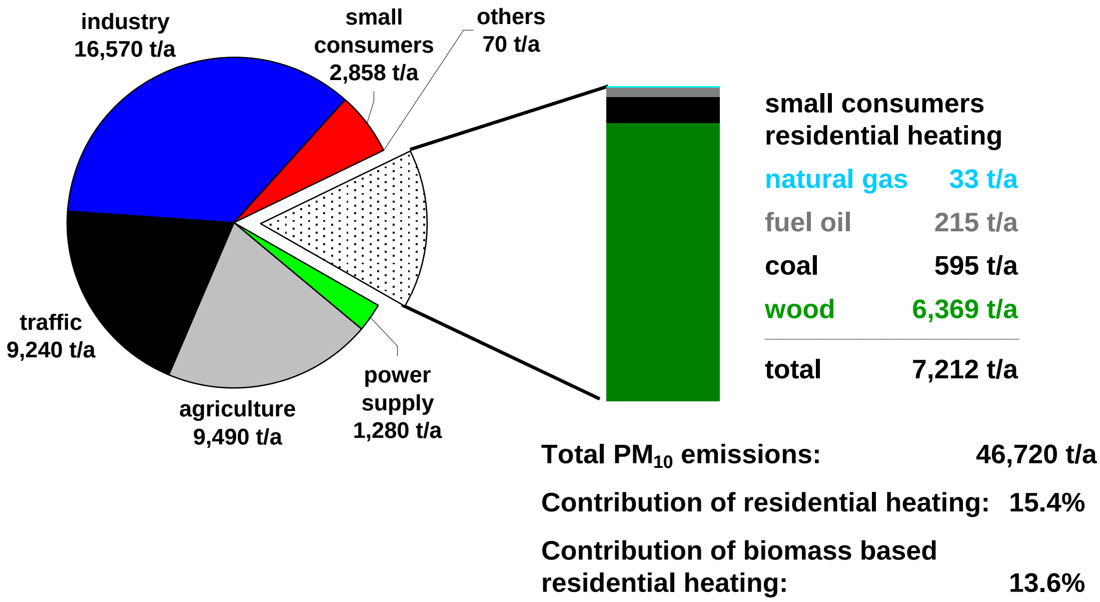



**Figure 2:** $PM_{10}$ emission sources in Austria (2004)

Explanations: source [63]

### 3.1.2 Description of the present situation of particle emissions in Canada

Residential wood fuel is a source of primary and secondary heat for about 3.5 million households in Canada. It is particularly important in areas where access to other heat sources is unavailable or cost prohibitive. In 2006, residential wood fuel use accounted for 12% of the total residential energy used for home heating (third behind natural gas and electricity). Residential wood combustion is a major source of anthropogenic particulate matter (PM) in Canada, accounting for approximately thirty percent of the national inventory (not including open sources such as agriculture or road dust). Efforts to address particulate matter (PM) levels in the air are important in both the United States and Canada. Canada and the United States have completed a joint transboundary PM science assessment report in support of the Canada-U.S. Air Quality Agreement.

In March 2010 the Canadian Standards Association B415 "Performance testing of solid-fuel-burning heating appliances" has been revised [17]. This standard specifies requirements for performance testing of solid-fuel-burning heating appliances, including maximum emission rates. Current standards for Fire Safety and Fuel Burning Equipment do not address add-on pollution control equipment.

The Solid Fuel Burning Domestic Appliance Regulation B.C. Reg. 302/94 was enacted under the Environmental Management Act (EMA) for the purpose of reducing air pollution from domestic wood heating. The regulation sets particulate matter (PM) emission standards applicable to specified new solid fuel burning domestic appliances (such as wood and pellet stoves) manufactured or sold in British Columbia. This Regulation prevents the sale of appliances predating 1994. Furthermore, the testing of the appliance must prove it meets US EPA or CSA (Canadian Standards Association) emission standards and residential pelletized fuels must meet provincial specification.

### 3.1.3 Description of the present situation of particle emissions in Denmark

The largest $PM_{2.5}$ emission sources in Denmark are residential heating systems (72 %), road traffic (12 %), combustion in agriculture, forestry and fishing (5 %) as well as animal husbandry and manure management (5 %) (see Figure 3). For residential plants the dominating source is wood combustion in stoves and boilers. For the road transport sector, exhaust emissions account for the major part (64 %) of the emissions the rest being tire and brake wear and road abrasion.

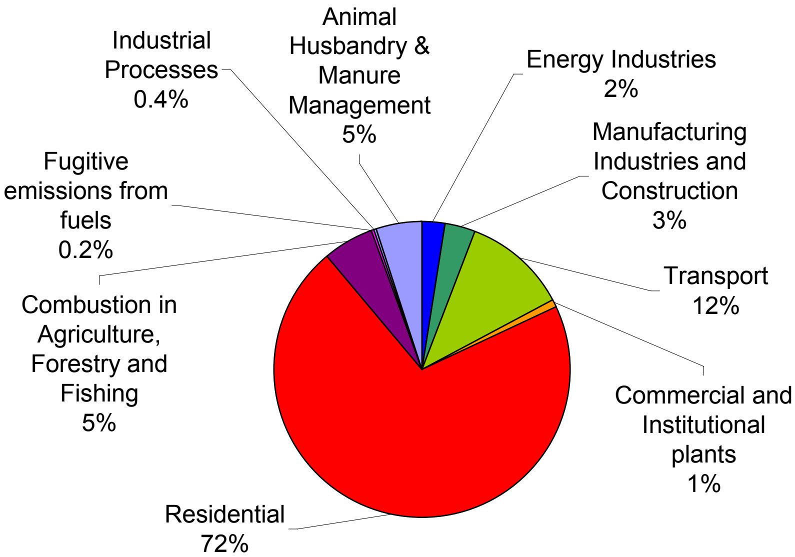



**Figure 3:** $PM_{2.5}$ emission sources in Denmark (2009)

Explanations: source [66]

The $PM_{2.5}$ emissions increased from 2000 to 2009 by 35 % due to increasing wood consumption in the residential sector (see Figure 4). Emissions peaked in 2007, in 2008 and 2009 emissions decreased due to a combination of lower wood consumption and a reduced aggregated emission factor caused by the gradual replacement of old wood combustion technologies with advanced technologies with more efficient combustion. The phasing in of new technologies is supplied by legislation regulating the PM emissions from all new wood combustion installations.

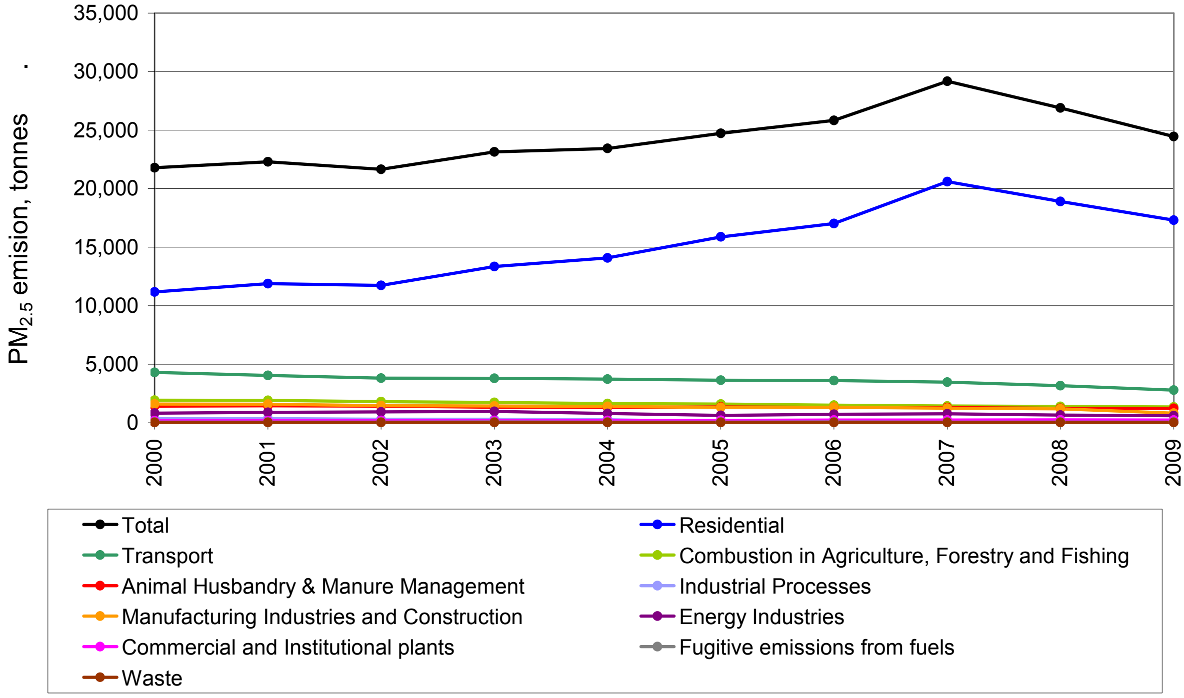



**Figure 4:** Trends of particle emissions in Demark

Explanations: source [66]

### 3.1.4 Description of the present situation of particle emissions in Finland

The situation of particle emissions in Finland can be summarized as follows [2, 3]. 22% of energy consumption in Finland is used for space heating. 12% of the energy for space heating is produced with wood (18% with oil). Wood is used as a fuel in one-family houses for 11.4 TWh. Over 1000 new households per year choose to heat primarily with wood. There are about 200 000 central-heating installations which use wood as fuel. Most of the wood is used as split logs. Wood chips are used in farms and public buildings. Wood pellets are used in 20,000 houses and in several hundred public buildings for heating purposes. The usage of wood pellets rose to 156,000 t in 2009.

Around 25% of primary $PM_{2.5}$ originates from residential wood combustion [32]. In wintertime residential wood combustion is one of the major sources of fine particles in Helsinki, contributing 40 % of fine organic aerosols [53].

### 3.1.5 Description of the present situation of particle emissions in Germany

Solid biomass combustion is increasingly criticised as a major source of PM emissions. Various measures are taken, e.g. largely stricter emission regulations from 2010 (step1) and 2015 (step 2), regular inspections by the chimney sweep (including fuel inspections and technical advisory actions) [41]. Limitations of the European fine dust immission directive are often violated in several cities. Therefore, wood combustion can be banned on municipality level or it can be limited to certain technologies. The development of ESP's for small scale applications is strongly supported and new measuring devices for on-site inspections (rapid PM-emission tester) are developed.

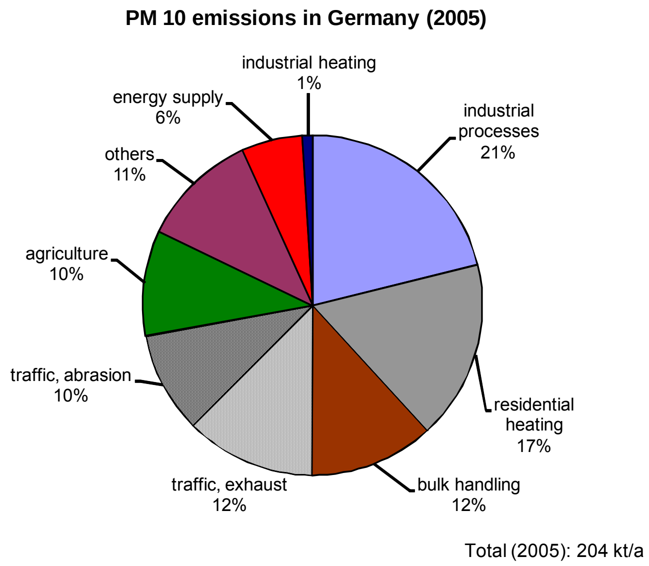



**Figure 5:** Situation of particle emissions in Germany (2005)

Explanations: source [62]

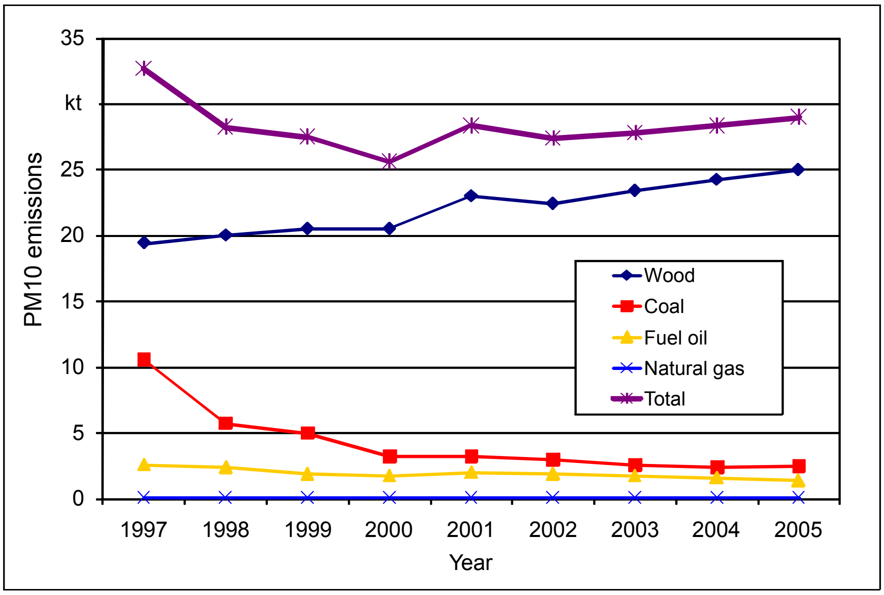



**Figure 6:** Trends of particle emissions in Germany

Explanations: source [62]

### 3.1.6 Description of the present situation of particle emissions in Ireland

Levels of ambient air pollutants are low in Ireland as a result of a low population and industrial base and because the predominant wind direction is from the Atlantic Ocean. However, of all the air quality parameters, levels of $PM_{10}$ tend to be closest to the limit values set in the EU directive on ambient air quality and cleaner air for Europe (2008/50/EC). In urban areas, levels of PM10 do occasionally exceed the limit value set in this directive.

### 3.1.7 Description of the present situation of particle emissions in the Netherlands

There are about 1.3 million households that have a fireplace (645,000) or wood stove (312,000 inserts and 439,000 free standing) [34]. They deliver 6.9 PJ of final energy. The total related particle emission amounts to about 1,750 tons per year, which is about 3.5% of the national $PM_{10}$ emission. As the main sources for $PM_{10}$ emissions traffic, industry and agriculture have been identified (see Figure 7). In the Netherlands fireplaces and stoves for creating atmosphere as well as burning cigarettes have been the major source of the $PM_{10}$ (particulate matter with a diameter <10 µm) emissions from the small consumer sector .

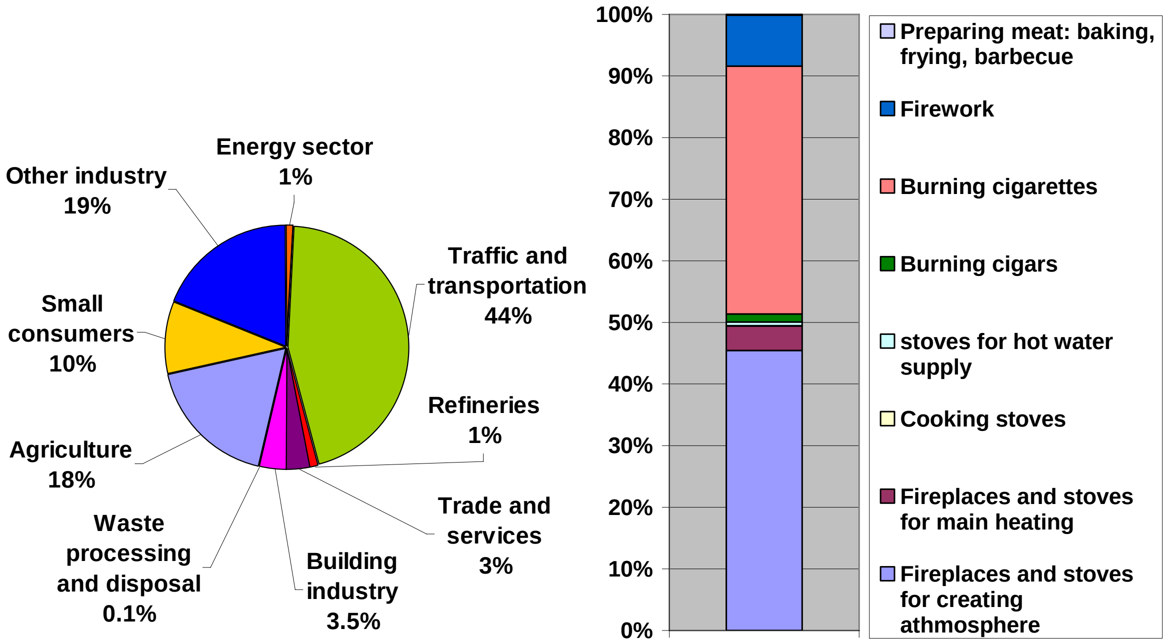



**Figure 7:** $PM_{10}$ emission sources in the Netherlands (2010)

Explanations: source [http://www.emissieregistratie.nl]

### 3.1.8 Description of the present situation of particle emissions in Sweden

In Sweden there are three main particle sources in the ambient air: traffic, long-distance transport and domestic wood combustion. Particles from residential combustion of biofuels constitute with a higher share when fine particles are considered. The domestic emissions (i.e. long-distance not included) of TSP have 11 % particles from residential biomass combustion, while the corresponding shares for $PM_{10}$ and $PM_{2.5}$ are 13 % and 19 % respectively.

### 3.1.9 Description of the present situation of particle emissions in Switzerland

In Switzerland, the limit on $PM_{10}$ in the ambient air of 50 mg/m³ (daily average) is regularly exceeded in large areas of the country, specifically during winter season in case of temporary inversion layers. As shown by chemical analysis of the PM in the ambient, biomass combustion is the main contributor to soot and carbon in PM. Consequently, measures to reduce PM from biomass combustion are of high priority. In addition, secondary organic aerosols (SOA) have been identified as the main contributor to the organic material in PM and thus VOC reduction is also of high priority. Thanks to novel emission limit values introduced in the Ordinance on Air Pollution Control in 2007, most biomass combustion devices > 70 kW are or will be equipped with particle removal devices such as electrostatic precipitators or fabric filters. However, there is a need for particle reduction from residential wood combustion. For this purpose, strict emission limit values are introduced, however, by type-tests only. Consequently, additional measures to avoid high PM emissions from RWC in practice will be necessary.

## 3.2 $PM_1$ and dust emission limits in the IEA Bioenergy Task32 member countries for residential biomass combustion

There are no specific PM1 emission limit values existing for biomass fired combustion systems in the IEA Bioenergy Task32 member countries.

### 3.2.1 Dust emission limits in Austria

The present dust emission limit values for small-scale combustion systems (< 50 kW) in Austria are listed in Table 1.

**Table 1:** Dust emission limit values in Austria

Explanations: source [1]

| appliance type | dust [mg/MJ] |
|---|---|
| pellet boiler | 60 |
| wood log boiler | 60 |
| wood log stoves | 60 |
| for furnaces utilizing herbaceous fuels | 60 |

The national quality label "Umweltzeichen 37" is a voluntary scheme for combustion systems (< 400 kW) with stricter emission limits (Table 2).

**Table 2:** Dust emission limit values according to quality label "Umweltzeichen 37"

Explanations: source [46]

<table>
<tr><th></th><th>appliance</th><th>type of fuel</th><th>emission limit value [mg/MJ]</th></tr>
<tr><td rowspan="4">automatically fed</td><td rowspan="2">boiler</td><td>pellets</td><td>15</td></tr>
<tr><td>wood chips</td><td>20</td></tr>
<tr><td rowspan="2">roomheating</td><td>pellets</td><td>30</td></tr>
<tr><td>wood chips</td><td>30</td></tr>
<tr><td rowspan="2">manually fed</td><td>boiler</td><td>log wood</td><td>30</td></tr>
<tr><td>roomheating</td><td>log wood</td><td>30</td></tr>
</table>

### 3.2.2 Dust emission limits in Canada

The present dust emission limit values in Canada for combustion systems having a minimum fuel input less than 5 kg/h are listed in Table 3.

**Table 3:** Dust emission limit values in Canada

Explanations: valid for combustion systems having a minimum fuel input less than 5 kg/h; source [16, 17]

| appliance type | dust [mg/MJ] | [g/h] |
|---|---|---|
| for an appliance not equipped with a catalytic combustor | 137 | 4.5 |
| for an appliance equipped with a catalytic combustor | 137 | 2.5 |
| for indoor central heating appliances | 400 | - |

### 3.2.3 Dust emission limits in Denmark

The present dust emission limit values for small-scale combustion systems (< 300 kW) in Denmark are listed in Table 4.

**Table 4:** Dust emission limit values in Denmark

Explanations: 1) dust measuring principle: dilution tunnel; 2) dust measuring principle: directly in flue gas pipe; source [48]

| appliance type | dust [g/kg fuel w.b.] | [mg/MJ] |
|---|---|---|
| space heaters | < 10 (<20 for each individual test) 1) | 50 2) |
| central heating boilers (manually fired) | | 72,7 |
| central heating boilers (automatically fired) | | 72,7 |

The quality label "Nordic Swan", which is also valid for Finland, Norway and Sweden, is a voluntary scheme and provides dust emission limit values for closed fireplaces (Table 5) and boilers (Table 6).

**Table 5:** Nordic swan emission limit values for closed fireplaces

Explanations: source [48]

| appliance type | dust [g/kg fuel w.b.] |
|---|---|
| slow heat relase appliance (manual fuel feeding) | 1 (nominal load) |
| stove (manual fuel feeding) | < 5 (3 low load) <10 (for each individual test) |
| stove (automatic fuel feeding) | < 5 (2 low load) <10 (for each individual test) |
| inset (manual fuel feeding) | < 8 (3 low load) <15 (for each individual test) |

**Table 6:** Nordic swan emission limit values for boilers

Explanations: source [48]

| appliance | nominal boiler capacity | dust [mg/Nm³ 10% $O_2$] |
|---|---|---|
| automatically fed boiler | ≤ 300 kW | 40 |
| manually fed boiler | ≤ 100 kW | 70 |

### 3.2.4 Dust emission limits in Finland

There are no dust emission limit values existing for biomass fired combustion systems in Finland. The quality label "Nordic Swan", which is also valid for Denmark, Norway and Sweden, is a voluntary scheme and provides dust emission limit values for closed fireplaces (Table 5) and boilers (Table 6).

### 3.2.5 Dust emission limits in Germany

The present dust emission limit values for small-scale combustion systems (≥ 4-500 kW) in Germany are listed in Table 7.

**Table 7:** Dust emission limit values in Germany

Explanations: source [41]

| | dust | | | |
|---|---|---|---|---|
| | after 22/03/2010 | | after 01/01/2015 | |
| | [mg/Nm³ 13% $O_2$] | [mg/MJ] | [mg/Nm³ 13% $O_2$] | [mg/MJ] |
| roomheaters with flat furnace | 75 | 50 | 40 | 27 |
| roomheaters with filling furnace | 75 | 50 | 40 | 27 |
| slow heat release appliances | 75 | 50 | 40 | 27 |
| insert appliances (closed operation) | 75 | 50 | 40 | 27 |
| tiled stove inserts with flat furnace | 75 | 50 | 40 | 27 |
| tiled stove inserts with filling furnace | 75 | 50 | 40 | 27 |
| residential cookers | 75 | 50 | 40 | 27 |
| central heating &residential cookers | 75 | 50 | 40 | 27 |
| pellet stoves without water jacket | 50 | 33 | 30 | 20 |
| pellet stoves with water jacket | 30 | 20 | 20 | 13 |

The national quality label "Blauer Engel" is a voluntary scheme with stricter emission limits for wood pellet stoves and boilers.

**Table 8:** Blauer Engel emission limit values for wood pellet stoves and boilers

Explanations: source [48]

| appliance | nominal boiler capacity | emission limit value | |
|---|---|---|---|
| | | [mg/Nm³ 13% $O_2$] | [mg/MJ] |
| wood-pellet stoves (RAL-UZ 111) | ≤ 15 kW | 25 | 17 |
| wood-pellet boilers (RAL-UZ 112) | ≤ 50 kW | 20 | 13 |

### 3.2.6 Dust emission limits in Ireland

The present dust emission limit values in Ireland, in line with the European Standard EN 303-5, for biomass combustion systems (< 300 kW) are listed in Table 9.

**Table 9:** Dust emission limit values in Ireland

Explanations: source [22]

| | dust [mg/MJ] |
|---|---|
| pellet boiler | 100 |
| wood log boiler | 100 |
| wood log stoves | 100 |

### 3.2.7 Dust emission limits in the Netherlands

There are no dust emission limit values existing for biomass fired combustion systems in the Netherlands. It can be expected that the EU ECOdesign Directive limits will be installed as national dust emission limits soon.

### 3.2.8 Dust emission limits in Sweden

There are no dust emission limit values existing for biomass fired combustion systems in Sweden. The quality label "Nordic Swan", which is also valid for Denmark, Finland and Norway, is a voluntary scheme and provides dust emission limit values for closed fireplaces (Table 5) and boilers (Table 6). The P-marking system is a voluntary certification system, which sets stricter emission limit values. Dust emission limit values exist only for pellet stoves (Table 10).

**Table 10:** Emission limit values for pellet stoves according to Swedish P-marking system

Explanations: source [48]

| appliance | testing conditions | dust | |
|---|---|---|---|
| | | [mg/Nm³ 13% $O_2$] | [mg/MJ] |
| pellet stove | at nominal heat output and at 3-5 kW output | 100 | 66.7 |

### 3.2.9 Dust emission limits in Switzerland

In Switzerland, emission limit values for wood heating devices greater than 70 kW including particulate matter emissions need to be ascertained and periodically (usually once per year or per two years) monitored in practice. For wood heating devices up to 70 kW, a certification in a type test is possible instead of emission monitoring in practice. For certified wood stoves and boilers, emission limit values need to be ascertained by a type-test (see Table 11).

**Table 11:** Dust emission limit values for type-tests in Switzerland

Explanations: source [37]

| appliance | dust | | | |
|---|---|---|---|---|
| | after 01/01/2008 | | after 01/01/2011 | |
| | [mg/Nm³ 13% $O_2$] | [mg/MJ] | [mg/Nm³ 13% $O_2$] | [mg/MJ] |
| central heating appliances | 150 | 100 | 120 | 80 |
| insert appliances (open operation) | 100 | 67 | 75 | 50 |
| open fireplaces | 100 | 67 | 75 | 50 |
| log wood boiler (manually fed) | 60 | 40 | 50 | 33 |
| automatic wood chip boiler | 90 | 60 | 60 | 40 |
| automatic pellet boiler | 60 | 40 | 40 | 27 |
| roomheaters | 100 | 67 | 75 | 50 |
| roomheaters for wood pellets | 50 | 33 | 40 | 27 |
| residential stoves | 110 | 73 | 90 | 60 |

## 3.3 Dust emission measurements – standards and specific problems regarding the determination of filter efficiencies

As it can be seen from section 3.2 there is no common international approach regarding PM emission limits. The same problem must be mentioned for PM emission measurements. Usually gravimetric methods, as for example the method according to VDI 2066 are applied. However, the different national regulations on residential combustion which include requirements for maximum particle matter (or dust) emissions do not define or refer to a specific method on how to determine particle matter emissions. Bearing in mind the growing awareness of the impact of PM on public health, various attempts to establish a common European method to determine PM emissions has been made within CEN during the last years. However, a common European method could not be brought to a European Technical Specification or a European standard yet. Nevertheless, the urgent need for a common European method is clearly endorsed by the standardisation groups CEN/TC 57 and CEN/TC 295. Therefore, presently a common research project called EN-PME-Test with participants from Austria, Denmark, Finland, France, Germany, Italy, Slovakia, Sweden and Switzerland is in preparation, which will have the aim to derive and validate a common European test method to determine particle matter emissions (PME) from residential heating appliances and boilers burning solid fuels. Also measurements at filters will be one topic within this project.

An important basis for this work within EN-PME-Test are the results of the ERA-NET project Biomass PM [30]. In this project, all relevant aspects of particulate emissions from residential biomass combustion including possible measurement and characterisation methods were thoroughly analysed, and important research findings were achieved. Also, recommendations on how to quantify and characterize the PME were given from health, environmental and technological perspectives with the emphasis of scientific research.

Moreover, also for the determination of filter efficiencies so far no common international approach exists. Regarding measurements downstream ESP for instance the influence of charged particles on particle precipitation in the sampling lines of measurement instruments is still unclear and needs some further investigations. But in this respect not only the dust emission measurement itself but also the process conditions of the stove respectively boiler connected to the filter as well as the position of the filter (directly connected to the stove/boiler or placed on the top the chimney) have to be considered due to the reasons described in the following.

During biomass combustion generally 4 different particle fractions are formed. One fraction are coarse fly ash particles (particles >1 µm ae.d. = aerodynamic diameter) which result from the entrainment of fuel, ash and charcoal particles from the fuel bed. The second fraction are inorganic aerosols (particles typically <1 µm ae.d.) which are mainly formed by the release of volatile ash forming species from the fuel to the gas phase during combustion (mainly K, S, Cl as well as heavy metals such as Zn and Pb) followed by gas phase reactions and particle formation by nucleation and condensation processes. These emissions mainly depend on the chemical composition of the fuel and cannot be significantly influenced by state-of-the-art combustion technologies. The third fraction are aerosol particles originating from the condensation of condensable organic compounds (COC) which result from poor burnout conditions and the fourth fraction are soot particles which consist of elemental carbon and also result from poor burnout conditions (local cold zones in the flame region). In boilers and stoves which operate at poor burnout conditions, a part of the COCs is still in the gas phase at stove/boiler outlet. When the flue gas further cools down, COCs condense and form particles. Consequently the concentration of organic aerosols increases with decreasing temperatures in the flue gas duct. More detailed information regarding these particle formation processes especially regarding COC particle formation is provided in [42]. The concentrations of inorganic particles on the other hand are not influenced by the temperature profile of the flue gas downstream boiler/stove outlet.

This particle formation due to COC condensation may significantly influence the results of measurements regarding the filter efficiency, especially when the filter is applied at an old technology boiler or a stove, where phases with poor burnout conditions and rather high flue gas outlet temperatures frequently occur. If a filter for instance is designed to be mounted on the top of the chimney, the flue gas will cool down in the section between stove/boiler outlet and filter and COC condensation will take place. Therefore, also at a filter test stand the filter should be tested at inlet temperatures as they prevail in the field application. Moreover, in the filter a further cooling of the flue gas could take place due to for instance purge air flows which are applied to protect the isolator of an ESP electrode. Therefore, in the ESP particle formation may take place downstream the charging electrode which in the worst case could lead to a higher aerosol load at filter outlet compared to filter inlet. Consequently, in order to determine the precipitation efficiency of a filter, the flue gas at filter inlet and filter outlet should be kept at about the same temperature or at least information about the temperatures up- and downstream the filter should be provided. The relevance of this effect may increase if the filter is mounted directly downstream the boiler/stove outlet and if high inlet temperatures prevail. Furthermore, parallel measurements before and after filter are crucial, especially for stoves.

Moreover, it has to be considered that although with the strategy proposed above the filter efficiency can be evaluated, no information on the full potential of PM emissions is provided as a fraction of COCs remain in the flue gas at sampling temperature and may form particles when mixing with the ambient air at chimney outlet. In order to also assess this particle emission potential for instance flue gas dilution to temperatures below 50°C prior to particle measurement could be an option but also a combination of dust measurements based on gravimetric filter methods followed by a set of impinger bottles containing different solvents could be applied. In both cases not only the aerosols already present in the flue gas but also the fraction of volatile COCs can be considered. From this point of view filters operating at as low as possible flue gas temperatures (e.g. roof top applications) are preferable. However, for roof top applications field testing is hardly possible and therefore, test stand procedures which provide conditions comparable with the field application have to be developed. Moreover, it has to be secured that relevant operation parameters which influence the performance of ESPs (e.g. ESP voltage and current) are the same during test stand and field operation. These parameters should generally be displayed and monitored in order to have indications regarding the filter performance during real-life operation.

The issues and problems pointed out in this section underline the need to develop internationally accepted standards regarding procedures for particle measurement and filter testing in order to ensure reliable and comparable results.

## 3.4 Subsidies or incentives as well as certificates for small-scale particle precipitation devices in the IEA Bioenergy Task32 member countries

Subsidies or incentives for small-scale particle precipitation devices are only available in Germany at present [50]. An "innovation bonus" of 500 € per unit is granted for particle precipitators for small-scale combustion systems (nominal boiler capacity < 100 kW). A precipitation efficiency of at least 50% (TSP of raw flue gas > 40 mg/m³) has to be proven during test runs, performed by an accredited test centre, in order to gain the subsidy. There are no certificates available for small-scale particle precipitation devices in the IEA Bioenergy Task32 member countries.

## 3.5 Recent and ongoing R&D projects regarding small-scale particle precipitation devices in the IEA Bioenergy Task32 member countries

Information regarding this chapter has been provided from Austria, Finland, Germany, Sweden and Switzerland.

### 3.5.1 Recent and ongoing R&D projects regarding small-scale particle precipitation devices in Austria

- Ongoing R&D project (ERA-NET FutureBioTec) regarding evaluation, development and optimisation of secondary measures for PM emission reduction in residential biomass combustion systems
  - Prof. Dr. Ingwald Obernberger
    E-Mail: Obernberger@bios-bioenergy.at
  - project duration: 01/10/2009 – 30/09/2012
- Ongoing project (e2020-BM-PM-Filtertest) regarding evaluation of ESPs in residential biomass combustion systems with focus on applicability of ESPs for old systems
  - BIOENERGY 2020+ GmbH (BE2020)
    Web: www.bioenergy2020.eu
  - project duration: 2011-2012

- Ongoing demonstration project (EU-FP7/EU-UltraLowDust)
  - The project aims at the demonstration of ultra-low emission technologies for residential biomass heating focusing on new technologies for automatic pellet boilers, wood stoves and a small-scale ESP system.
  - Prof. Dr. Ingwald Obernberger
    E-Mail: Obernberger@bios-bioenergy.at
  - project duration: 01/01/2011- 30/06/2013
- Study concerning availability, applicability and precipitation efficiency of particle precipitation devices for small-scale biomass combustion systems
  - I. Obernberger, T. Brunner, G. Bärnthaler,
  - project duration: 2008-2009
  - report available in German:
    - I. Obernberger, T. Brunner, G. Bärnthaler, Studie bezüglich der Verfügbarkeit, Anwendbarkeit und Abscheideeffizienz von Feinstaubabscheidern für Biomasse-Kleinfeuerungen, Endbericht zum gleichnamigen Forschungsprojekt des Amtes der Stmk. Landesregierung, 2008 (in German) [43]

### 3.5.2 Recent and ongoing R&D projects regarding small-scale particle precipitation devices in Finland

- Reduction of particulate emissions from wood combustion with aid of heat exchangers, LÄPI
  - Jorma Jokiniemi, UEF/VTT, Ari Auvinen VTT
  - project duration: 2006-2007
  - Publications in English:
    - Suonmaa, V., Gröhn, A., Jokiniemi, J. 2007. Reduction of particulate emissions from wood combustion with the aid of heat exchangers
    - Gröhn, A., Suonmaa, V., Auvinen, A., Lehtinen, K.E.J., Jokiniemi, J. (2009) Reduction of Fine Particle emissions from Wood combustion with Optimized condensing Heat Exchangers. Environ. Sci. Technol. 43, 6269-6274.
- Prestudy of alternatives for reducing particulate emissions from small-scale wood combustion, PÄVÄ
  - Jorma Jokiniemi UEF/VTT, Heikki Oravainen VTT
  - project duration: 2005-2007
  - Report in english:

- Hytönen, K., Jokiniemi, J. (eds.) 2007. Reduction of fine particle emissions from residential wood combustion. Workshop in Kuopio on May 22-23, 2006. Kuopion yliopiston ympäristötieteen laitoksen monistesarja 3/2007. University of Kuopio. https://www.uef.fi/c/document_library/get_file?uuid=9413c09a-505

- Development of electrically assisted fly ash particle removal technology for small-scale combustion
  - Martti Aho, University of Jyväskylä
  - project duration: 2005-2007
  - Some results in english:
    - Niemelä, 2009. https://www.uef.fi/c/document_library/get_file?uuid=9413c09a-505

### 3.5.3 Recent and ongoing R&D projects regarding small-scale particle precipitation devices in Germany

**Recent and ongoing R&D projects**

- S. Kiener, P. Turowski, H. Hartmann: Bewertung kostengünstiger Staubabscheider für Einzelfeuerstätten und Zentralheizungskessel. Berichte aus dem TFZ, Straubing, Berichte aus dem TFZ Nr. 23, Straubing, published 2010, available under www.tfz.bayern.de/sonstiges/15951/23_bericht_internet_geschuetzt.pdf (in German)
- F. Ellner-Schuberth, H. Hartmann, P. Turowski, P. Roßmann: Partikelemissionen aus Kleinfeuerungen für Holz und Ansätze für Minderungsmaßnahmen. Berichte aus dem TFZ Nr. 22, Straubing, published 2010, available under www.tfz.bayern.de/sonstiges/15951/22_bmu_feinstaub_geschuetzt.pdf (in German)
- F. Ellner-Schuberth, H. Hartmann, P. Turowski, P. Roßmann: Feinstaubemissionen aus Kleinfeuerungsanlagen für Getreide- und Strohbrennstoffe, final report, will be published in 2011
- Hartmann, H.; Roßmann, P.; Link, H.; Marks, A. (2004): Erprobung der Brennwerttechnik bei häuslichen Hackschnitzelfeuerungen mit Sekundärwärmetauscher. Berichte aus dem TFZ, Nr. 2. Straubing: Technologie- und Förderzentrum (TFZ), available under www.tfz.bayern.de/sonstiges/15951/bericht_2_gesch_tzt.pdf (in German)
- Hartmann, H.; Roßmann, P.; Turowski, P.; Ellner-Schuberth, F. (2007): Getreidekörner als Brennstoff für Kleinfeuerungen. Berichte aus dem TFZ, Nr.

13. Straubing: Technologie- und Förderzentrum (TFZ), available under www.tfz.bayern.de/sonstiges/15951/bericht_13_gesch_tzt.pdf (in German)

- FOERDERKENNZEICHEN: 22006807 01.02.2008 bis 30.11.2009 Integration von Feinstaubreinigungstechniken in Regelungssystem zur Feuerungsoptimierung von Scheitholzöfen Vereta GmbH, Hansestr. 6 37574 Einbeck; will be published
- FOERDERKENNZEICHEN: 22021106 01.01.2008 bis 31.12.2008 Entwicklung und Umsetzung eines neuartigen zweistufigen Filtrations- und Wäscher-Systems zur Abscheidung von Feinstäuben aus Holz-Kleinfeuerungsanlagen (30 bis 500kW) Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik (UMSICHT), Osterfelder Str. 3, 46047 Oberhausen; available under http://www.fnr-server.de/ftp/pdf/berichte/22021106.pdf (in German)
- FOERDERKENNZEICHEN: 20017603 Weiterentwicklung einer Feuerungsanlage für die Nutzung fester Bioenergieträger mit dem Schwerpunkt Staubreduzierung durch Einsatz eines Elektrofilters DEULA Schleswig-Holstein GmbH Lehranstalt für Agrar- und Umwelttechnik, Am Kamp 13, 24768 Rendsburg; available under http://www.fnr-server.de/ftp/pdf/berichte/22017603.pdf (in German)
- FOERDERKENNZEICHEN: 22021907 15.11.2007 bis 31.10.2008 Serienreife Abscheideeinrichtungen für kleine Festbrennstofffeuerungen (<15kW) mit Biomasse Kiefel Geräte- und Metallbau GmbH & Co. KG Frankenberger Landstr. 4, 09661 Rossau; available under http://www.fnr-server.de/ftp/pdf/berichte/22021907.pdf (in German)
- FOERDERKENNZEICHEN: 22020706 01.07.2007 bis 31.12.2008 Verfahrenstechnische Grundlagen für eine Abscheideeinrichtung zur Emissionssenkung an Holzheizungen Institut für Luft- und Kältetechnik gemeinnützige Gesellschaft mbH Bertolt-Brecht-Allee 20, 01309 Dresden; will be published
- FOERDERKENNZEICHEN: 22006506 01.11.2006 bis 30.06.2008 Feinstaubemissionen aus Kleinfeuerungsanlagen für Getreide- und Strohbrennstoffe - Einflüsse und Minderungsmöglichkeiten - (B 06-22) DBFZ Deutsches BiomasseForschungsZentrum gemeinnützige GmbH Torgauer Str. 116, 04347 Leipzig; will be published
- FOERDERKENNZEICHEN: 22022006 01.04.2008 bis 31.03.2009 Keramikfilter in der Abgasanlage zur Staubemissionsminderung von Biomassefeuerungsanlagen Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. (FhG), Hansastr. 27 c, 80686 München; available under http://www.fnr-server.de/ftp/pdf/berichte/22022006.pdf (in German)
- FOERDERKENNZEICHEN: 22021506 01.05.2007 bis 30.04.2008 Optimierung der Schräder HydroCube- Nachrüstbarer Abgaswärmetauscher für Abgasreinigung, Entstaubung und Brennwertnutzung bei Biomasse-Heizkesseln Karl Schräder Nachf., Abt. F+E Hemsack 11-13, 59174 Kamen; will be published

- FOERDERKENNZEICHEN: 22021906 01.04.2007 bis 31.10.2007 Feinstaubfilter für Einzelfeuerstätten: Praxiserprobung und Optimierung eines Kaminofens mit einem Modul zur Partikelemissionsminderung bei gleichzeitiger Steigerung der Energieeffizienz. Spartherm Feuerungstechnik GmbH, Maschweg 38, 49324 Melle; will be published
- FOERDERKENNZEICHEN: 22022406 01.03.2007 bis 28.02.2008 Entwicklung eines offenen Lamellenfilters für die Minderung von Staubemissionen aus biomassebetriebenen Kleinfeuerstätten Kliewe GmbH Krähenweg 9, 22459 Hamburg; available under http://www.fnr-server.de/ftp/pdf/berichte/22022406.pdf (in German)

### 3.5.4 Recent and ongoing R&D projects regarding small-scale particle precipitation devices in Sweden

- Development and testing of ESP R_ESP (Residential Electrostatic Precipitator)
    - report (in Swedish):
        - Bäfver, L., Yngvesson, J. Kompakt elektrostatiskt filter vid småskalig förbränning av askrika bränslen , SP Rapport 2009:47,
        - report available under www.sp.se/en/publications/Sidor/Publikationer.aspx (in Swedish)
- Demonstration and evaluation of the possibility to avoid corrosion problems and to minimize emissions of acid species and dust during combustion of grain by the use of a flue gas well
    - report (in Swedish):
        - M. Rönnbäck, O. Arkelöv, M. Johansson, H. Persson, Flue gas well during combustion of energy grain, SP Rapport 2007:02 , Borås, Sweden

### 3.5.5 Recent and ongoing R&D projects regarding small-scale particle precipitation devices in Switzerland

- Development of a small-scale ESP (Air-Box)
    - Schmatloch et al., EMPA Dübendorf
    - project duration: approx. from 1996 to 2004
    - see chapter 4.2.9 for details
- Development of a small-scale ESP (Zumikron)
    - Rüegg AG
    - see chapter 4.2.3 for details

- Development of a small-scale ESP (Spider)
  - Bolliger R.
  - Publication:
    - Bolliger R., Elektroabscheider „Spider“ für Holzfeuerungen bis 70 kW, 10. Holzenergiesymposium, 12.09.2008, Zürich, Switzerland
- Development of a small-scale ESP (Oekotube)
  - Oekosolve AG
  - see chapter 4.2.4 for details
- Proposal for the measurement of small-scale ESP which was adopted in the Swiss OAPC (Ordinance on Air Pollution Control) for certification of small-scale ESP
  - Griffin T., Burtscher H
  - Publication:
    - Griffin T., Burtscher H.; Evaluation von Messverfahren zur Messung der Wirksamkeit von Partikelabscheidern bei kleinen Holzfeuerungen, final report, Bundesamt für Umwelt und Bundesamt für Energie, 31.01.2008, Switzerland
- Investigation of the particle characteristics in an electric field in order to derive basic information for the design and operation of ESP
  - Nussbaumer T., Lauber A.
  - Publication:
    - Nussbaumer T., Lauber A., Formation mechanisms and physical properties of particles from wood combustion for design and operation of electrostatic precipitators, In: Proceedings of 18th European Biomass Conference, Lyon, France, 2010

# 4 Particle precipitation devices investigated

A literature survey as well as data available from manufacturers, data from the IEA Bionergy Task32 member countries and from national and international projects formed the basis of this survey. The work mainly focused on all technologies which are already available on the market or are under development at present.

## 4.1 Overview over particle precipitation devices investigated

The survey involved the evaluation of 12 electrostatic precipitators, 2 catalytic converters, two ceramic filters, three flue gas condensers and one additional device (flue gas well).

### 4.1.1 Electrostatic precipitators

The investigated electrostatic precipitators are listed in Table 12.

**Table 12:** Investigated electrostatic precipitators

| name of device | manufacturer | country |
|---|---|---|
| R_ESP | Applied Plasma Physics ASA | Norway |
| Carola | Karlsruher Institut für Technologie | Germany |
| Zumikron | Kutzner+Weber | Switzerland |
| OekoTube | OekoSolve | Liechtenstein |
| Dry ESP | Robert Bosch GmbH | Germany |
| RuFF-KAT | RuFF - KAT GmbH | Germany |
| AL-Top | Schräder Abgastechnologie | Germany |
| SF20 | Spanner Re$^2$ GmbH | Germany |
| AirBox | Spartherm | Switzerland |
| Nasu®ESP | Tassu ESP | Finland |
| Feinstaubkiller | TH-Alternativ-Energie | Germany |
| Dry ESP | Windhager | Austria |

### 4.1.2 Flue gas condensers

A specially developed high temperature condensing heat exchanger, a pellet boiler with integrated flue gas condensation and a flue gas condenser (condensing heat exchanger) have been considered for the study. The investigated devices are listed in Table 13.

**Table 13:** Investigated flue gas condensers

Explanations: Pellematic Plus … pellet boiler with integrated flue gas condensation

| name of device | manufacturer | country |
|---|---|---|
| UEF | University of Eastern Finland | Finland |
| Pellematic Plus | ÖkoFen | Austria |
| Öko-Carbonizer | Bschor GmbH | Germany |

### 4.1.3 Ceramic filters

The survey involved the evaluation of a wood log fired stove with an integrated foam ceramic filter and a ceramic filter (Table 14).

**Table 14:** Investigated ceramic filters

Explanations: ECO plus … wood log fired stove with integrated ceramic filter

| name of device | manufacturer | country |
|---|---|---|
| ECO plus (log wood stove) | HARK GmbH & Co. KG | Germany |
| Ceramic filter | Interfocos BV | The Netherlands |

### 4.1.4 Catalytic converters

Two catalytic converters have been considered for the survey (Table 15).

**Table 15:** Investigated catalytic converters

| name of device | manufacturer | country |
|---|---|---|
| KlimaKat | Caminos | Germany |
| MEKAT | IUTA/moreCAT GmbH | Germany |

### 4.1.5 Other devices

Additionally, a Swedish home built system called "flue gas well" has been investigated.

## 4.2 Evaluation of particle precipitation devices investigated

### 4.2.1 ESP $R_{esidential}$ESP - APP (Norway)

In Figure 8 a scheme of the ESP as well as a picture of the ESP, mounted on the top of a chimney, are presented.

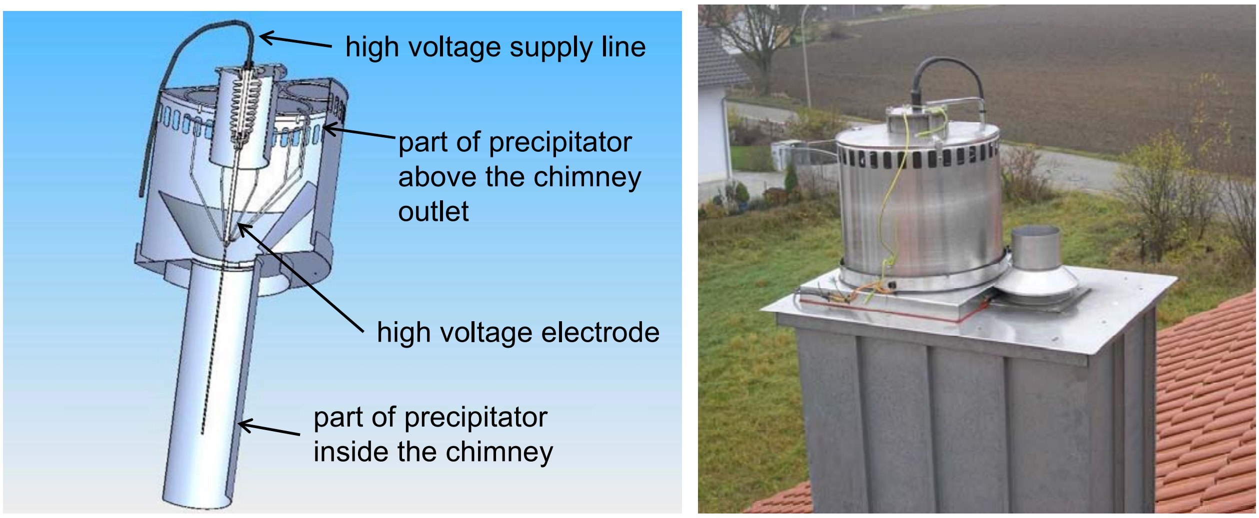



**Figure 8:** Scheme of the $R_{esidential}$ESP technology (left) and picture of the ESP (right)

Explanations: source [5]

#### 4.2.1.1 Basic data

- **Contact:**
  Ernst Henriksen (APP Applied Plasma Physics ASA)
  P.O Box 584
  4305 Sandnes, Norway
  phone: 516022-0016
  email: ernst.henriksen@app.no; web: http://www.app.no

- **Basic technological data**
  - **Description of technology:**
    - tube-type electrostatic precipitator
    - device is mounted on top of chimney
    - power consumption: 40-110 W (mean 180 W during test runs performed by TFZ Straubing) during operation
    - voltage of high-voltage power supply: 30 kV
  - **Field of application (according to manufacturer):**
    - old wood stoves (natural draught), coal stoves, automated boilers up to 20 kW continuous load fired with fuels with high ash content (tested for bark pellets and reed canary grass pellets)

#### 4.2.1.2 Technical evaluation

- **Operating behaviour:**
  - The unit has been tested with old and modern stoves as well as automated boilers.
  - The ESP is a stand alone "top of chimney" unit, and needs no interaction from the user. The unit starts and stops depending on flue gas temperature.
  - Some software adjustments to be done to handle spark-over issues that may occur during the operation of the unit. Spark-over is noisy and may be annoying for neighbours.
  - The ESP unit has no influence on the chimney draught.

- **Cleaning procedure:**
  - manual cleaning by chimney sweep on his regular visits (interval depends on operating time and type of furnace)

- **Installation:**
  - installation on top of the chimney
  - The unit can be fitted to most existing chimneys with a diameter of >150 mm.
  - height of filter unit about 0.5 m over the chimney's top
  - electric connection (230V) required

- **Maintenance:**
  - Recommended cleaning cycle is once or twice a year depending on the emission load. Cleaning has to be performed by the chimney sweep at regular visits.

- Dust/particles are removed from the existing dust pan via sweeping hatch in the chimney.

- **Results of test runs performed (I):**
  - Field test runs performed by National Institute of Technology (Norway)
    - 61 days test run at 0.11 W power consumption, old wood stove, during the whole period a cleaning efficiency for total dust of 54 to 61% has been achieved
  - Test runs performed at test stand (Figure 9) by SP Technical Research Institute of Sweden (Sweden)
    - The wood combustion cases included an old stove combined with normal supply of air. The combustion device used was an old cast iron wood stove (1220x320x270 mm) produced in Norway in the 1960’s. The test represented a measurement period of approximately 250 minutes and started with cold fireplace and included five full burning cycles. For determination of particle separation efficiency of the R_ESP unit, particles were measured upstream and downstream of the particle separation device. The particle concentration upstream of the R_ESP was 30 mg/MJ. Particle separation efficiency based on total mass concentrations was calculated to 86 ± 4 %. The results demonstrate a particle separation efficiency (with respect to number of particles) between 85 and 99 % of particles in the particle size range from 0.04 to 8.7 um (see Figure 10).

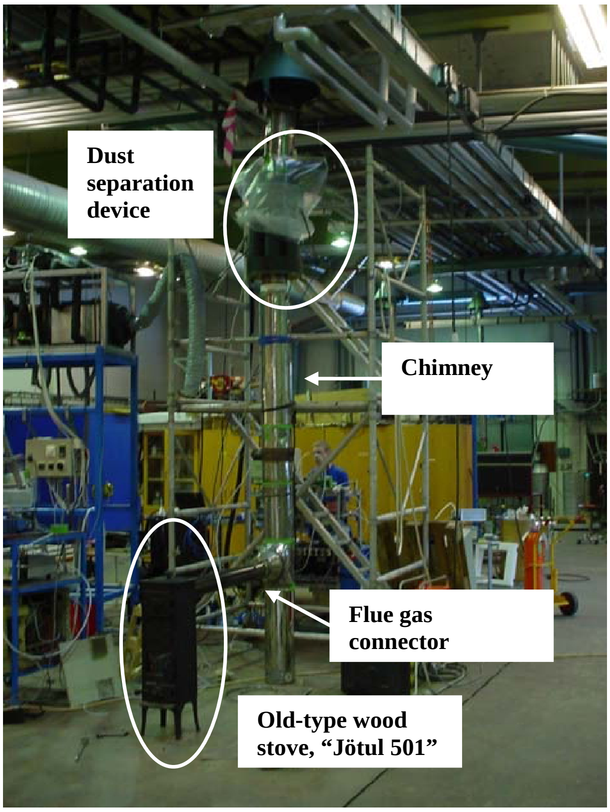



**Figure 9:** Picture of test stand at SP laboratories

**Table 16:** Flue gas composition before ESP

Explanations: CO and $NO_x$ related to 13% $O_2$ and dry flue gas

| $O_2$ (%) | $CO_2$ (%) | CO mg/Nm³ | TOC | $NO_x$ mg/Nm³ | Particles mg/MJ | Particles (1/MJ) |
|---|---|---|---|---|---|---|
| 15.8 | 4.4 | 1400 | | 130 | 30 | 2E+14 |

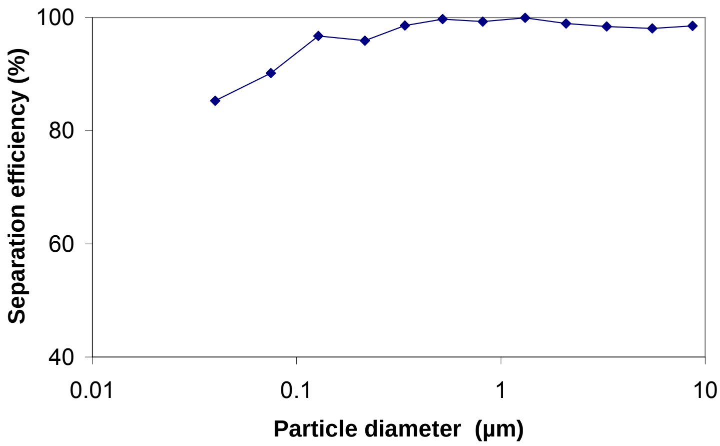



**Figure 10:** Particle separation efficiency of $R_{esidential}$ESP

Explanations: test run with old wood stove; precipitation efficiency related to number of particles

- **Results of test runs performed (II):**
  - Second set of test runs performed at test stand by SP Technical Research Institute of Sweden (Sweden) [6]
    - The ESP has been tested with an automatic multi-stoker boiler (65 kW). Results of test runs are presented in Table 17 and in Figure 11 and Figure 12

**Table 17:** Conditions of test runs performed

Explanations: CO and OGC related to 10% $O_2$ and dry flue gas; source [6]

| | Load (kW) | $CO_2$ (%) | CO $(mg/m_N^3)^*$ | OGC $(mg/m_N^3)^*$ | Particles $(\#/cm_N^3)$ |
|---|---|---|---|---|---|
| **Reed canary grass** | 17 | 5,2 | 440 | 21 | $2,5 \cdot 10^7$ |
| **Bark** | 21 | 6,5 | 17 | 1 | $1,9 \cdot 10^7$ |

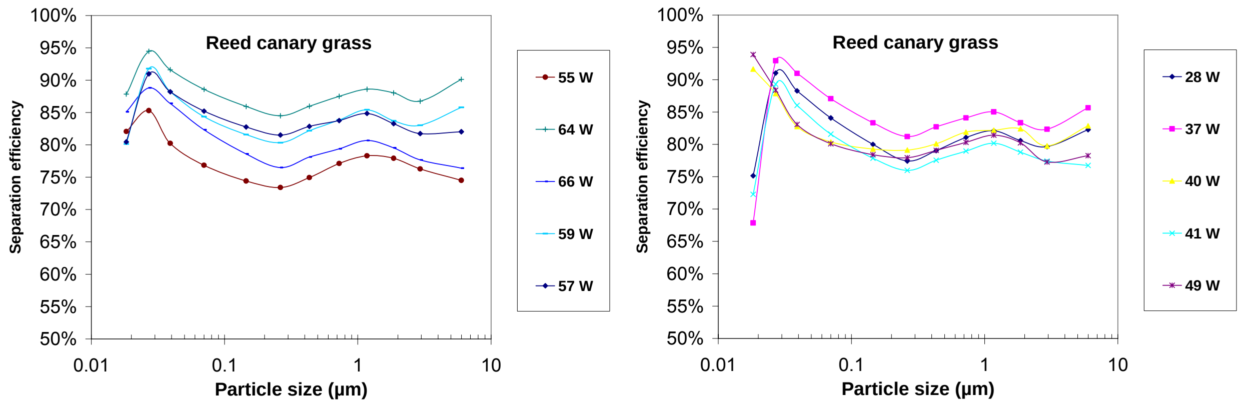



**Figure 11:** Particle separation efficiency of R$_{esidential}$ESP at different power consumptions

Explanations: test run with automatic boiler; precipitation efficiency related to number of particles; source [6]

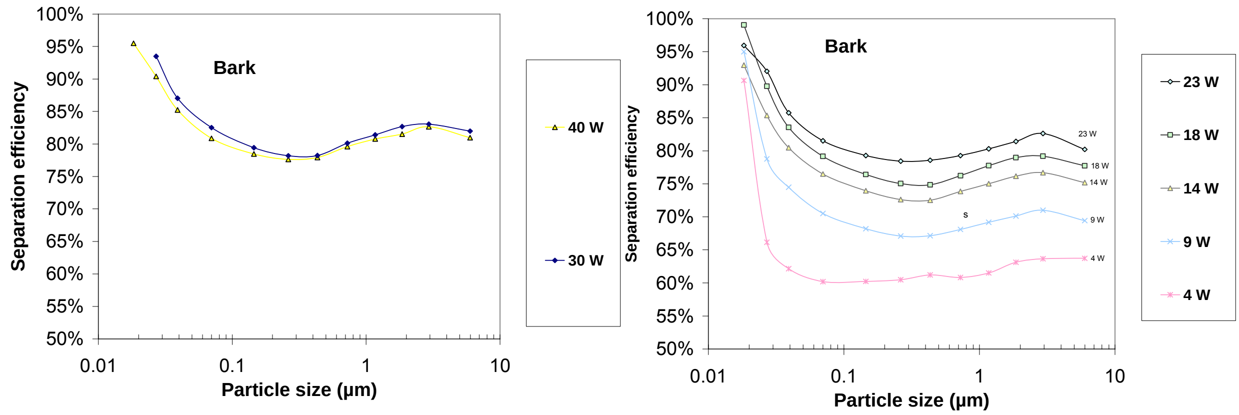



**Figure 12:** Particle separation efficiency of R$_{esidential}$ESP at different power consumptions

Explanations: test run with automatic boiler; precipitation efficiency related to number of particles; source [6]

- **Results of test runs performed (III):**
  - Test runs performed by TFZ Straubing (Germany) [33]
    - Field test runs and test runs at test stand (measurement methodology shown in Figure 13) performed with two chimney stoves and a tiled stove; 4 ESPs have been tested; estimated operating time (based on fuel consumption): 4,300 h
    - Conclusions of field test runs:
      - spark-over repeatedly occurred during running of the unit
      - spark-over due to deposition of ash and soot on high voltage electrode
      - failure of one unit due to deposition of ash and soot on high voltage electrode
      - neighbours complained about noise caused by spark-over
      - failure of one high voltage unit which had to be replaced

- high power consumption

- Results of test runs performed at test stand with two chimney stoves are summarised in Table 18, Table 19, Figure 14 and Figure 15

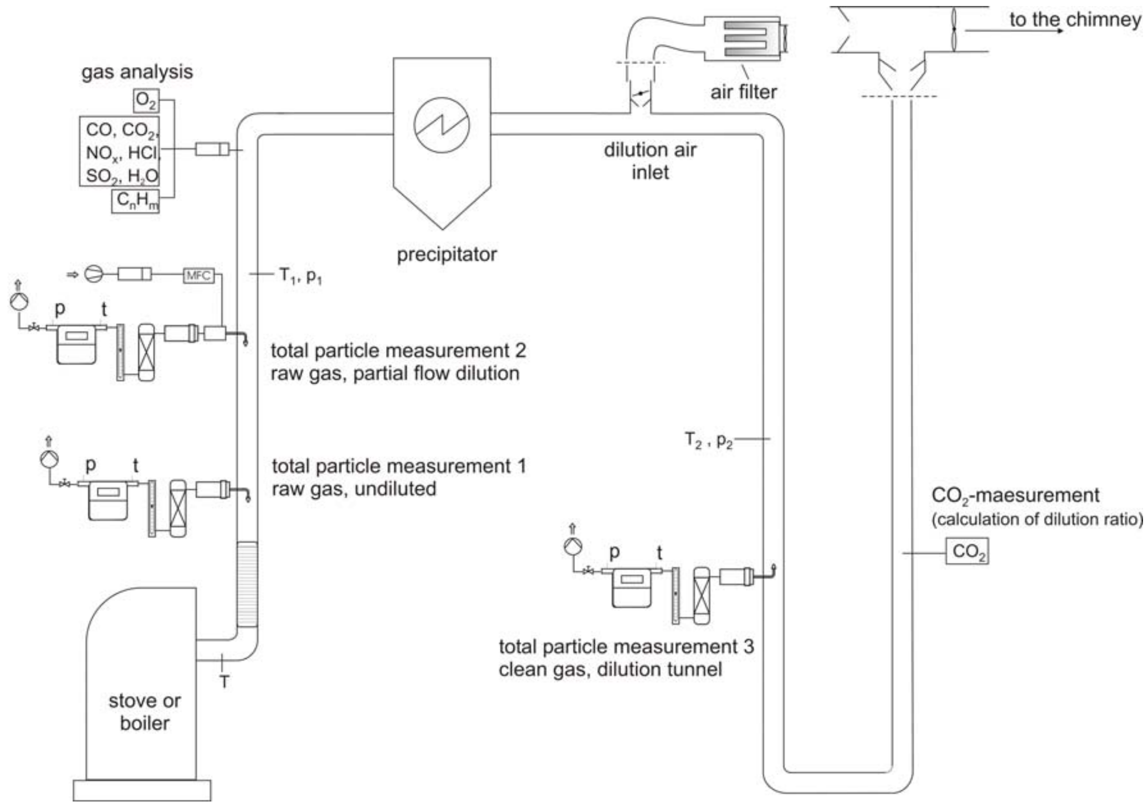



**Figure 13:** Scheme of measurement methodology of test runs at test stand performed by TFZ Straubing

Explanations: source [33]

**Table 18:** Results of test runs performed by TFZ Straubing – modern stove

Explanations: average of 18 measurements performed with ESP; test run with wood stove Wodtke Moon, which represents a modern high quality stove; fuel: beech log wood; source [33]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 1898 | 793 | 4957 |
| org. C | mg/m³ (13 % $O_2$) | 261 | 43 | 1274 |
| $O_2$ | vol.-% d.b. | 11.4 | 7.4 | 15.5 |
| flue gas temperature | ° C | 365 | 288 | 389 |
| flue gas pressure | Pa | -9.4 | -15.4 | -5.9 |
| dilution ratio | - | 6.6 | 6.4 | 6.8 |

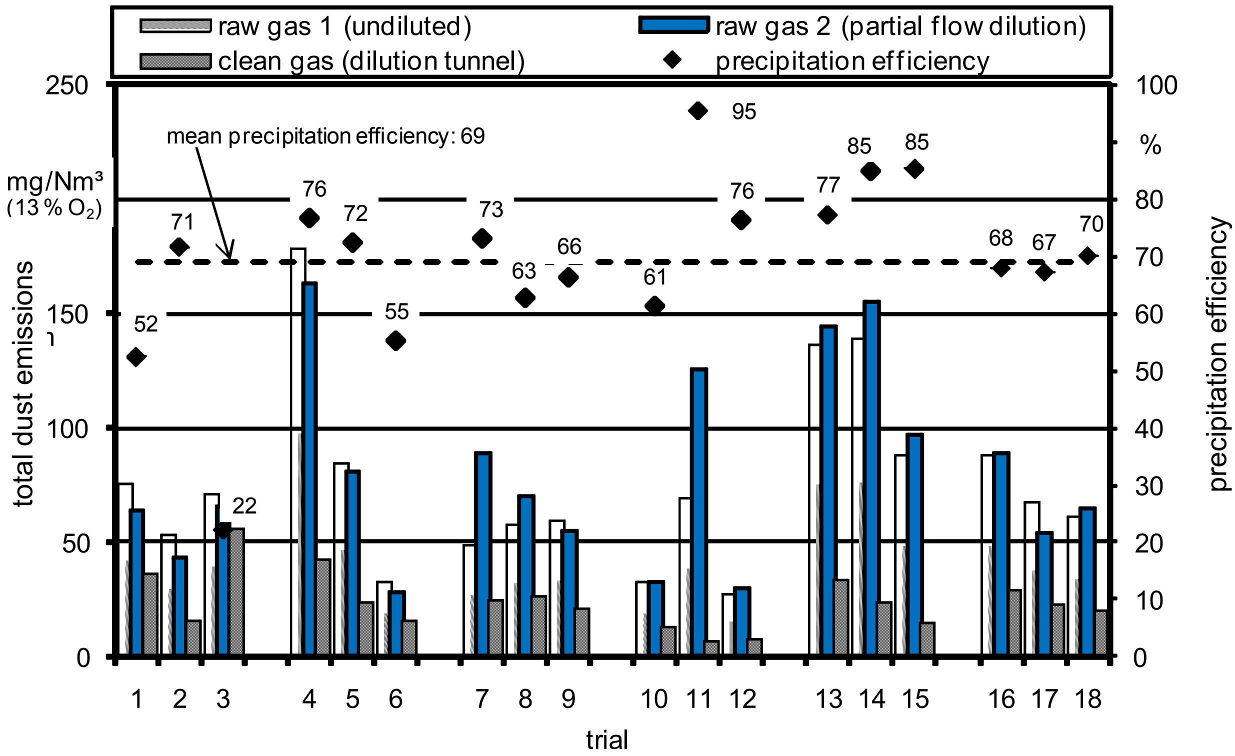



**Figure 14:** TSP precipitation efficiency of R$_{esidential}$ESP – modern stove

Explanations: values of 18 measurements performed with ESP; test run with wood stove Wodtke Moon, which represents a modern high quality stove; fuel: beech log wood; mean power consumption: 180 W; source [33]

**Table 19:** Results of test runs performed by TFZ Straubing – old stove

Explanations: average of 18 measurements performed with ESP; test run with wood stove Oregon, which represents a cheap stove; fuel: beech log wood; source [33]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 3508 | 1362 | 7506 |
| org. C | mg/m³ (13 % $O_2$) | 614 | 89 | 2994 |
| $O_2$ | vol.-% d.b. | 11.4 | 2.2 | 15.9 |
| flue gas temperature | ° C | 405 | 336 | 498 |
| flue gas pressure | Pa | -8.5 | -16.1 | -4.5 |
| dilution ratio | - | 6.5 | 5.8 | 6.7 |

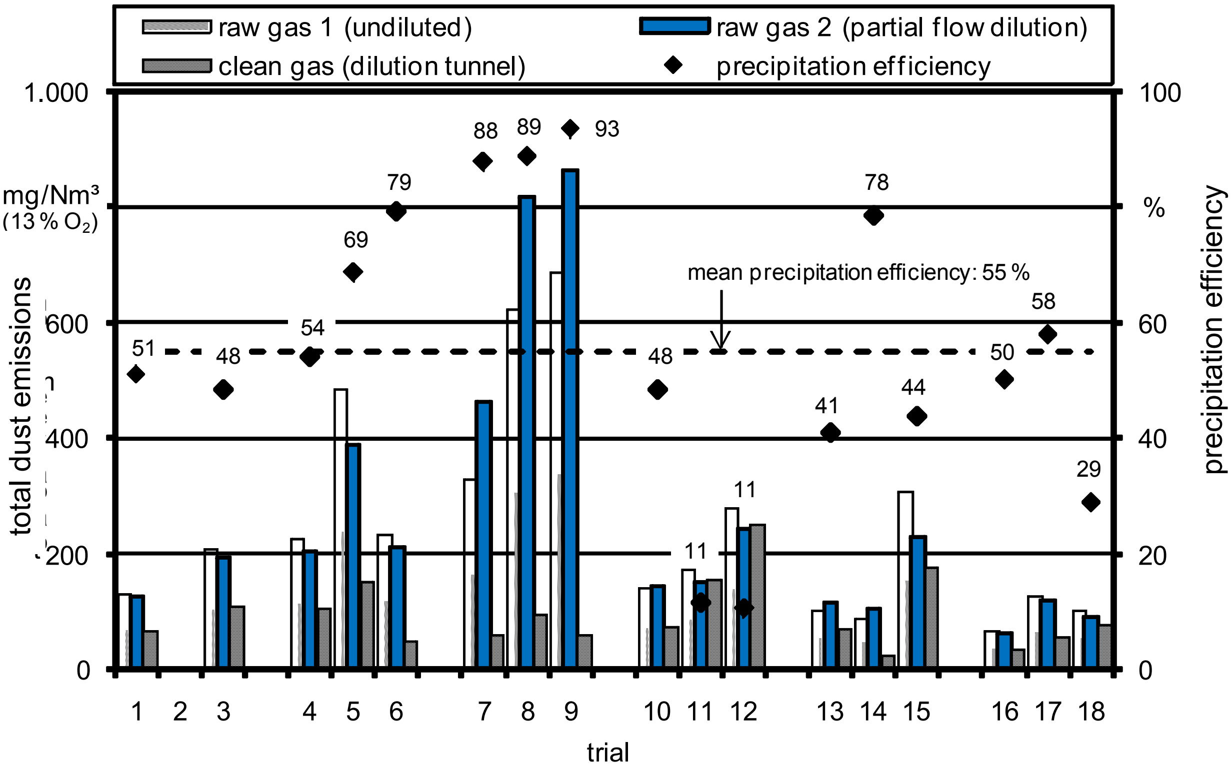



**Figure 15:** TSP precipitation efficiency of R$_{esidential}$ESP – old stove

Explanations: values of 18 measurements performed with ESP; test run with wood stove Oregon, which represents a cheap stove; fuel: beech log wood; mean power consumption: 180 W; source [33]

### *4.2.1.3 Relevant economic data*

- **Investments Costs:**
  - The unit is still under development and is not available on the market. The target selling price for the unit is 1,000 to 2,000 € (incl. VAT)
- **Annual operating costs:**
  - power consumption: up to 180 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - costs for chimney sweep (proportionate costs)

### *4.2.1.4 Summery and conclusions*

The device has been under development since 1996. Experience has shown that the unit can achieve cleaning efficiencies from 50 to 99% depending on fuel types, loads, stoves etc. The performed test runs showed that the ESP is basically suitable for old systems, but further development sure needed as availability not yet proven over a long time. The unit can easily adapt to both boilers and stoves. Field test shows that the unit is easy to install and run. Some software adjustments to be done to handle spark-over issues that repeatedly occurred during running of the unit are needed. Spark-over is noisy and may be annoying for neighbours. Longer field tests are needed. The power consumption of the ESP is too high (power consumption up to 180 W). The power supply has to be finalised and certified to comply with safety standards. The mechanical design of the ESP has to be finalised and optimised for mass production. Finally, certification to show performance in accordance with national regulations has to be carried out.

### 4.2.2 ESP CAROLA - KIT (Germany)

In Figure 16 a scheme of the ESP as well as a picture of the ESP are presented.

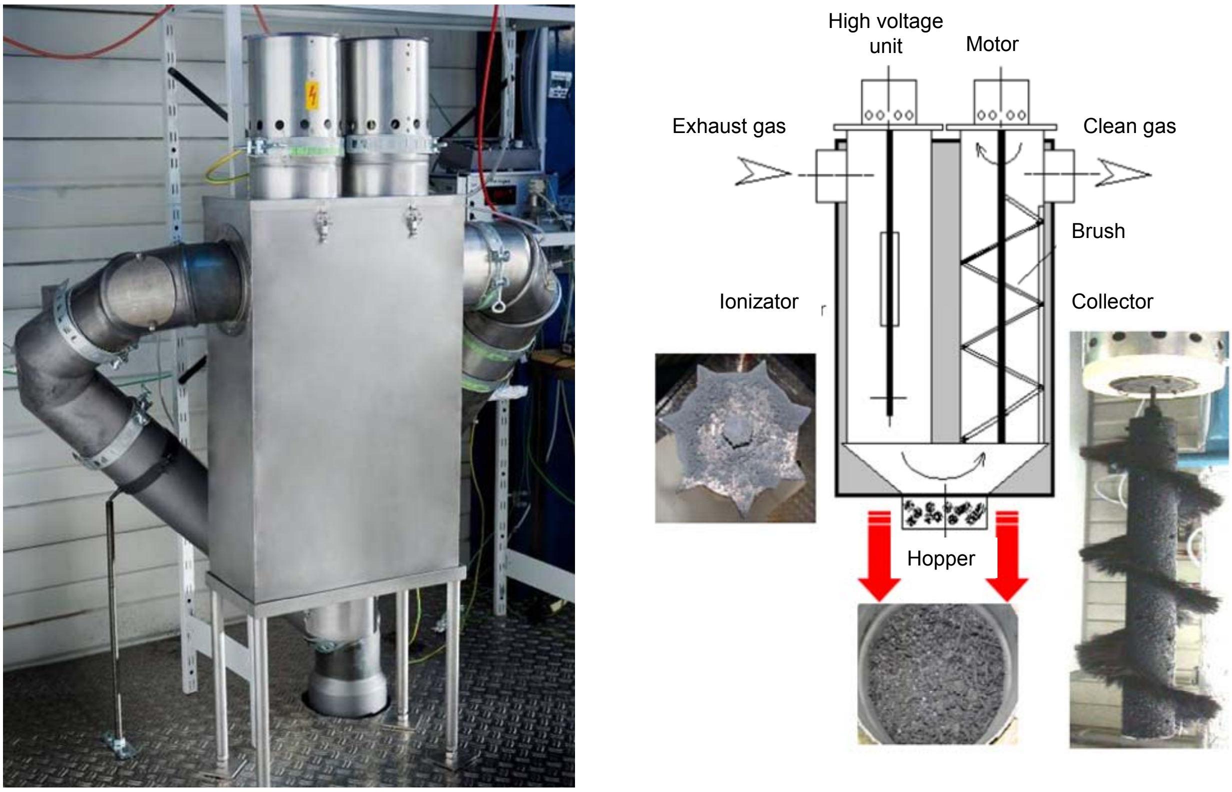



**Figure 16:** Picture of the ESP (left) and scheme of the Carola technology (right)

Explanations: source [11, 12]

#### *4.2.2.1 Basic data*

- **Contact:**
  Andrei Bologa
  Forschungszentrum Karlsruhe, Institut für Technische Chemie (KIT)
  Postfach 3640
  76021 Karlsruhe, Germany
  email: andrej.bologa@kit.edu; http://www.kit.edu
- **Basic technological data**
  - **Description of technology:**
    - two-stage process: ionising stage and collector stage
    - ionising stage consists of high voltage isolator, a rod and a high voltage electrode
    - collector stage consists of a grounded tube with a metallic brush inside

- pilot ESP needs no purge gas or air to protect high voltage isolator
- voltage of high-voltage power supply: 16-20 kV
- power consumption: mean 36 W during operation

▪ **Field of application (according to manufacturer):**
- for biomass combustion systems in general
- tested with modern wood log stoves (8 and 9 kW), modern wood pellet boiler (20 kW) and modern multi-fuel boiler (32 kW)

#### *4.2.2.2 Technical evaluation*

▪ **Operating behaviour:**
- stable operation of ESP when collector is cleaned by rotation of the brush for 1 minute every hour
- decrease of mass collection efficiency observed for batch wise operated stoves at the beginning of batch caused by increase of the corona suppression in the ionising stage and decrease of the corona current due to high particulate emissions
- pressure drop: up to 10 Pa

▪ **Cleaning procedure:**
- collection stage cleaned automatically for one minute once an hour with the brush inside (grains and straw pellets: 1 minute every 30 minutes)
- collection of dust in hopper

▪ **Installation:**
- installation between furnace and chimney
- required space: approx. 0.8m x 0.44m x 0.22m
- electric connection (230 V) is required

▪ **Maintenance:**
- automatic cleaning system is sufficient with brush
- filter ash must be discharged from the hopper (no time interval specified)

▪ **Results of test runs performed:**
- Test runs performed at test stand with a log wood stove, a pellet stove and an automatic pellet boiler by KIT (see Figure 17)


**Figure 17:** Pictures of combustion devices used for test runs

Explanations: left side: 9 kW modern wood log stove (Nr. 1), middle: 32 kW modern multi fuel boiler (Nr. 2), right side: 20 kW modern pellet boiler (Nr. 3); source [11]

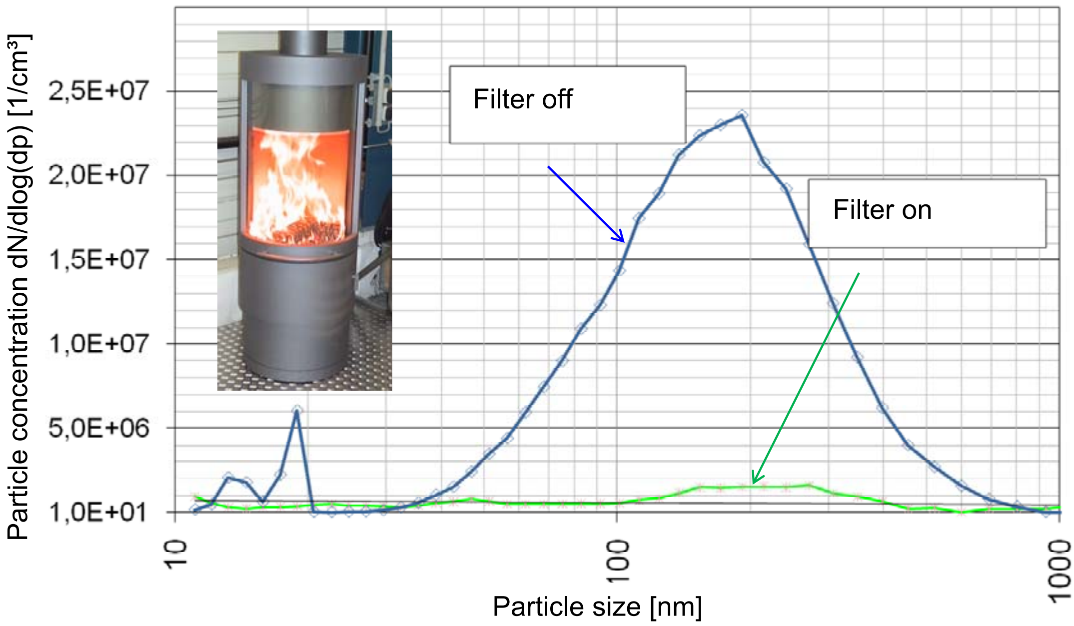



**Figure 18:** $PM_1$ precipitation efficiency of ESP Carola

Explanations: $PM_1$ measured with SMPS; source [11]

**Table 20:** TSP precipitation efficiency of ESP Carola

Explanations: TSP related to 13% $O_2$ and dry flue gas; source [11]

| Fuel | Mass concentration raw gas, mg/Nm³ | Mass concentration clean gas, mg/Nm³ | Precipitation efficiency % |
|---|---|---|---|
| Wood log | 29-35 | 3-5 | 87±3 (No.1) |
| wood pellets | 10-11 | 1-3 | 82±7 (No.2) |
| | 20-21 | 3-4 | 82±2 (No.3) |
| grain pellets | 107-143 | 19-39 | 73±7 (No.2) |
| mixed pellets | 117-133 | 28-32 | 77±1 (No.2) |
| straw pellets | 340-440 | 73-99 | 77±3 (No.2) |

- **Precipitation efficiency:**
  - TSP: 87 % precipitation efficiency for the log wood stove and up to 82 % for the wood pellet boiler investigated; 73 to 77 % precipitation efficiency for non-wood fuels (see Table 20)

#### *4.2.2.3 Relevant economic data*

- **Investments Costs:**
  - approx. 1,200 € (20% VAT included) for a 20 kW unit
- **Annual operating costs:**
  - power consumption: mean 36 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - no data/experience available yet

#### *4.2.2.4 Summery and conclusions*

The ESP is suitable for flue gas temperatures up to 300°C. The space requirements of the device are still high. The ESP is still in prototype-phase. The precipitation efficiency is sufficiently high and the automatic cleaning system seems to be efficient. Further developments regarding design and dimension are necessary in order to reduce space requirements. Test runs to prove applicability for old systems and stability of cleaning system are recommended.

### 4.2.3 ESP Zumik®on - K+W (Switzerland)

In Figure 19 a scheme of the ESP as well as a picture of the ESP are presented.

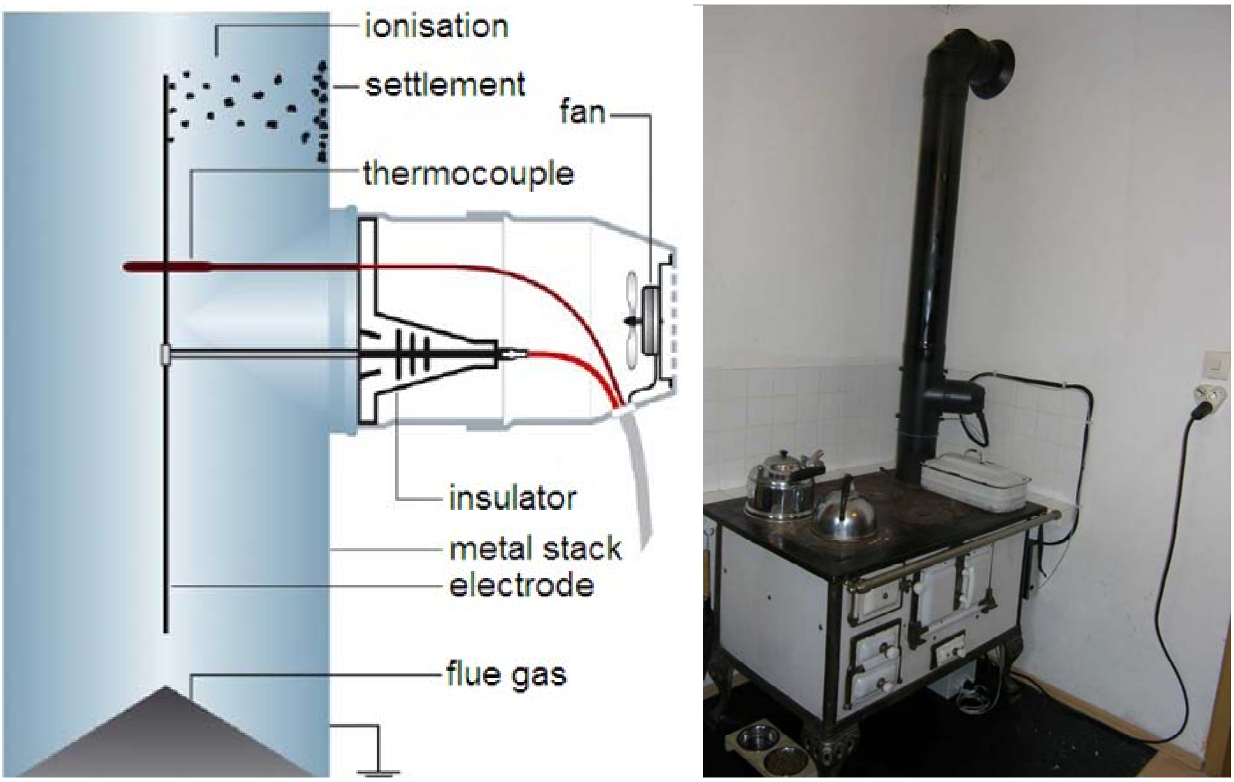



**Figure 19:** Scheme of the Zumik®on technology (left) and picture of the ESP (right)

Explanations: source [36]

#### 4.2.3.1 Basic data

- **Contact:**
  M. Pabst (Kutzner und Weber GmbH)
  Frauenstraße 32
  82216 Maisach, Germany
  phone: 08141-957121
  email: info@kutzner-weber.de; http://www.kutzner-weber.de

- **Basic technological data**
  - **Description of technology:**
    - tube-type electrostatic precipitator
    - high-voltage insulators and housings purged with air to prevent deposition of soot and condensation (additional fan)
    - power consumption: max. 15 W during operation (5 W Standby)
    - voltage of high-voltage power supply: 19-22.5 kV
  - **Field of application (according to manufacturer):**
    - pellet boilers, automatic wood chip and wood log boilers, pellet and log wood stoves
    - applicable for biomass combustion systems up to 35 kW (modern automatic systems up to 100 kW)

#### 4.2.3.2 Technical evaluation

- **Operating behaviour:**
  - precipitation efficiency reduced due to deposition of soot and tars on high voltage electrode
  - electrode has to be changed periodically due to corrosion (interval unknown)
  - minor damages of ESP due to high flue gas temperatures
  - flue gas temperatures may not exceed 400°C
  - Customers repeatedly complained about noise emissions
- **Cleaning procedure:**
  - cleaning will be carried out by chimney sweep on his regular visits (interval depends on operation time and type of furnace)
- **Installation:**
  - installation in steel tube between stove and chimney or in chimney (steel or stainless steel)
  - length of flue gas tube after ESP: min. 2m
  - diameter of flue gas tube: min. 130mm
  - space required by electronic circuit: 300 mm x 300 mm
  - ESP must be accessible for cleaning/maintenance
  - electric connection (230V) required
- **Maintenance:**
  - will be carried out by chimney sweep on his regular visits (interval depends on operating time and type of furnace)
- **Results of test runs performed (I):**
  - Test runs performed by Graz University of Technology (Austria)
    - Field test runs (measurement methodology shown in Figure 20) and test runs at test stand performed with log wood boiler, total operating time: 545 h
    - Results of field test runs are summarised in Figure 21, Table 21 and Table 22

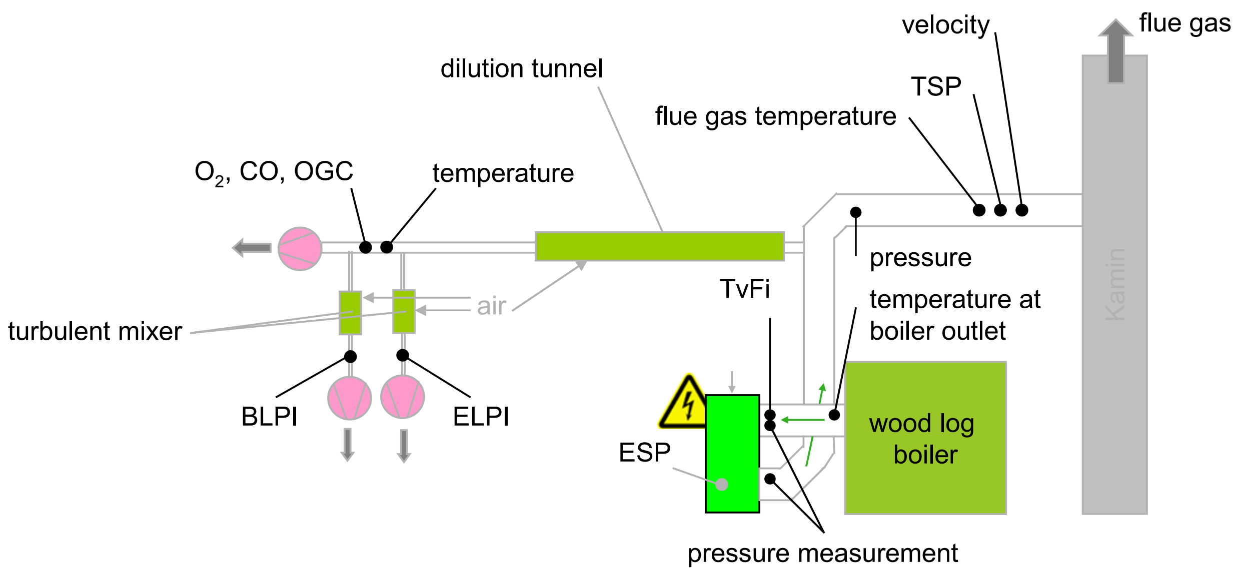



**Figure 20:** Scheme of measurement methodology of field test runs performed by Graz University of Technology

Explanations: BLPI ... 9-stage Berner-type low-pressure impactor; ELPI ... electrical low pressure impactor; TvFi ... temperature at filter inlet; TSP (total suspended particulate matter ) measurements according to VDI 2066; log wood boiler Fröling FHG 2000 (2002 model); source: [43]

**Table 21:** Results of field test runs with ESP Zumikron performed by Graz University of Technology

Explanations: sampling time of each measurement performed: 10 min.; max ... maximum value; min ... minimum value; field test run with log wood boiler Fröling FHG 2000 (2002 model); source: [43]

| **Parameter** | **ESP** | **mean value** | **standard deviation** | **Min** | **Max** |
|---|---|---|---|---|---|
| **dp ESP** | off | 4.7 | 4.0 | 0 | 27.2 |
| [Pa] | on | 4.6 | 3.8 | 0 | 30.7 |
| **CO** | off | 56 | 86 | 3 | 1804 |
| [mg/Nm³ tr. RG 13 Vol.% $O_2$] | on | 120 | 263 | 3 | 8684 |
| **OGC** | off | 53 | 22 | 1 | 716 |
| [mg/Nm³ tr. RG 13 Vol.% $O_2$] | on | 58 | 27 | 1 | 1013 |

**Table 22:** TSP precipitation efficiency of ESP Zumikron

Explanations: mean values of 13 measurements performed (11 with ESP); max ... maximum value; min ... minimum value; TSP ... total suspended particulate matter; field test run with log wood boiler Fröling FHG 2000 (2002 model); source: [43]

| **Parameter** | **ESP** | **mean value** | **standard deviation** | **min** | **max** | **precipitation efficiency** |
|---|---|---|---|---|---|---|
| **TSP** | off | 22.6 | 11.2 | 9.2 | 41.9 | |
| [mg/Nm³ 13 Vol.% $O_2$ d.b.] | on | 13.3 | 4.5 | 4.2 | 19.2 | 41% |

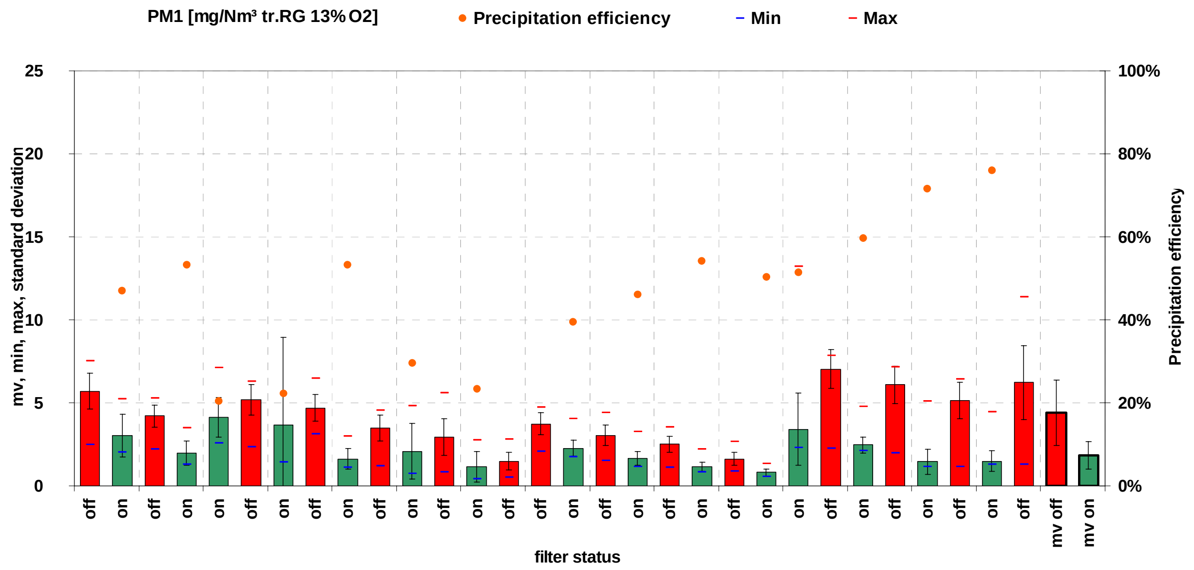



**Figure 21:** $PM_1$ precipitation efficiency of ESP Zumikron during field test runs performed by Graz University of Technology

Explanations: mv ... mean value; max ... maximum value; min ... minimum value; field test run with log wood boiler Fröling FHG 2000 (2002 model); results of ELPI measurements; sampling time of each measurement: 2 min.; source: [43]

- **Precipitation efficiency (I):**
  - $PM_1$ emissions: 20-76% (mean 53%) precipitation efficiency (see Figure 21)
  - TSP: mean 41% precipitation efficiency (see Table 22)
- **Results of test runs performed (II):**
  - Test runs performed by TFZ Straubing (Germany)
    - Field test runs and test runs at test stand (measurement methodology shown in Figure 22) performed with chimney stove, tiled stove and residential cooker; 5 ESPs have been tested; estimated operating time (based on fuel consumption): 3,700 h
    - Conclusions of field test runs:
      - spark-over repeatedly occurred during running of the unit
      - customer complained about noise caused by spark-over and purge air fan
      - high voltage electrode broke due to high flue gas temperature of old tiled stove
    - Results of test runs at test stand are summarised in Table 23 and Table 24 as well as in Figure 23 and Figure 24

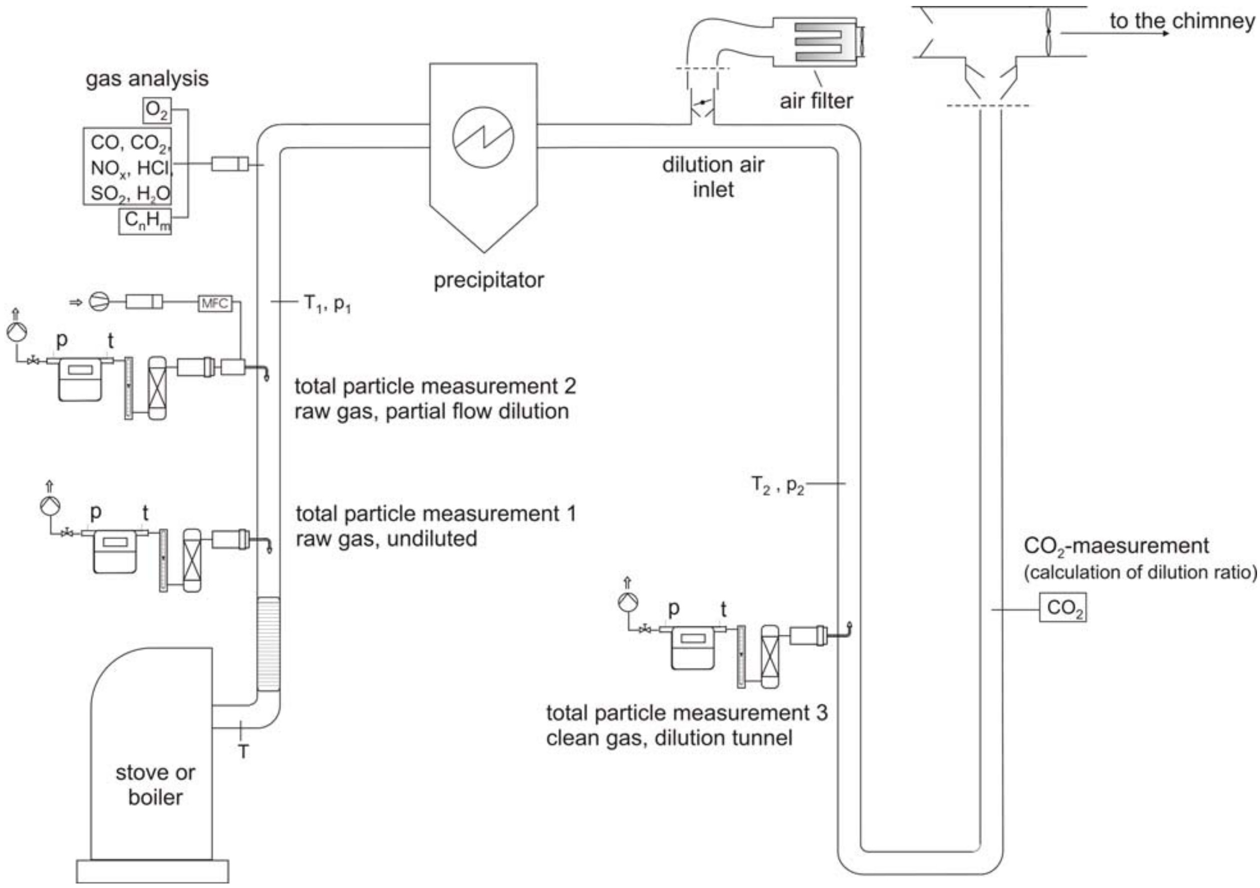



**Figure 22:** Scheme of measurement methodology of test runs at test stand performed by TFZ Straubing

**Table 23:** Results of test runs at test stand performed by TFZ Straubing – modern stove

Explanations: average of 18 measurements performed with ESP; test run with wood stove Wodtke Moon, which represents a modern high quality stove; fuel: beech log wood; source [33]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 1914 | 540 | 5996 |
| org. C | mg/m³ (13 % $O_2$) | 225 | 25 | 866 |
| $O_2$ | vol.-% d.b. | 11.6 | 5.9 | 16.6 |
| flue gas temperature | ° C | 387 | 315 | 440 |
| flue gas pressure | Pa | -10.7 | -12.3 | -8.5 |
| dilution ratio | - | 4.7 | 4.7 | 4.9 |

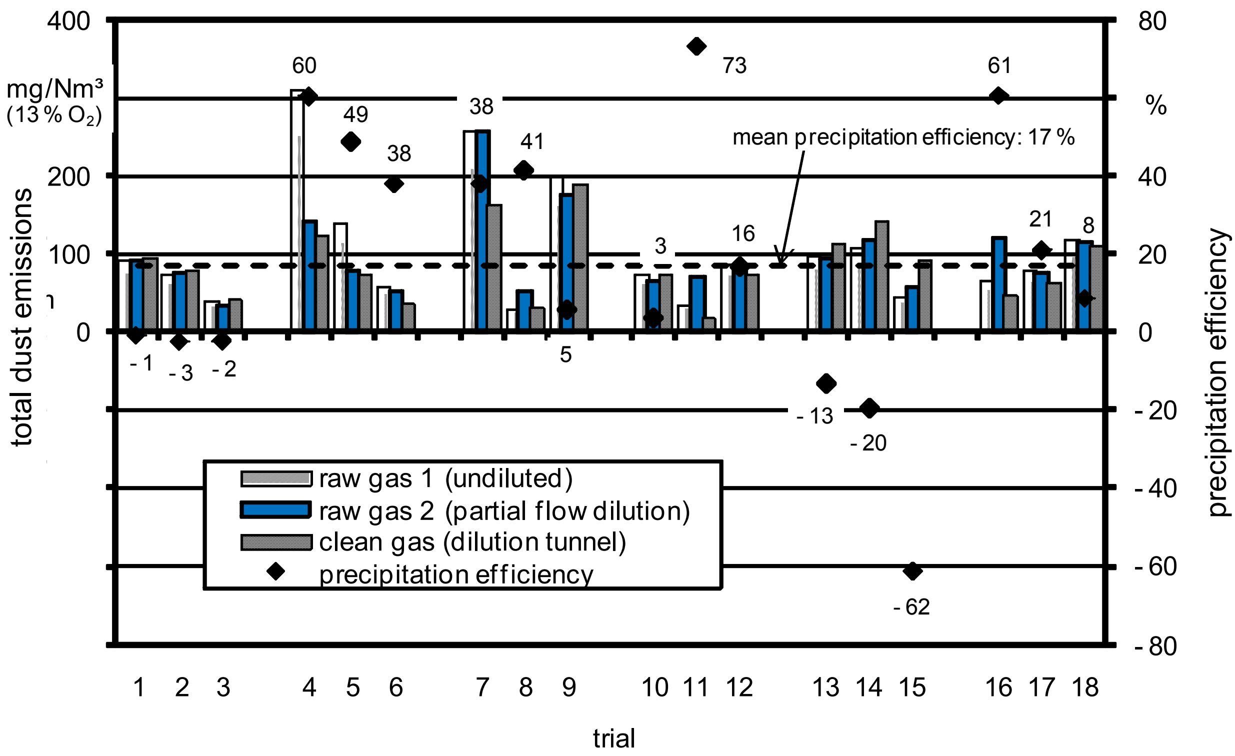



**Figure 23:** TSP precipitation efficiency of ESP Zumik®on – modern stove

Explanations: values of 18 measurements performed with ESP; test run with wood stove Wodtke Moon, which represents a modern high quality stove; fuel: beech log wood; source: [33]

**Table 24:** Results of test runs at test stand performed by TFZ Straubing – old stove

Explanations: average of 18 measurements performed with ESP; test run with wood stove Oregon, which represents a cheap stove; fuel: beech log wood; source: [33]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 3488 | 1826 | 5900 |
| org. C | mg/m³ (13 % $O_2$) | 394 | 54 | 961 |
| $O_2$ | Vol.-% d.b. | 10.3 | 5.9 | 15.8 |
| flue gas temperature | ° C | 455 | 392 | 507 |
| flue gas pressure | Pa | -12.4 | -18.6 | -8.8 |
| dilution ratio | - | 4.7 | 4.3 | 4.9 |

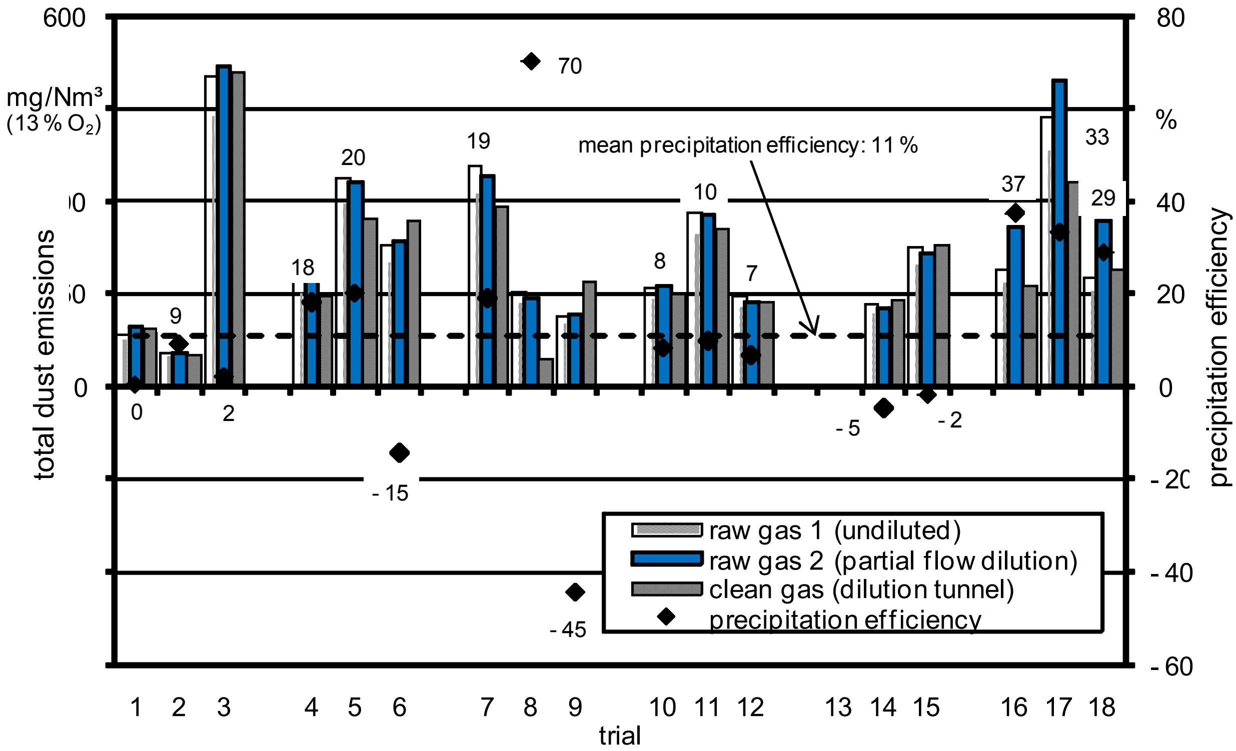



**Figure 24:** TSP precipitation efficiency of ESP Zumik®on – old stove

Explanations: values of 18 measurements performed with ESP; test run with wood stove Oregon, which represents a cheap stove; fuel: beech log wood; source: [33]

- **Precipitation efficiency (II):**
  - TSP: in test runs only an mean precipitation efficiency of 11 and 17 % was determined (see Figure 23 and Figure 24)

#### *4.2.3.3 Relevant economic data*

- **Investments Costs:**
  - approx. 1,500 € (20% VAT included) + installation
- **Annual operating costs:**
  - power consumption: approx. 5-15 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - costs for chimney sweep (proportionate costs)
  - costs for replacement of high voltage electrode (interval unknown)

#### *4.2.3.4 Summery and conclusions*

The ESP is available on the market since 2007 and almost 1200 units have been sold so far. The ESP is limited suitable for old boilers and stoves due to possible condensation of tars on the electrode. The flue gas temperature may not exceed 400 °C in order to avoid damages of the ESP. The ESP must be continuously purged with air. The precipitation efficiency of the

ESP is low. Customers repeatedly complained about noise emissions. The reliability of the ESP during performed field test runs was rather poor.

### 4.2.4 ESP OekoTube - OekoSolve (Liechtenstein)

In Figure 16 a scheme of the ESP OekoTube as well as pictures of the ESP are presented.


**Figure 25:** Scheme of the OekoTube technology (left), picture of electrode (middle) and picture of mounted ESP (right)

Explanations: 1 ... metal tube; 5 ... insulator; 9 ... electronic circuit; 10 ... electrode; 12 ... ESP cover; 13 ... chimney hood; source: [40]

#### *4.2.4.1 Basic data*

- **Contact:**
  Beat Müller (OekoSolve AG)
  Essanestrasse 127
  9492 Eschen, Liechtenstein
  phone: 0041+81 755 44 48
  email: beat.mueller@oekosolve.ch; http://www.oekosolve.ch

- **Basic technological data**
  - **Description of technology:**
    - tube-type electrostatic precipitator
    - unit is mounted on the top of the chimney
    - power consumption: 20-30 W during operation
    - voltage of high-voltage power supply depends on decompositions on electrode (15-30 kV)
  - **Field of application (according to manufacturer):**
    - applicable for biomass combustion systems up to 70 kW

#### *4.2.4.2 Technical evaluation*

- **Operating behaviour:**
  - precipitation efficiency reduced due to deposition of soot on high voltage electrode
  - by ESP removed filter ash gets partly blown out and is distributed on roof
- **Cleaning procedure:**
  - cleaning will be carried out by chimney sweep on his regular visits (interval depends on operating time and type of furnace)
- **Installation:**
  - metal tube (length: 2m) inside chimney not obligatory
  - precipitation efficiency for stone chimneys slightly lower
  - length of vertical chimney: min. 2m
  - diameter of chimney: min. 150mm
  - chimney must be accessible for cleaning/maintenance
  - Electric connection (230V) required
- **Maintenance:**
  - will be carried out by chimney sweep on his regular visits (interval depends on operating time and type of furnace)
  - filter ash must be discharged periodically from the bottom of the chimney
- **Results of test runs performed (I):**
  - Results of test runs performed at test stand are summarized in Figure 26

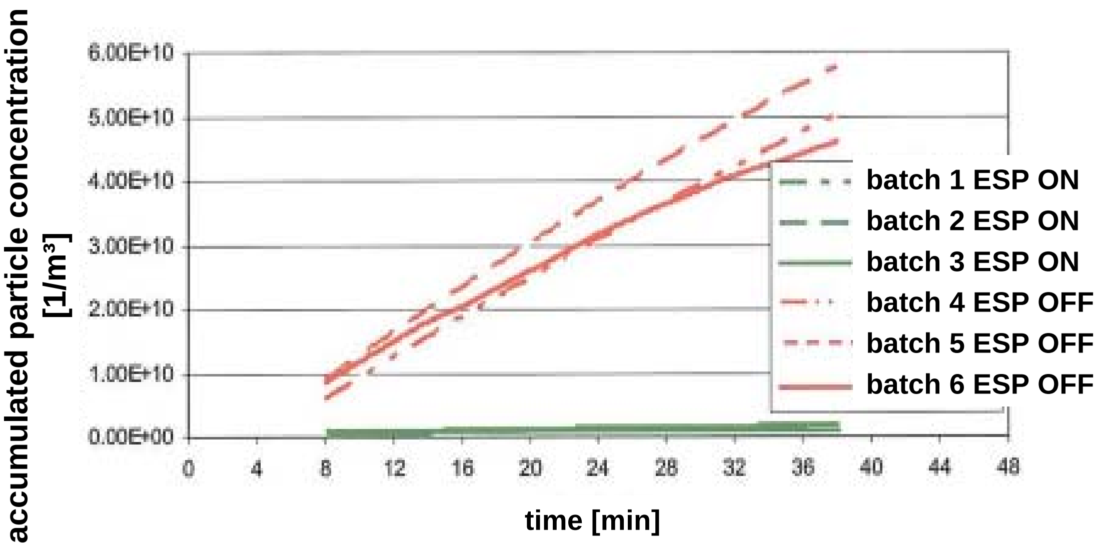



**Figure 26:** Results of PM measurements during test run with ESP Oekotube

Explanations: test run with 7 insert appliance (Mars 510K); fuel: beech wood log; load: 7 kW; PM measured with Diffusion Size Classifier (DiSC); source [65]

- **Results of test runs performed (II):**
  - Test runs performed by Graz University of Technology (Austria)
    - Test runs at test stand performed with a modern pellet boiler within an ongoing R&D project (ERA-NET FutureBioTec)
    - Results of one representative test run are summarised in Figure 27

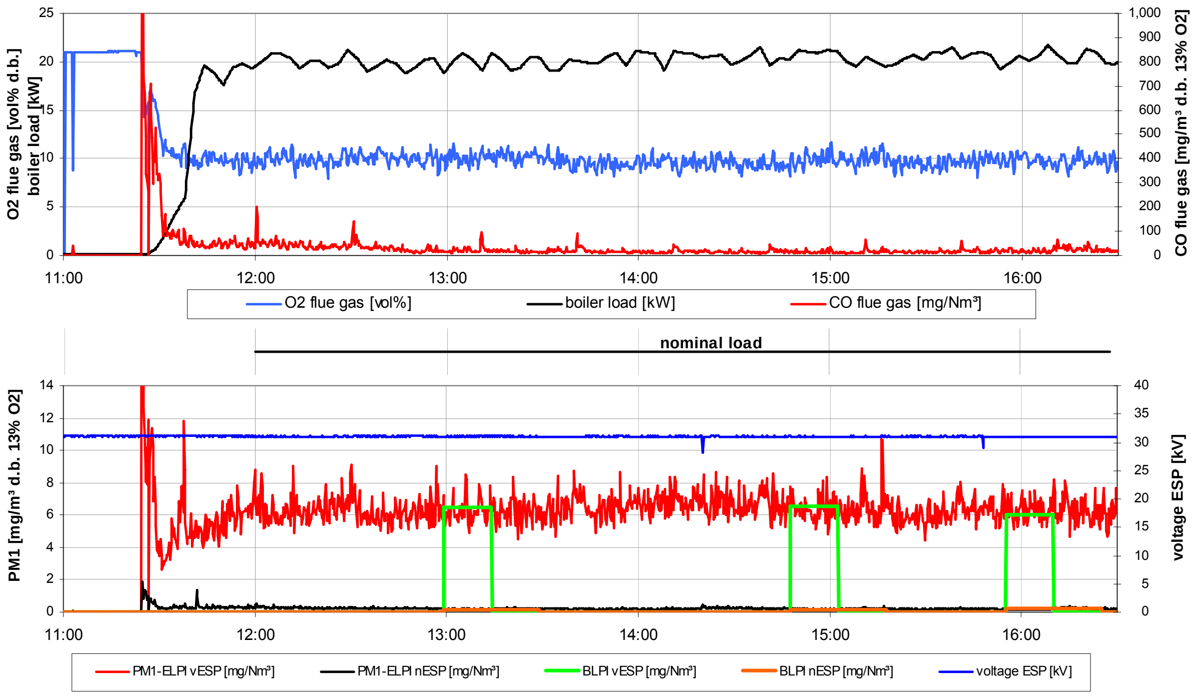



**Figure 27:** Results of a test run at test stand with the ESP Oekotube

Explanations: test run with automatic pellet boiler; fuel: wood pellets; PM measured with BLPI (9-stage Berner-type low-pressure impactor); ELPI … Electrical low pressure impactor; vESP … at filter inlet; nESP … at filter outlet

- **Precipitation efficiency (II):**
  - $PM_1$ emissions: 96.7 to 97.5% precipitation efficiency

### *4.2.4.3 Relevant economic data*

- **Investments Costs:**
  - ESP: 1,600-2,000 € (7.6% VAT included) → 1,784-2,230 € (20% VAT included)
  - installation: 500-1,000 € (7.6% VAT included) → 558-1,115 € (20% VAT included)
- **Annual operating costs:**
  - power consumption: 20-30 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - costs for chimney sweep (proportionate costs)

#### *4.2.4.4 Summery and conclusions*

The ESP is already available on the market since 2008 and 700 units have been installed to far. The ESP is suitable for biomass combustion systems up to 70 kW. The ESP is mounted on top of the chimney (no extra space required). The precipitation efficiency of the ESP is high (according to the manufacturer). Long-term field tests and test stand test by experienced scientists in the field are recommended. Furthermore, the applicability of the ESP for old systems is not clarified so far.

### 4.2.5 ESP Bosch (Germany)

In **Figure 28** pictures of the ESP are presented.

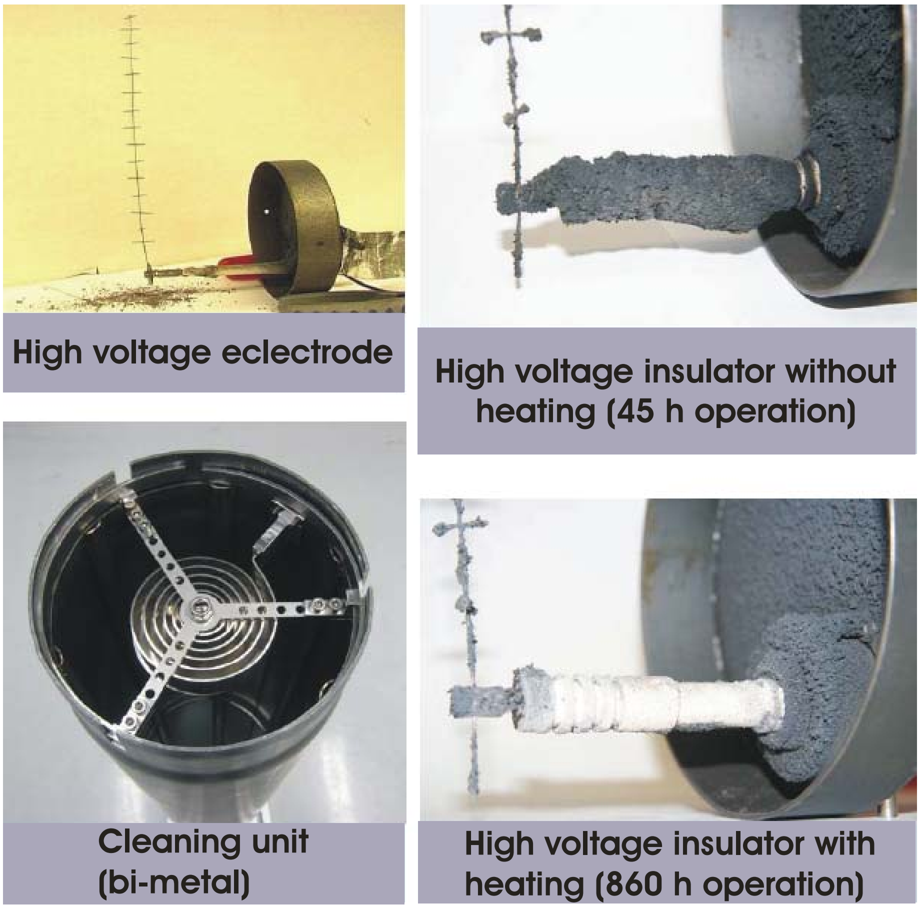



**Figure 28:** Pictures of the ESP Bosch

Explanations: source: [59]

#### *4.2.5.1 Basic data*

- **Contact:**
  Dr. Dietmar Steiner (Robert Bosch GmbH)
  Robert-Bosch-Straße 2
  70442 Stuttgart, Germany
  phone: 0711 811 34046
  email: dietmar.steiner@de.bosch.com; http://www.bosch.de

- **Basic technological data**
  - **Description of technology:**
    - tube-type electrostatic precipitator
    - high-voltage insulator heated to prevent deposition of soot and condensation of hydrocarbons
    - voltage of high-voltage power supply: 12-17 kV (depending on ash deposit formation on the electrode)
    - power consumption: 34 W during operation, 2 W (Standby)
  - **Field of application (according to manufacturer):**
    - pellet boiler, log wood boiler, pellet stove, log wood stove
    - technology applicable for old stoves and natural draught systems (pressure drop max. 6 Pa)
    - prototype applicable for biomass combustion systems up to 25 kW; system can be adapted for 50 kW boiler capacity

#### 4.2.5.2 Technical evaluation

- **Operating behaviour:**
  - no field test runs performed
  - test run for 860 h at test stand with automatic pellet boiler (50 mg/Nm³ PM1 after boiler)
  - pressure drop in operation: max. 6 Pa
  - tested with pellet and log wood boiler, pellet and wood log stoves
  - system available after 30 seconds after ignition of fuel
- **Cleaning procedure:**
  - automatic tube cleaning system by bi-metal spring (no power needed) during start up
  - tube cleaning system (no power needed) must be activated manually (after 50 to 100 h of operation)
  - no tube cleaning system for operation with automatic pellet boiler ( $PM_1$ <50 mg/Nm³)
- **Installation:**
  - installation in flue gas duct
  - electric connection required (230 V)
  - required space:
    - tube length: 1.25 m (diameter: 150mm for ESP, 180mm for precipitation tube)
    - electronic circuit: 0.2m x 0.19m x 0.065m
- **Maintenance:**
  - no maintenance necessary during test run at test stand with automatic pellet boiler (860 h)

- **Results of test runs performed:**
  - Internal measurements performed at test stand (see Figure 29)

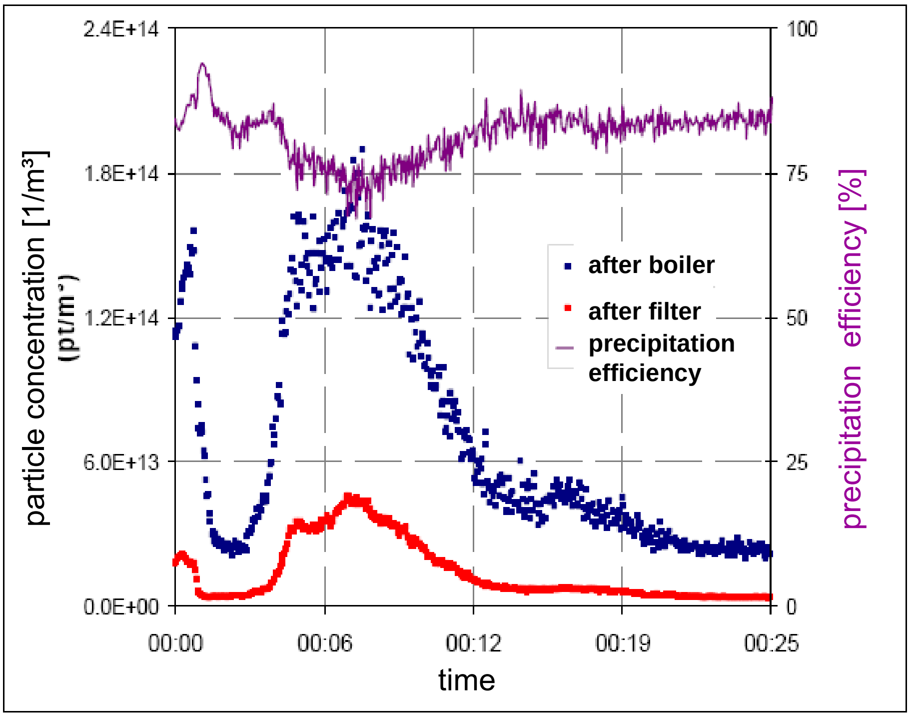



**Figure 29:** Results of PM measurements during test run with ESP Bosch

Explanations: test run with log wood fired stove; $PM_1$ emissions: max. 500 mg/Nm³; measured with parallel DiSC's and TEOM; source: [59]

- **Precipitation efficiency (according to manufacturer):**
  - $PM_1$ emissions:
    - 60% precipitation efficiency for $PM_1$ emissions >400 mg/Nm³ in raw flue gas
    - 80-90% precipitation efficiency for $PM_1$ emissions <100 mg/Nm³ in raw flue gas
    - 70% precipitation efficiency after test run (860 h) at test stand ($PM_1$ emissions after pellet boiler: ~ 50 mg/Nm³)

### *4.2.5.3 Relevant economic data*

- **Investments costs (19% VAT included):**
  - ESP: 715-950 € → 721-958 € (20% VAT included)
  - tube cleaning system: 240-360 €→ 242-363 € (20% VAT included)
  - Installation: 240 €→ 242 € (20% VAT included)
- **Annual operating costs:**
  - power consumption: max. 34 W (costs depend on operation time and electricity price)

- **Annual maintenance and other costs:**
  - No data/experience available yet

### *4.2.5.4 Summery and conclusions*

The ESP is still in prototype-phase. A maintenance free operation for 860 h with a modern pellet boiler has been proven. Field test runs are necessary for further evaluation since the device has not been sufficiently tested so far. The device is not ready for market as applicability and stability of technology have not been proven so far. The applicability for old stoves and boilers is not clarified.

## 4.2.6 ESP RuFF-Kat (Germany)

In Figure 30 a scheme of the ESP as well as a typical application in connection with a tiled stove are presented.

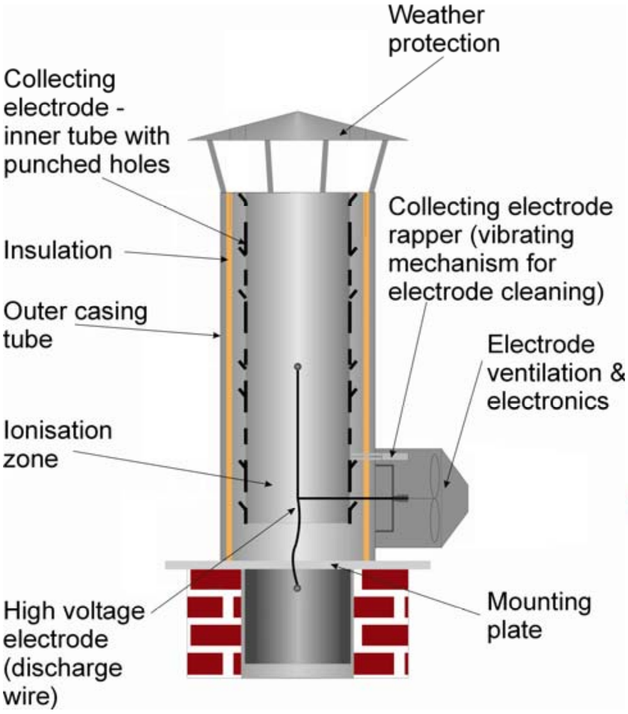




**Figure 30:** Scheme of the RuFF ESP technology (left) and typical example for the application of the ESP (right)

Explanations: source: [19]

### *4.2.6.1 Basic data*

- **Contact:**
  Fred Wilhelmer (RuFF-Kat GmbH)
  Poststraße 14
  83119 Obing, Germany
  phone: +49 (0)8624-89 89-40
  email: info@ruff-kat.de; http://www.ruff-kat.de

- **Basic technological data**
  - **Description of technology:**
    - tube-type electrostatic precipitator
    - unit is mounted on the top of chimney
    - filter consists of outer casing tube and inner tube, consisting of a mesh of springs, which is introduced in outer tube
    - high-voltage insulators purged with air (fan) to prevent deposition of soot and condensation
    - power consumption: max. 20 W during operation
    - voltage of high-voltage power supply: max. 30 kV
  - **Field of application (according to manufacturer):**
    - pellet boilers, all kinds of stoves and residential log wood boilers
    - applicable for biomass combustion systems up to 40 kW

#### *4.2.6.2 Technical evaluation*

- **Operating behaviour:**
  - pressure losses negligible
  - flue gas temperatures may not exceed 400°C
- **Cleaning procedure:**
  - automatic cleaning system (interval depends on operating time and type of furnace)
  - Cleaning is achieved with a periodically operated magnetic vibrator which is connected with springs of inner tube
  - electrode is cleaned by chimney sweep on his regular visits (interval depends on operating time and type of furnace)
- **Installation:**
  - device is mounted directly on the stack and therefore no additional space required
  - height of filter unit about 1 m, diameter 120-350 mm
  - electric connection (230V) required
- **Maintenance:**
  - filter ash must be discharged periodically from bottom of chimney
- **Results of test runs performed:**
  - Test runs performed by TFZ Straubing (Germany)
    - Test runs at test stand performed with modern automatic wood chip boiler within ongoing demonstration project (EU-FP7/EU-UltraLowDust)
    - ESP equipped with double-sided cylindrical helix electrode (22 kV)
- **Precipitation efficiency :**
  - TSP: >70% precipitation efficiency

#### *4.2.6.3 Relevant economic data*

- **Investments Costs:**
  - approx. 1,500 € (20% VAT included) + installation
- **Annual operating costs:**
  - power consumption: approx. 20 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - costs for chimney sweep (proportionate costs)

#### *4.2.6.4 Summery and conclusions*

The device is mounted directly on the stack and therefore has no additional space demand. The device is equipped with an automated cleaning system assuring for long-term operation without a need for manual cleaning (except electrode). The flue gas temperature may not exceed 400 °C in order to avoid damages of ESP. The market introduction of the ESP is foreseen soon. The applicability for old systems has not been proven so far. The ESP will be comprehensively tested within the EU FP7 Demo project (EU-FP7/EU-UltraLowDust).

### 4.2.7 ESP AL-Top - Schräder (Germany)

In Figure 16 a scheme of the ESP AL-Top as well as a picture of the ESP are presented.

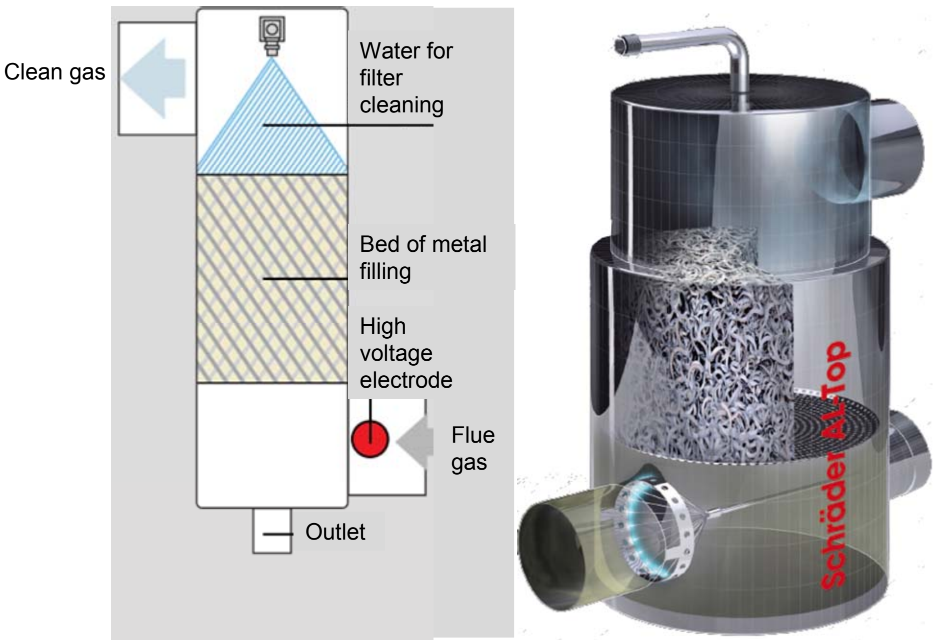



**Figure 31:** Scheme of the AL-Top technology (left) and picture of the ESP (right)

Explanations: source: [10, 11]

#### *4.2.7.1 Basic data*

- **Contact:**
  T. Böhm (Schräder Abgastechnologie)

Hemsach 13
59174 Kamen, Germany
phone: 0230797300 - 0; fax: 0230797300 - 55
email: t.boehm@schraeder.com; http://www.schraeder.com

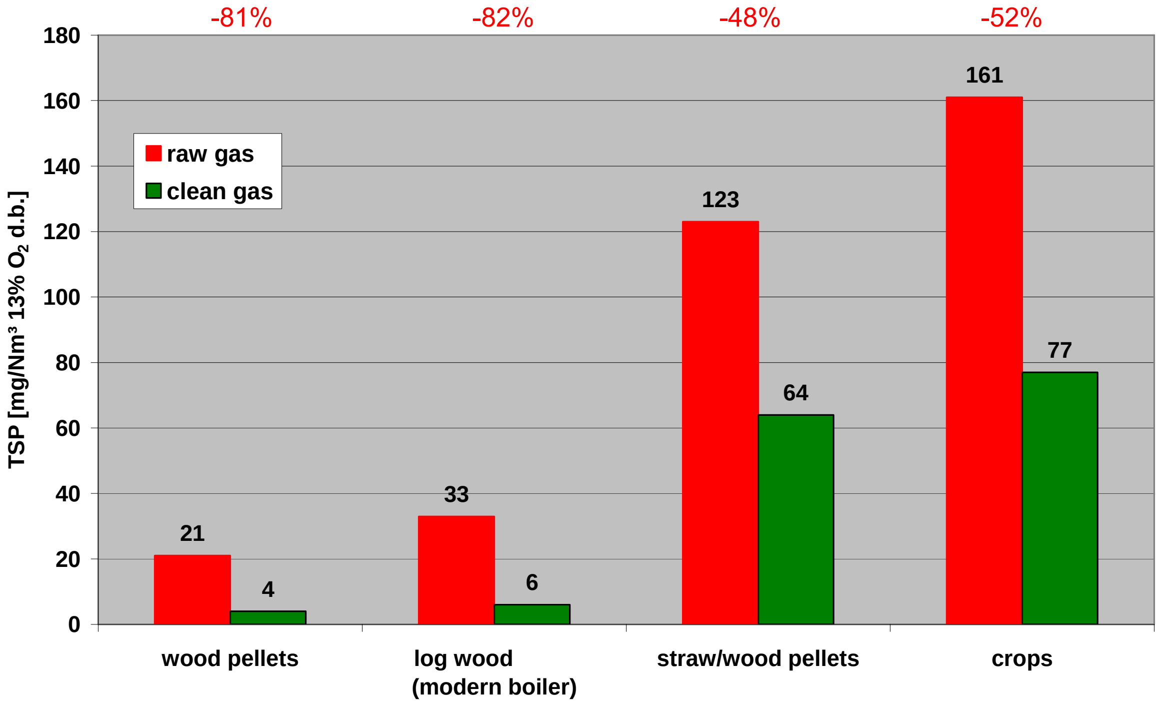
- **Basic technological data**
  - **Description of technology:**
    - electrostatic precipitator with metal filter bed
    - particles are precipitated within metal filter bed
    - filter bed is periodically cleaned by means of water spray
  - **Field of application (according to manufacturer):**
    - for pellet and wood chip boilers from 15-150 kW

#### *4.2.7.2 Technical evaluation*

- **Operating behaviour:**
  - pressure drop: max. 10 Pa
- **Cleaning procedure:**
  - automatic cleaning by water spray after defined pressure drop is exceeded
  - no additional removal of dust necessary
- **Installation:**
  - installation in flue gas duct
  - required space: approx. 0.4m x 0.5m x 1m
  - electric (230 V) as well as tab and waste water connection required
- **Maintenance:**
  - no data regarding treating of waste water available yet
- **Results of test runs performed:**
  - Test runs at test stand performed by DBFZ Leipzig (see Table 25)

**Table 25:** TSP precipitation efficiency of ESP AL-Top

Explanations: source of input data: [11]




- **Precipitation efficiency:**
  - TSP: up to 82% precipitation efficiency

#### *4.2.7.3 Relevant economic data*

- **Investments Costs:**
  - approx. 3000 € (19% VAT included) for unit applicable to combustion systems up to 50 kW
- **Annual operating costs:**
  - no data/experience available yet
- **Annual maintenance and other costs:**
  - no data/experience available yet

#### *4.2.7.4 Summery and conclusions*

The precipitation efficiency of the ESP is sufficiently high. The cleaning system is fully automatic. The device is still in prototype-phase. Test runs in order to gain more data regarding precipitation efficiency and stability of the cleaning system as well as regarding the applicability for old systems should be performed. Furthermore, no information is available regarding the treatment of the waste water.

### 4.2.8 ESP SF20 - Spanner (Germany)

In Figure 16 a scheme of the ESP SF20 as well as a picture of the ESP are presented.

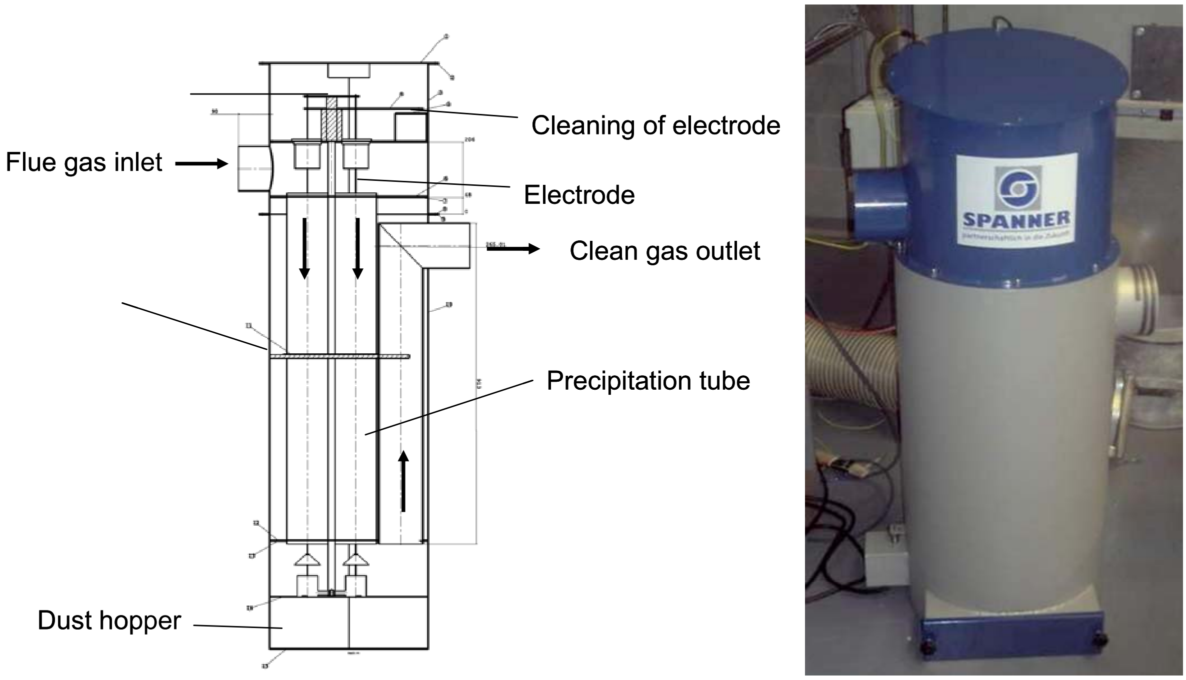



**Figure 32:** Scheme of the SF20 technology (left) and picture of the ESP (right)

Explanations: source: [43]

#### *4.2.8.1 Basic data*

- **Contact:**
  Georg Kuffer (Otto Spanner GmbH)
  Ergoldsbacher Straße 16
  84092 Bayerbach, Germany
  phone: 08773/70 7 98 – 21; fax: 08773/70 7 98 - 20
  email: georg.kuffer@spanner.de; http://www.spanner.de

- **Basic technological data**
  - **Description of technology:**
    - tube-type electrostatic precipitator
    - additional flue gas fan integrated in order to handle pressure drop
    - high-voltage insulators purged with air to prevent deposition of soot and condensation
    - voltage of high-voltage power supply: 15 kV
    - power consumption: 30 W during operation
  - **Field of application (according to manufacturer):**
    - pellet boilers, automatic wood chip and wood log boilers
    - applicable for biomass combustion systems up to 35 kW (Type SF20)

#### 4.2.8.2 Technical evaluation

- **Operating behaviour:**
  - problems (soot deposition on the isolator, which causes short circuits) can partially be attributed to low burnout quality of the log wood boiler, which represents old type boilers
  - additional flue gas fan required due to high pressure drop
  - flue gas temperature exceeded allowed values (due to test in combination with old log wood boiler)
  - minor damages of ESP due to high flue gas temperatures
  - good function with less failures during operation with modern boilers
- **Cleaning procedure:**
  - automatic mechanic cleaning system for the electrode (once a day, has to be started manually)
- **Installation:**
  - installation between boiler/stove and chimney
  - required space: approx. 0.4m x 0.5m x 1m
  - electric connection (230V) required
- **Maintenance:**
  - automatic cleaning system inefficient (tubes had to be cleaned manually in operation with an old wood log boiler)
  - additional to the automatic cleaning the precipitator has to be cleaned manually to remove ash deposits
  - filter ash must be discharged periodically from bottom of ESP (according to the manufacturer twice a year)
- **Results of test runs performed (I):**
  - Test runs performed by Graz University of Technology (Austria)
    - Field test runs (measurement methodology shown in Figure 33) and test runs at test stand performed with log wood boiler, total operating time: 410 h
    - Results of field test runs are summarised in Table 26, Table 27 and Figure 34

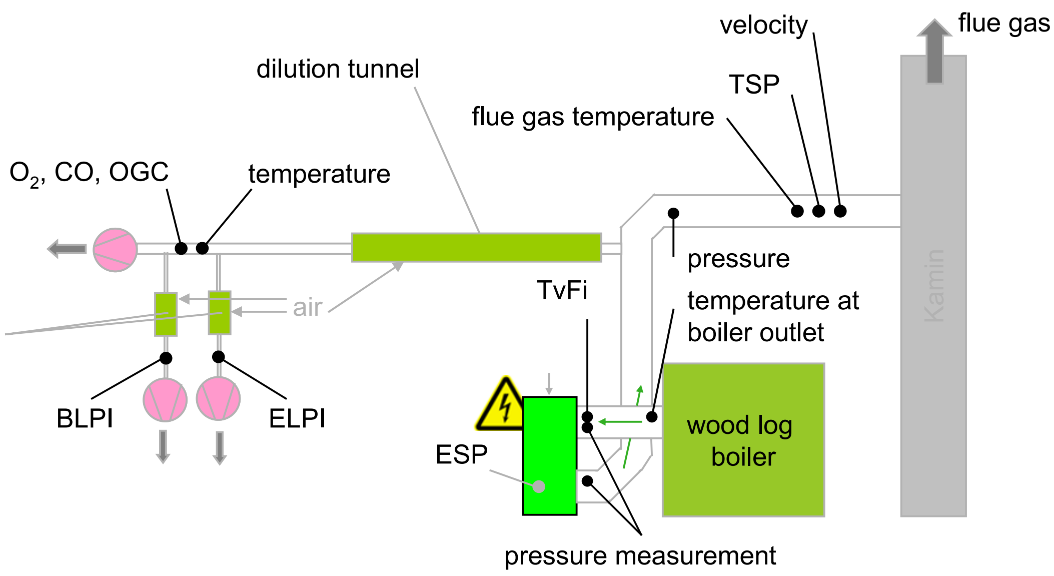



**Figure 33:** Scheme of measurement methodology of field test runs performed by Graz University of Technology

Explanations: BLPI ... 9-stage Berner-type low-pressure impactor; ELPI ... electrical low pressure impactor; TvFi ... temperature at filter inlet; TSP (total suspended particulate matter) measurements according to VDI 2066; log wood boiler Windhager FKN 265 (1989 model); source: [43]

**Table 26:** Results of field test runs performed by Graz University of Technology

Explanations: sampling time of each measurement performed: 10 min.; max ... maximum value; min ... minimum value; field test run with log wood boiler Windhager FKN 265 (1989 model); source: [43]

| Parameter | ESP | mean value | standard deviation | Min | Max |
|---|---|---|---|---|---|
| **dp ESP** | off | 20.7 | 17.4 | 0 | 65.5 |
| [Pa] | on | 20.7 | 17.4 | 0 | 65.1 |
| **CO** | off | 12271 | 5039 | 2063 | 28908 |
| [mg/Nm³ 13 Vol.% $O_2$ d.b.] | on | 12345 | 4668 | 2538 | 30235 |
| **OGC** | off | 2825 | 1821 | 174 | 11905 |
| [mg/Nm³ 13 Vol.% $O_2$ d.b.] | on | 2869 | 1780 | 219 | 8123 |

**Table 27:** TSP precipitation efficiency of ESP SF20

Explanations: mean values of 10 measurements performed (7 with ESP); max ... maximum value; min ... minimum value; field test run with log wood boiler Windhager FKN 265 (1989 model); source: [43]

| Parameter | ESP | mean value | standard deviation | min | max | precipitation efficiency |
|---|---|---|---|---|---|---|
| **TSP** | off | 424.0 | 439.5 | 72.8 | 917.0 | |
| [mg/Nm³ 13 Vol.% $O_2$ d.b.] | on | 137.3 | 77.6 | 44.6 | 225.2 | 68% |

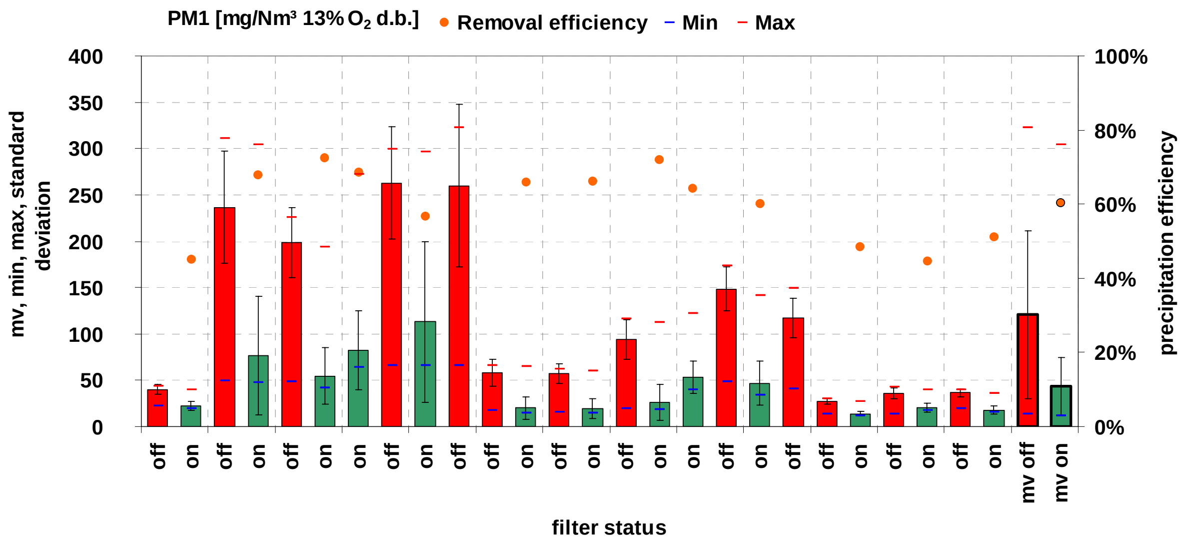



**Figure 34:** $PM_1$ precipitation efficiency of ESP SF20 during field test runs performed by Graz University of Technology

Explanations: mv ... mean value; max ... maximum value; min ... minimum value; field test run with log wood boiler Windhager FKN 265 (1989 model); results of ELPI measurements; sampling time of each measurement: 2 min.; source: [43]

- **Precipitation efficiency (I):**
  - TSP: mean 68% precipitation efficiency
  - $PM_1$ emissions: 45-73% (mean 60%) precipitation efficiency

- **Results of test runs performed (II):**
  - Test runs performed by TFZ Straubing (Germany)
    - Field test runs and test runs at test stand (measurement methodology shown in Figure 33) performed with a pellet boiler, a log wood boiler and a wood chip boiler, 4 ESPs have been tested; estimated operating time (based on fuel consumption): 2,900 h
    - Conclusions of field test runs:
      - cleaning procedure time-consuming
      - customer complained about noise caused by purge air fan
      - purge air fan influenced combustion behaviour of furnace
      - ESP was switched on too late by automatic control system due to deposition of ash and soot on temperature sensor
    - Results of test runs at test stand are summarised in Table 28, Table 29 and Table 30 as well as in Figure 36, Figure 37 and Figure 38

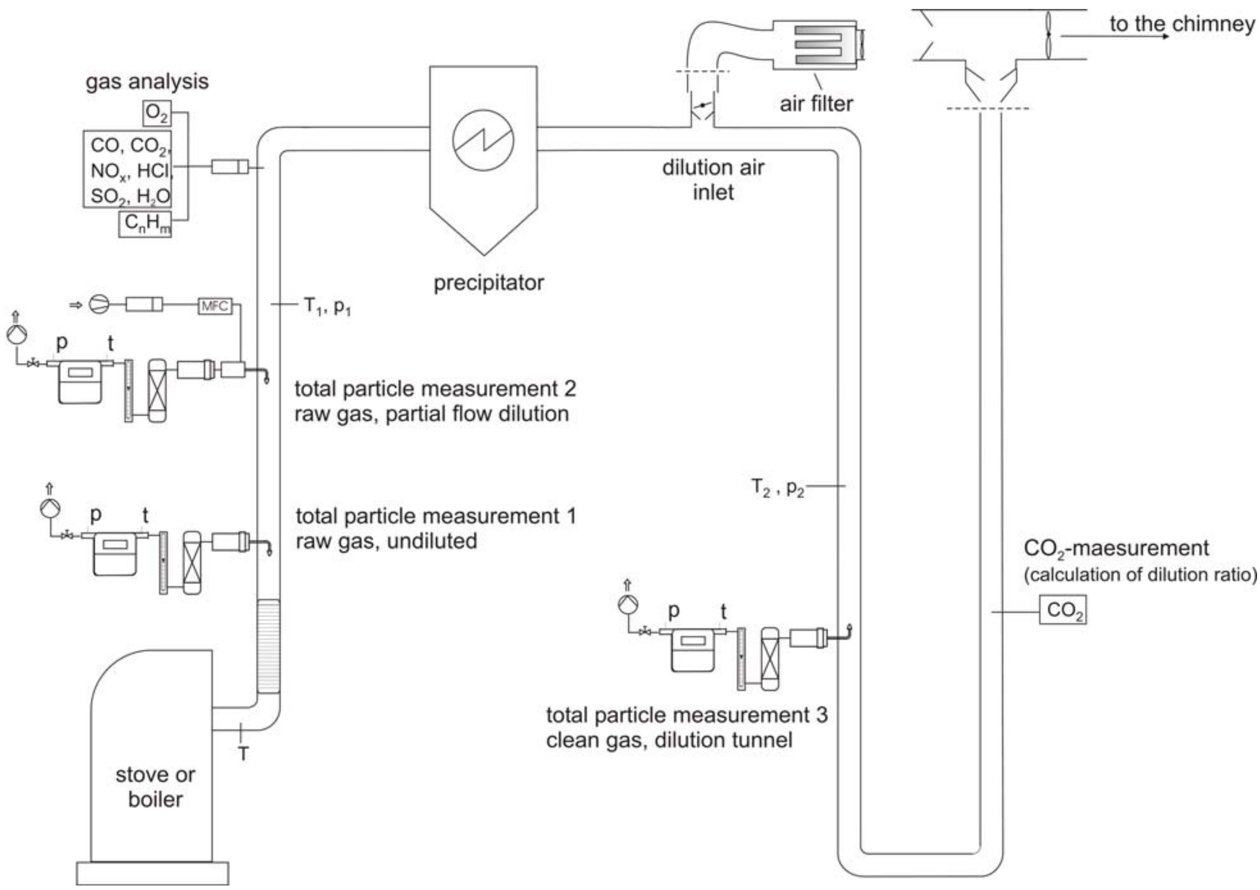



**Figure 35:** Scheme of measurement methodology of test runs at test stand performed by TFZ Straubing

**Table 28:** Results of test runs at test stand performed by TFZ Straubing –old log wood boiler

Explanations: means of 15 measurements performed with ESP; test run with wood log boiler HDG SL 14, which represents an old type boiler; fuel: spruce wood log; source: [33]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 3438 | 471 | 8927 |
| org. C | mg/m³ (13 % $O_2$) | 416 | 35 | 1930 |
| $O_2$ | vol.-% d.b. | 9.1 | 5.7 | 15.2 |
| flue gas temperature | ° C | 224 | 175 | 267 |
| flue gas pressure | Pa | -31.1 | -41.2 | -21.5 |
| dilution ratio | - | 3.9 | 3.8 | 4.0 |

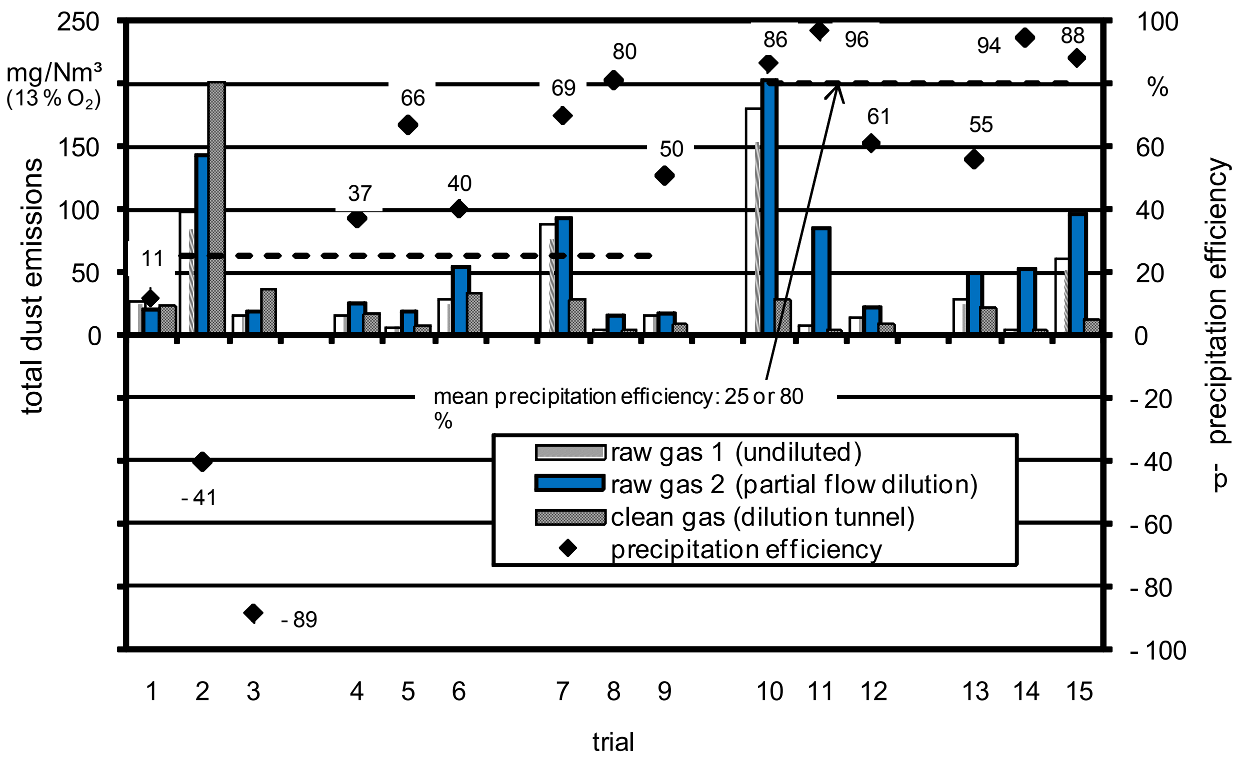



**Figure 36:** TSP precipitation efficiency of ESP SF20 – old log wood boiler

Explanations: values of 15 measurements performed with ESP; test run with wood log boiler HDG SL 14, which represents an old type boiler; trial 1 - 9 performed without bypass and trial 10 – 15 performed with bypass, which was used in the start up phase; fuel: spruce wood log; source: [33 ]

**Table 29:** Results of test runs at test stand performed by TFZ Straubing – modern boiler

Explanations: means of 10 measurements performed with ESP; test run with biomass boiler Agroflamm Agro 40 and different biomass fuels; source: [20]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 54 | 22 | 130 |
| org. C | mg/m³ (13 % $O_2$) | 1 | - | - |
| $O_2$ | vol.-% d.b. | 5.3 | - | - |
| flue gas temperature | ° C | 203 | - | - |
| flue gas pressure | Pa | -10.2 | - | - |

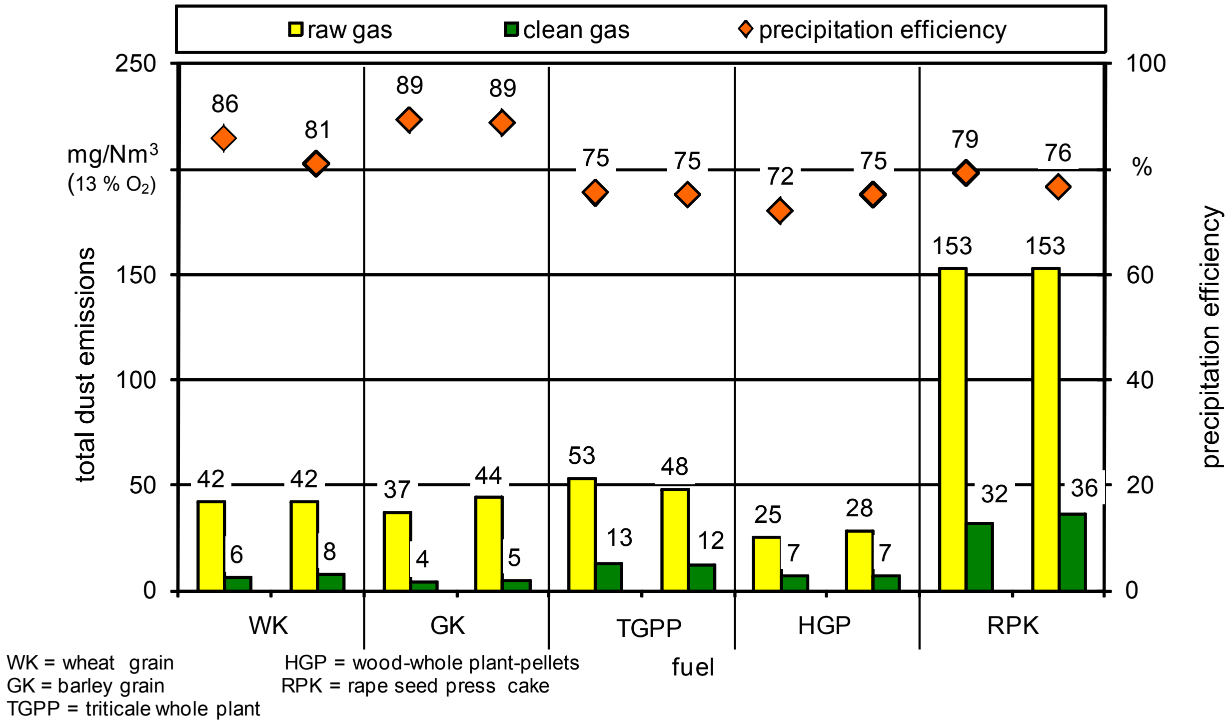



**Figure 37:** TSP precipitation efficiency of ESP SF20 – modern boiler

Explanations: values of 10 measurements performed with ESP; test run with biomass boiler Agroflamm Agro 40 and different biomass fuels; source: [20]

**Table 30:** Results of test runs at test stand performed by TFZ Straubing – modern log wood boiler

Explanations: means of 15 measurements performed with ESP; test run with wood log boiler Fröling FHG 3000 turbo, which represents a modern log wood boiler; fuel: spruce wood log; source: [21]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 427 | 78 | 1030 |
| $O_2$ | vol.-% d.b. | 9.1 | 8.1 | 10.8 |

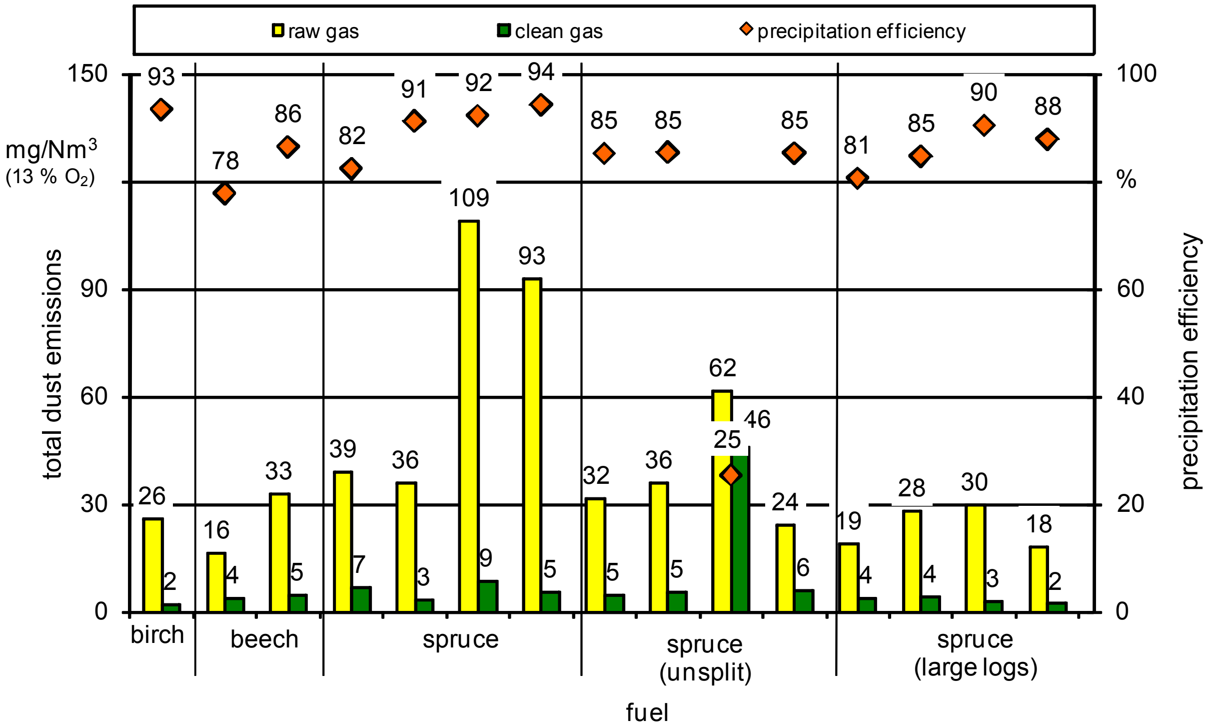



**Figure 38:** TSP precipitation efficiency of ESP SF20 – modern log wood boiler

Explanations: values of 15 measurements performed with ESP; test run with wood log boiler Fröling FHG 3000 turbo, which represents a modern log wood boiler; fuel: spruce wood log; source: [21]

- **Precipitation efficiency (II):**
  - In combination with modern boilers high precipitation efficiencies are possible. During the test runs with modern biomass boilers TSP precipitation efficiencies between 25 and 94 % were achieved. Almost all values are above 70 %, except for one measurement (25%). During the test runs with an old log wood boiler TSP precipitation efficiencies between 11 and 96 % were achieved. Most values are above 50 %.
  - For boilers with poor burning conditions a bypass is needed for the start-up phase. If there is no bypass, soot is collected on the isolators and causes short circuits.

### *4.2.8.3 Relevant economic data*

- **Investments Costs:**
  - approx. 1,200 € (20% VAT included) + installation
- **Annual operating costs:**
  - power consumption: approx. 30 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - No data/experience available yet

#### *4.2.8.4 Summery and conclusions*

The ESP is possibly not suitable for old wood log boilers and stoves due to possible condensation of tars and deposition of soot. The flue gas temperature may not exceed 200 °C in order to avoid damages of ESP. Therefore, the ESP may not be suitable for old systems and stoves. The integrated flue gas fan must be adjusted to the furnace connected to the ESP. The space requirements of the device are high. The automatic cleaning system has to be started manually. Therefore, a fully automatic system should be integrated. The prototype has been improved several times based on test runs. Test runs with the improved prototype to prove the applicability for old systems should be performed.

### 4.2.9 ESP Airbox - Spartherm (Switzerland)

In Figure 39 pictures of the ESP Airbox are presented.

**Figure 39:** Picture of mounted ESP Airbox (left) and picture of the ESP (right)

Explanations: source: [54]

#### *4.2.9.1 Basic data*

- **Contact:**
  Dr. Volker Schmatloch (Spartherm Feuerungstechnik GmbH)
  Maschweg 38
  49324 Melle, Germany
  phone: 05422-9441-0; fax: 05422-9441-14
  email: info@spartherm.com; web: http://www.spartherm.com

- **Basic technological data**
  - **Description of technology:**
    - electrostatic precipitator
    - several horizontal precipitation plates inside to collect the dust
    - voltage of high-voltage power supply: 12 kV
    - power consumption: 10-20 W during operation
  - **Field of application (according to manufacturer):**
    - for chimney stoves with a maximum power output of 20 kW

#### *4.2.9.2 Technical evaluation*

- **Operating behaviour:**
  - ESP has to be cleaned after operation of about 100 h
  - ESP has to be turned on manually
- **Cleaning procedure:**
  - manual cleaning by vacuum/hand every 100 h of operation through opening on the ESP, takes about 15 min
- **Installation:**
  - installation directly on top of fireplace
  - required space: approx. 0.7m x 0.45m x 0.45m
  - length of flue gas tube after ESP: min. 1m
  - electric connection (230V) required
- **Maintenance:**
  - regular manual cleaning of the ESP (depending on operation time)
- **Results of test runs performed:**
  - Test runs performed by the accredited test centre Rhein-Ruhr Feuerstätten Prüfstelle (Germany)
    - Results of test runs at test stand are summarised in Table 31
- **Precipitation efficiency:**
  - TSP: 60-80 % precipitation efficiency for 15 kW unit (see Table 31)

**Table 31:** TSP precipitation efficiency of ESP Airbox

Explanations: emissions related to dry flue gas and 13% $O_2$; test runs with log wood fired stoves (7-20 kW); source: [55]

| cartridge Nr. | total dust | removal efficiency |
|---|---|---|
| | [mg/Nm³ ] | [%] |
| 520 | 33 | - |
| - | - | - |
| 879 | 14 | 58 |
| 562 | 46 | - |
| 462 | 15 | 67.4 |
| 504 | 38 | - |
| 528 | 10 | 73.6 |
| 550 | 37 | - |
| 544 | 13 | 64.9 |
| 462 | 89 | - |
| 562 | 27 | 69.7 |
| 577 | 85 | - |
| 501 | 18 | 78.8 |
| 579 | 58 | - |
| 520 | 14 | 75.8 |

#### *4.2.9.3 Relevant economic data*

- **Investments Costs:**
  - approx. 1,561 € (20% VAT included)
- **Annual operating costs:**
  - power consumption: approx. 10-20 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - no data/experience available yet

#### *4.2.9.4 Summery and conclusions*

The precipitation efficiency of the ESP is sufficiently high. The ESP is available on the market since 2008. The ESP has to be cleaned manually every 100 h which is not practicable. However, the cleaning of the ESP in a living room is not practicable at all. Furthermore, the ESP is only available in combination with Spartherm chimney stoves by now.

### 4.2.10 Nasu®ESP - Tassu ESP (Finland)

Pictures of the ESP are not available so far.

#### *4.2.10.1 Basic data*

- **Contact:**
  Mr. Ari Laitinen (TassuESP)
  Tassu ESP Ltd.
  Graanintie 5, 50190 Mikkeli, Finland
  email: info@tassuesp.fi

- **Basic technological data**
  - **Description of technology:**
    - charging based on diffusion charging of air outside of the flue gas stack, ions are transferred with pressurized air into the flue gas channel
    - optimised for particles smaller than 2 µm in diameter
    - construction of the collector is still not published
  - **Field of application (according to manufacturer):**
    - small- to medium-scale processes producing particles mainly smaller than 2 µm in diameter (e.g. pellet boilers, continuously operated biomass combustion)
    - application for batch-wise operated biomass combustion under development

#### *4.2.10.2 Technical evaluation*

- **Operating behaviour:**
  - small air compressor needed for operation
  - for batch-wise combustion systems operation without compressor is possible
- **Cleaning procedure:**
  - removal of particles by electric forces
  - disposal of fly ash collected into a container (either manual or automatic)
  - manual cleaning approximately once a year (if not automated)
- **Installation:**
  - required space: 1.5-2.0m x flue gas volume/s
  - approx. 0.5m x 0.5m x 1,5m for 20 kW pellet boiler
  - electric connection (230 V) required
  - requires a small compressor (except for batch-wise units)
- **Maintenance:**
  - disposal of fly ash collected into a container: either manual or automatic
  - manual cleaning approximately once a year (if not automated)
  - replacement of the charging unit approx. every 5 years
  - with batch-wise combustion units more frequent cleaning and washing with water
- **Precipitation efficiency (according to manufacturer):**
  - $PM_1$ emissions: 85-90% removal efficiency (continuous processes)
  - higher removal efficiency can be obtained by increasing ESP size
  - for batch-wise combustion removal efficiency: 80 % (due to smaller ESP size)

#### 4.2.10.3 Relevant economic data

- **Investments Costs:**
  - not defined yet
- **Annual operating costs:**
  - power consumption: couple of hundreds Watts (costs depend on operating time and electricity price)
  - for batch-wise units the operation possibly without compressor → power consumption: 10-20 W
- **Annual maintenance and other costs:**
  - replacement of charger unit → couple of tens of euro/year

#### 4.2.10.4 Summery and conclusions

The high operating costs as well as the noise of the compressor may be a drawback. The concept of the technology has been tested with flue gas from pellet combustion. The overall system has been tested with emissions produced during glass production. The technology is in prototype-phase and the development of the commercial product is still ongoing. An application, which is currently developed without compressor for batch-wise operated biomass system, may be more promising and should be evaluated.

### 4.2.11 ESP Kamin-Feinstaubkiller - TH-AE (Germany)

In Figure 40 a scheme of the ESP Kamin-Feinstaubkiller is presented.

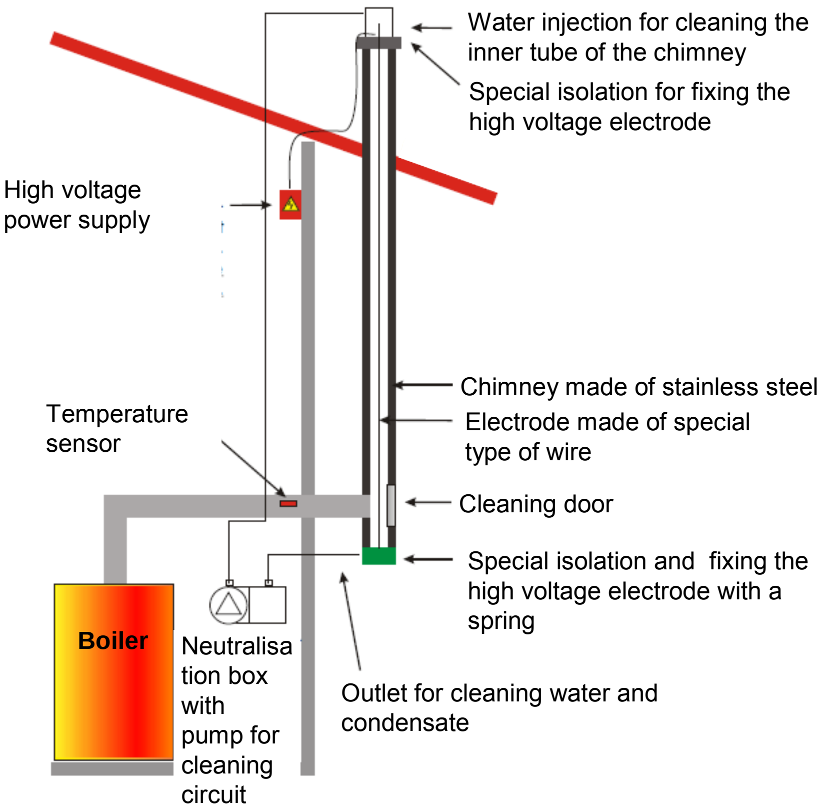



**Figure 40:** Scheme of the Kamin-Feinstaubkiller technology

Explanations: source: [61]

#### *4.2.11.1 Basic data*

- **Contact:**
  Thomas Hipp (TH Alternativ Energie)
  Rothelebuch 3
  87637 Seeg/Allgäu, Germany
  phone: 08364/9848470; fax: 008364/986,94
  email: info@th-alternativ-energie.de; http://www.th-alternativ-energie.de

- **Basic technological data**
  - **Description of technology:**
    - tube-type electrostatic precipitator
    - high voltage electrode is embedded into the chimney
  - **Field of application (according to manufacturer):**
    - only suitable for chimneys made of stainless steel
    - for wood and biomass in general
    - maximum nominal boiler: 30 – 500 kW

#### *4.2.11.2 Technical evaluation*

- **Operating behaviour:**
  - no data/experience available
- **Cleaning procedure:**
  - automatic cleaning through water injection into chimney (every 3 hours)
  - dust, which is removed with the water, settles and is collected in the neutralization box
  - dust has to be periodically removed as slurry from the neutralization box
- **Installation:**
  - installation of the fixing and isolation of the electrode on top of chimney
  - only suitable for chimneys made of stainless steel
  - electric connection as well as tab water connections are required
- **Maintenance:**
  - automatic cleaning system integrated
  - slurry has to be removed manually from the neutralisation box (interval depends on operation time and type of furnace)
- **Results of test runs performed:**
  - test runs performed by TFZ Straubing (Germany)
    - test runs at test stand performed with log wood boiler; estimated operation time (based on fuel consumption): 30 h
    - results of test runs at test stand are summarised in Table 32 and Figure 42

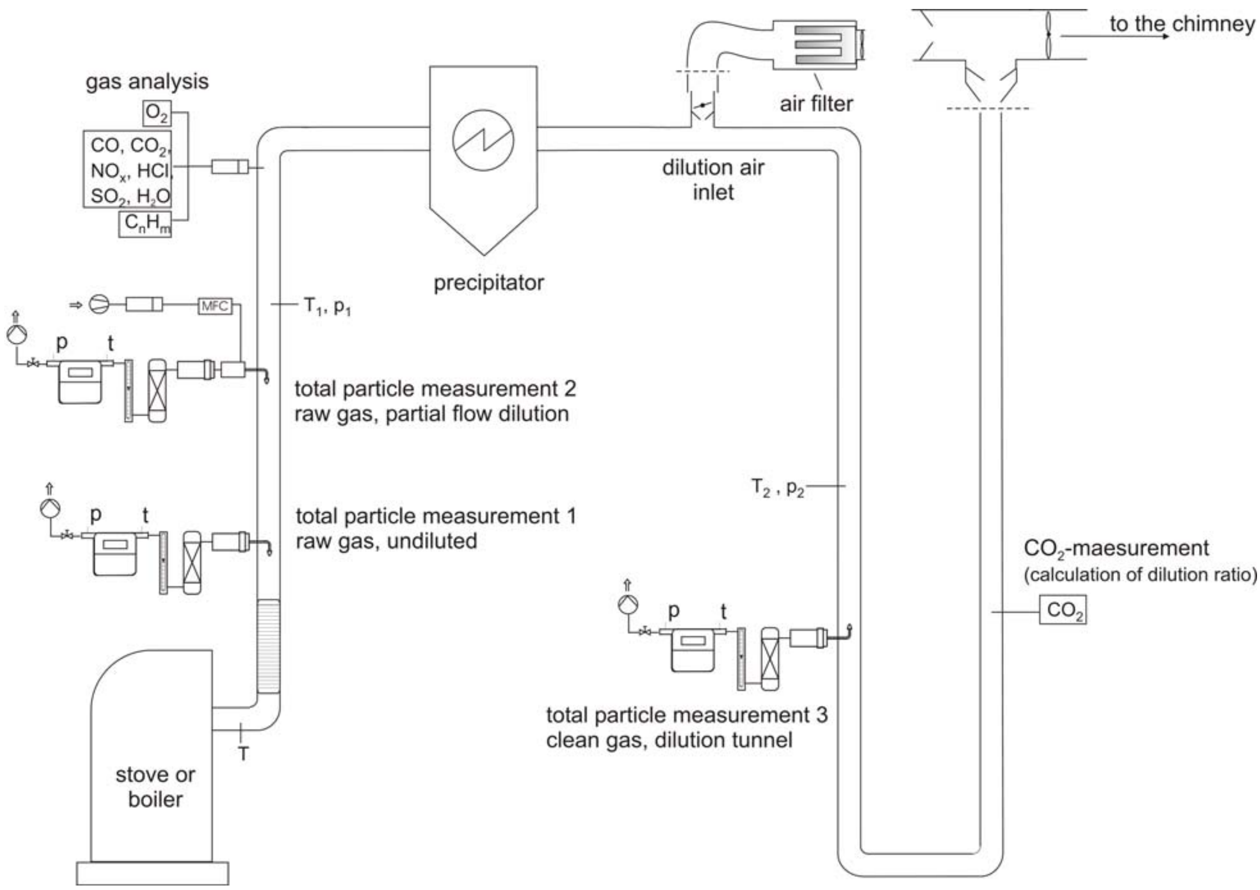



**Figure 41:** Scheme of measurement methodology of test runs at test stand performed by TFZ Straubing

Explanations: source: [33]

**Table 32:** Results of test runs at test stand performed by TFZ Straubing – old wood log boiler

Explanations: values of 9 measurements performed with ESP; test run with wood log boiler HDG SL 14, which represents an old type boiler; fuel: spruce wood log; source: [33]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 2740 | 714 | 7508 |
| org. C | mg/m³ (13 % $O_2$) | 308 | 32 | 1246 |
| $O_2$ | vol.-% d.b. | 9.4 | 4.8 | 14.9 |
| flue gas temperature | ° C | 256 | 213 | 284 |
| flue gas pressure | Pa | -28.2 | -29.5 | -26.1 |
| dilution ratio | - | 3.1 | 1.8 | 3.9 |

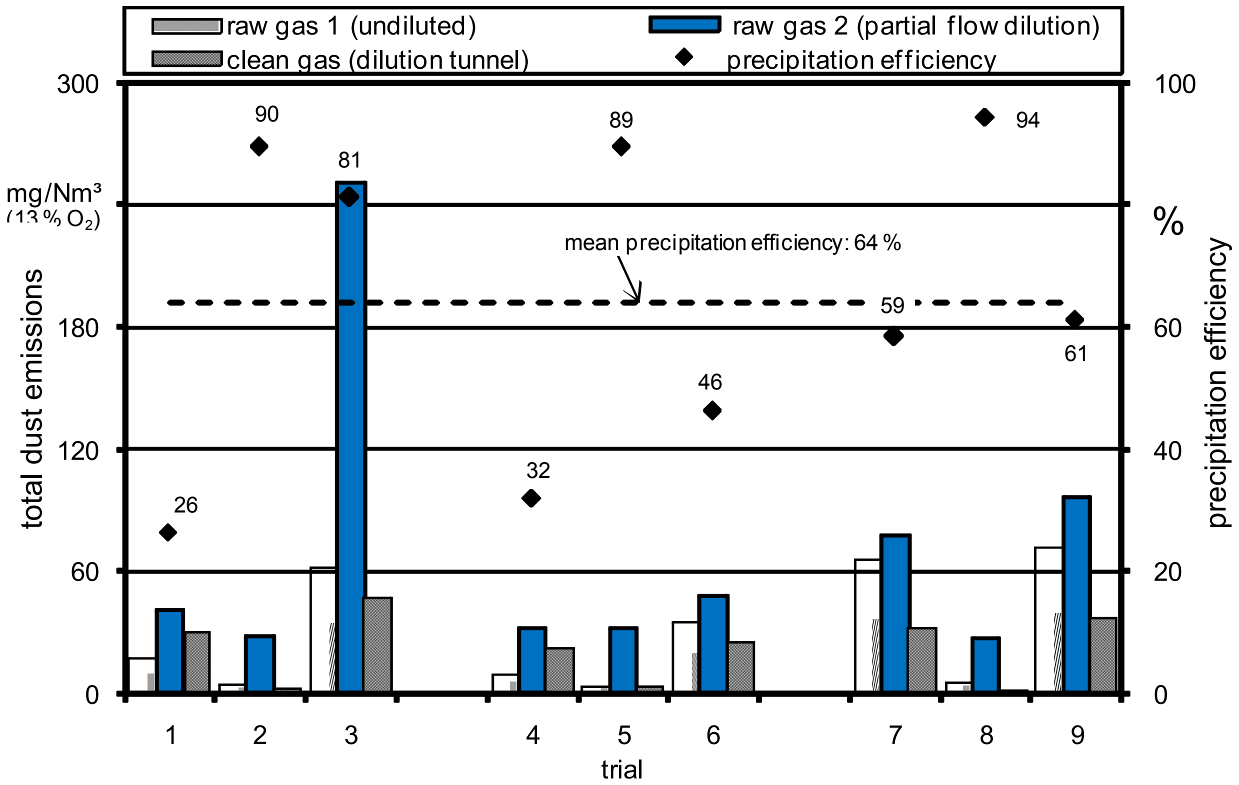



**Figure 42:** TSP precipitation efficiency of ESP Kamin-Feinstaubkiller –old wood log boiler

Explanations: values of 9 measurements performed with ESP; test run with wood log boiler HDG SL 14, which represents an old type boiler; fuel: spruce wood log; source: [33]

- **Precipitation efficiency:**
  - TSP: 26 to 94 % precipitation efficiency (average precipitation efficiency of 9 trials: 64 %)

#### *4.2.11.3 Relevant economic data*

- **Investments Costs:**
  - approx. 1,515 € (20% VAT included) + installation
- **Annual operating costs:**
  - power consumption: approx. 40-80 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - no data/experience available yet

#### *4.2.11.4 Summery and conclusions*

The ESP is still in the prototype phase. The design of the cleaning system is quite complex but fully automatic. Furthermore, the ESP is only suitable for chimneys made of stainless steel and old systems are usually not equipped with chimneys made of stainless steel. The precipitation efficiency is acceptable. The performed test runs showed that the device is basically applicable for old systems. Test runs should be performed in order to gain detailed information about technology and performance and to prove the long-term applicability for old systems.

### 4.2.12 ESP Windhager (Austria)

#### *4.2.12.1 Basic data*

- **Contact:**
  Jürgen Brandt (WINDHAGER ZENTRALHEIZUNG Technik GmbH)
  Anton-Windhager-Str. 20
  5201, Seekirchen am Wallersee, Austria
  phone: 06212/2341 – 298
  email: juergen.brandt@windhager.com; web: http://www.windhager.com
- **Basic technological data**
  - **Description of technology:**
    - tube-type electrostatic precipitator
    - high-voltage power supply
    - power consumption: 12-18 W during operation
    - automatic cleaning system of electrode and tube
  - **Field of application (according to manufacturer):**
    - tested only with automatic pellet boiler so far
    - applicable for biomass combustion systems up to 25 kW
- **Technology**
  - used technology as well as pictures and drawings are not released for any publication

#### *4.2.12.2 Technical evaluation*

- **Operating behaviour:**
  - no field test runs performed so far
  - ESP has been tested in total for 5.500 hours with automatic pellet boilers (nominal boiler capacity: 15 and 21 kW)
  - long term test run for 1.750 h at test stand with automatic pellet boiler at different loads (12-22 mg/Nm³ total dust emissions after boiler) successful without major problems
  - pressure drop: 5-10 Pa
  - ash deposit formation on electrode and interior of tube, the influence of ash deposits on the precipitation efficiency is small
  - filter ash must be discharged periodically from ash box (once a year)
  - performance of automatic cleaning system satisfying

- **Installation:**
  - installation between stove/boiler and chimney
  - required space: approx. 0.5m x 0.2m x 1m
- **Results of test runs performed:**
  - Test runs performed by BIOS (Austria) and Windhager (Austria)
    - Test runs with automatic pellet boilers performed at test stands (measurement methodology shown in Figure 43); total operating time: 5,500h
    - Results of test runs at test stand are summarised in Figure 44 and Figure 45.

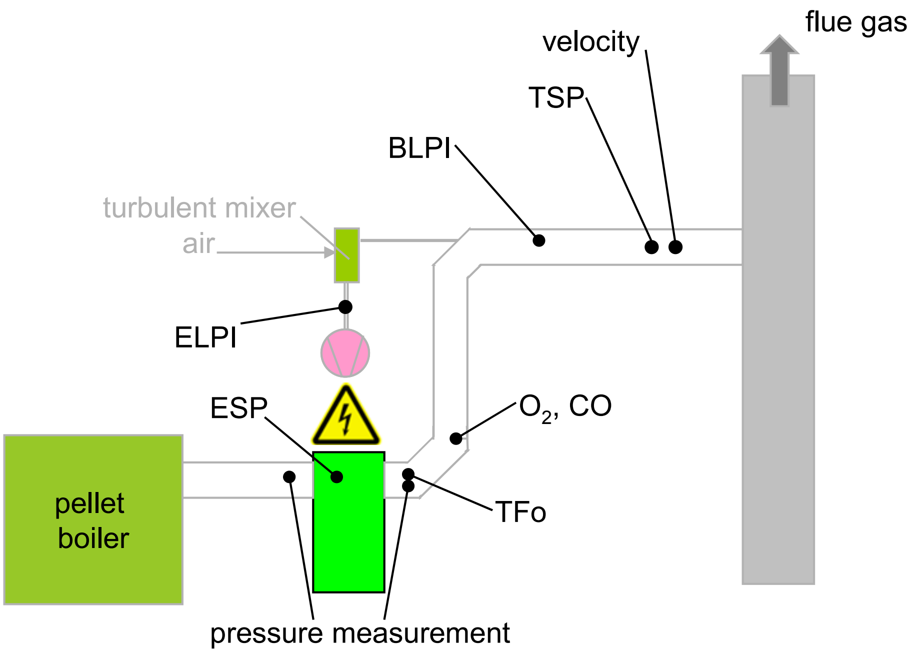
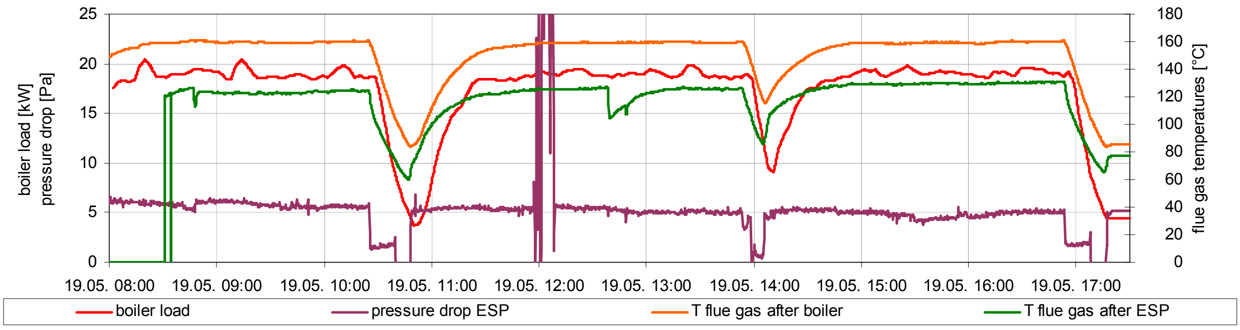



**Figure 43:** Scheme of measurement methodology of test runs at test stand performed by BIOS and Windhager

Explanations: BLPI ... 9-stage Berner-type low-pressure impactor; ELPI ... electrical low pressure impactor; TFo ... temperature at filter outlet; TSP (total suspended particulate matter) measurements according to VDI 2066; test runs performed with pellet boiler Windhager BioWin 210



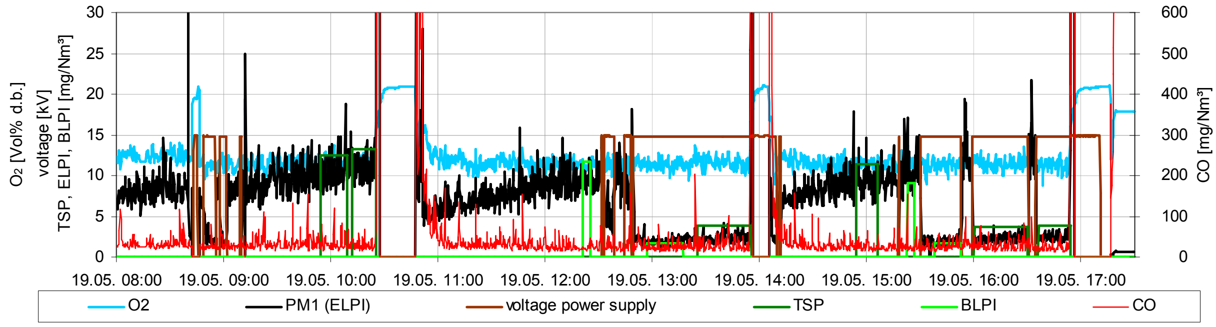




**Figure 44:** Results of test runs at test stand performed by BIOS and Windhager

Explanations: emissions related to dry flue gas and 13% $O_2$; TSP ... total suspended particulate matter; test runs performed at test stand with pellet boiler Windhager BioWin 210; operating time of ESP: 1.750 h

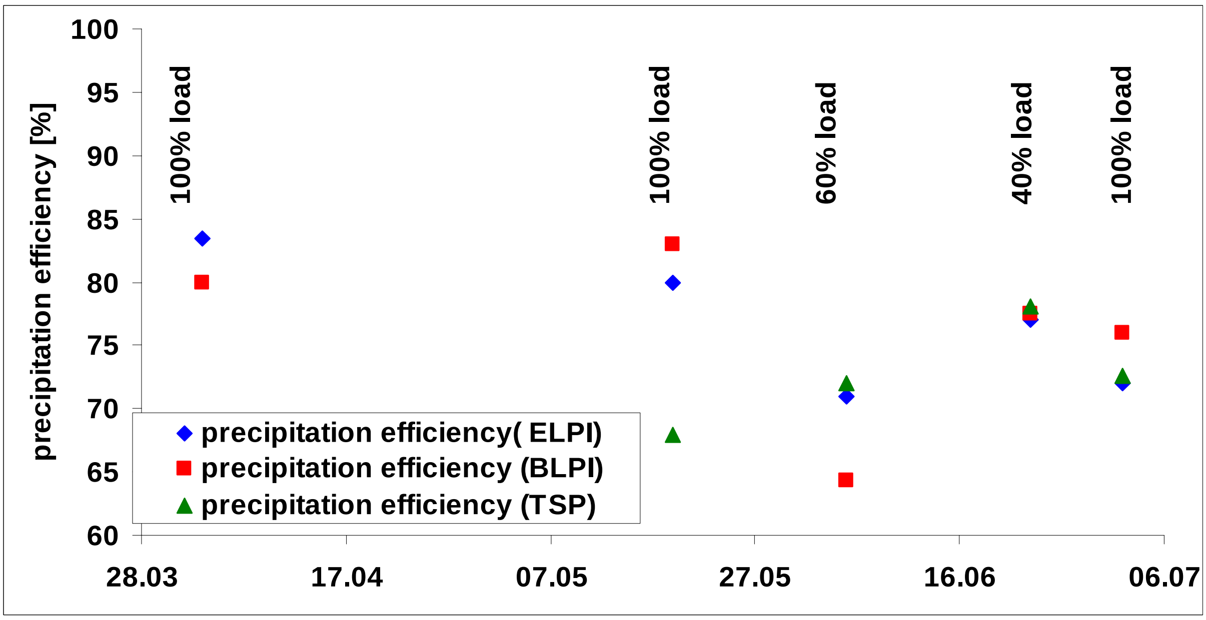



**Figure 45:** Precipitation efficiency of the Windhager ESP

Explanations: measured values are mean values (at least 3 measurements in each case performed); TSP ... total suspended particulate matter; test runs performed at test stand with pellet boiler Windhager BioWin 210

- **Precipitation efficiency:**
  - $PM_1$ emissions (ELPI): 71-83% precipitation efficiency

- $PM_1$ emissions (BLPI): 64-83% precipitation efficiency
- TSP: 68-78% precipitation efficiency

#### *4.2.12.3 Relevant economic data*

- **Investments Costs:**
  - approx. 1,500 € (20% VAT included) + installation
- **Annual operating costs:**
  - power consumption: 12-18 W (costs depend on operating time and electricity price)
- **Annual maintenance and other costs:**
  - no data/experience available yet

#### *4.2.12.4 Summary and conclusions*

The ESP is still in the prototype phase. Several test runs (overall 5.500 h) with automatic pellet boilers at the test stands have already been performed. The ash deposit formations on the electrode and the interior tube wall have minor influence on the precipitation efficiency. The performance of the automatic cleaning system is satisfying. The precipitation efficiency is sufficiently high and operating costs are low. The device should be tested with wood log boilers and stoves in order to prove its applicability for old systems.

### 4.2.13 Flue gas condenser UEF (Finland)

In Figure 46 schemes of the UEF technology as well as a picture of the flue gas condenser are presented.

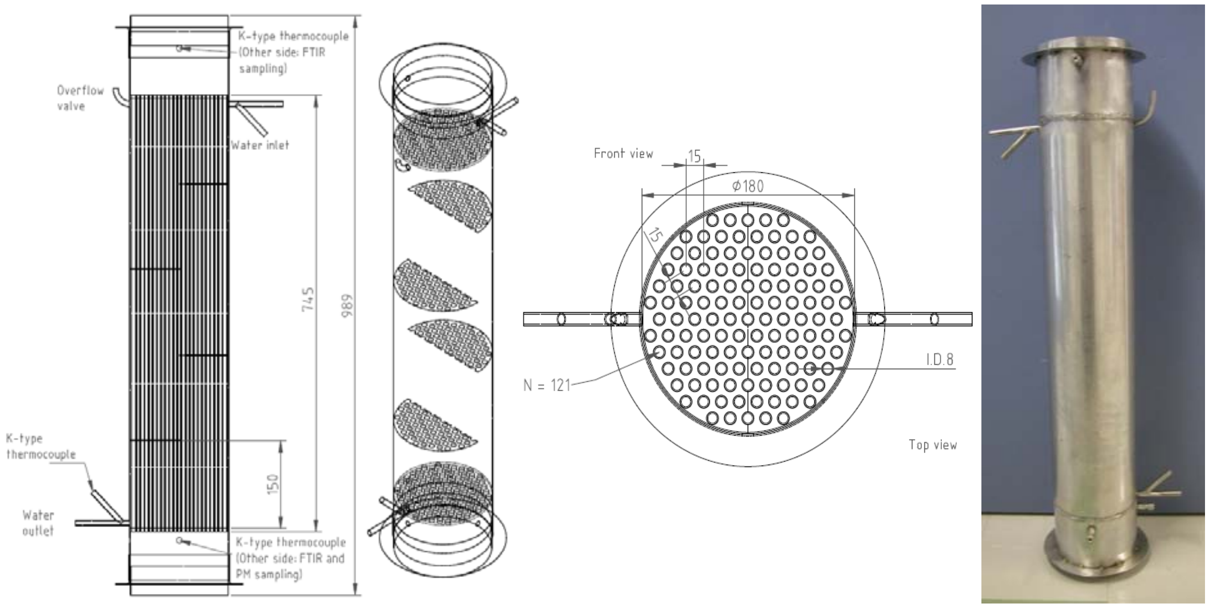



**Figure 46:** Schemes of the UEF technology and picture of the flue gas condenser (right)

#### *4.2.13.1 Basic data*

- **Contact:**
  Jorma Jokiniemi, Professor
  Fine Particle and Aerosol Technology Laboratory
  Department of Environmental Science, University of Eastern Finland
  P.O.Box 1627, FIN-70211 Kuopio
  e-mail: Jorma.Jokiniemi@uef.fi
- **Basic technological data**
  - **Description of technology:**
    - Condensing heat exchanger that has optimized dimensions for fine particle removal.
    - The flue gas is directed in a vertical counterflow heat exchanger with a vertical tube bundle. The flow is divided to several small tubes. Inside condensation of the water vapour generates a liquid film flowing downward the tube surfaces. The condensed water can be collected at the bottom of the heat exchanger. Particle removal is based on thermophoresis (due to temperature gradient) and diffusiophoresis (due to water vapour pressure gradient).
  - **Field of application:**
    - continuously operated burning devices that use fuels containing naturally high concentrations of $H_2O$ and low concentrations of corroding agents (wood chips, pellets with additional water feed)
    - can also be used in sulphur removal (with additives)
    - in theory the condenser is scalable

#### *4.2.13.2 Technical evaluation*

- **Results of test runs performed:**
  - test runs performed by UEF (Finland) (Gröhn et al. 2009)
  - operating & boundary conditions within all measurements:
    - approx. 800 lpm (NTP) flue gas flow
    - inlet temperature of flue gas: 140 – 180 °C
    - Outlet temperature of flue : 25 – 60 °C
    - inlet coolant: 10 °C
    - outlet coolant: 15 – 50 °C
    - $H_2O$ content flue gas: 5 – 30 vol%
- **Thermal efficiency:**
  - The thermal efficiency depends on flue gas inlet temperature, flue gas moisture and coolant inlet and outlet temperatures used. In the test run the calculated overall heat

efficiency was approximately 85 % including the consideration of the water vapour latent heat with following boundary conditions:

- flue gas inlet temperature: 156 °C
- flue gas outlet temperature: 34 °C
- coolant outlet temperature: 34 °C

- **Precipitation efficiency:**
  - $PM_1$ emissions: 0-30% precipitation efficiency (25 – 40 % reduction efficiency in number concentrations)
  - estimated maximum of the particle removal efficiency (with the heat exchanger model): 60 – 70% reduction in number concentration
  - modeled particle removal efficiency of 70.2% with following values:
    - 800 lpm (NTP) flue gas flow
    - inlet temperature of flue gas: 600 °C
    - outlet temperature of flue gas: 51 °C
    - $H_2O$ content of flue gas: 20 Vol%
    - coolant flow 0,1 kg/s
    - inlet coolant: 35.5 °C
    - outlet coolant: 60 °C

#### *4.2.13.3 Relevant economic data*

- **Investments Costs:**
  - approx. 5000 € for a prototype
- **Annual operating costs:**
  - not specified
- **Annual maintenance and other costs:**
  - not specified

#### *4.2.13.4 Summery and conclusions*

The technology has potential, but needs further research on thermal and precipitation efficiency, design, implementation in heating systems, economic aspects, maintenance and long-term stability. Acceptable precipitation efficiencies can be reached with high flue gas inlet temperatures. The condensing heat exchanger could be applied in various systems where the need for low-cost precipitation overrules the need for high deposition efficiencies. The fuel water content is of relevance, thus moist biomass fuels are more suitable than others. More information on usability and implementation into “real-life” systems are needed. Further R&D of the technology is still ongoing.

## 4.2.14 Flue gas condenser Öko-Carbonizer - Bschor (Germany)

In Figure 47 a scheme of the Öko-Carbonizer technology is presented.

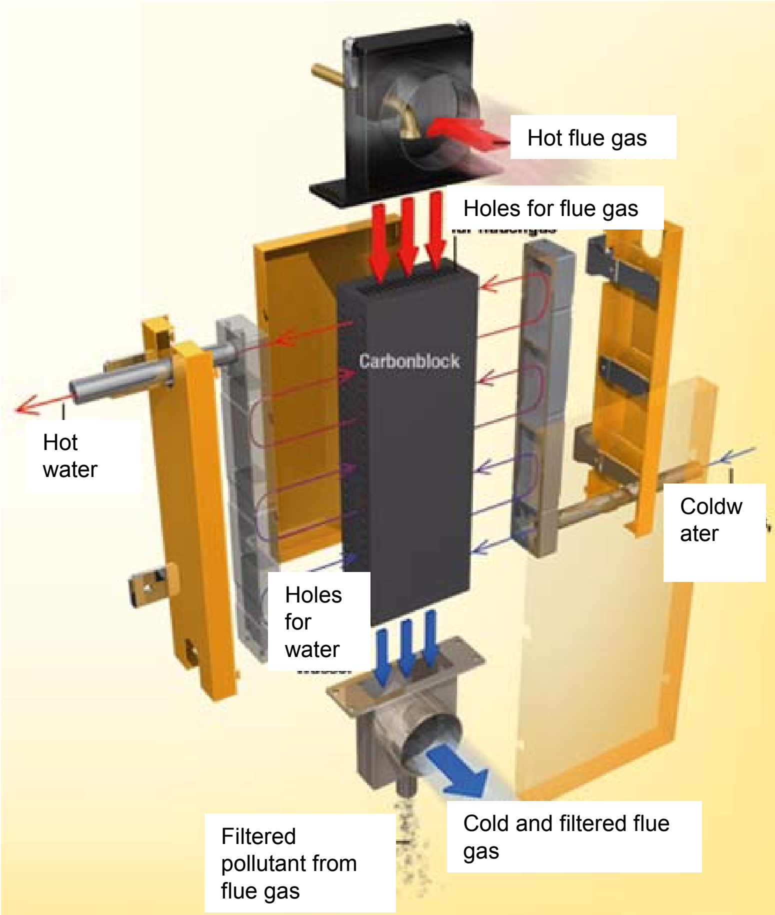



**Figure 47:** Scheme of the Öko-Carbonizer technology

Explanations: source: [44]

### *4.2.14.1 Basic data*

- **Contact:**
  M. Kimmerle (Bschor GmbH)
  An der Kohlplatte 7
  89420 Höchstädt
  phone: 09074-9574-58; fax: 09074-9574-59
  email: kim@carbonizer.de; web: http://www.carbonizer.de
- **Basic technological data**
  - **Description of technology:**
    - condensing heat exchanger
    - consists of carbon block acting as heat exchanger
    - cooling of flue gases and condensation, particles are trapped in condensate
  - **Field of application:**
    - pellet, log wood and chip wood boilers up to 60 kW

#### 4.2.14.2 Technical evaluation

- **Operating behaviour:**
  - heating system with a return temperature of maximum 35 °C is needed to achieve condensation
- **Cleaning procedure:**
  - carbon block is cleaned by condensate of flue gas
- **Installation:**
  - only suitable for chimneys made of stainless steel
  - installation in flue gas pipe between boiler and chimney
  - waste water connections is required
- **Maintenance:**
  - self cleaning of carbon block with condensate
- **Results of test runs performed:**
  - Rest runs performed by TFZ Straubing (Germany)
    - Test runs at test stand performed with multi-fuel boiler (Agroflamm) and wood chip boiler (HDG Bavaria)
    - Results of test runs at test stand are summarised in Table 33, Table 34, Figure 48 and Figure 49

**Table 33:** Results of test runs at test stand performed by TFZ Straubing – modern boiler

Explanations: average of 5 trials made with Öko-Carbonizer connected to biomass boiler Agroflamm Agro 40 and different biomass fuels; source: [20]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 176 | 57 | 472 |
| org. C | mg/m³ (13 % $O_2$) | 31 | 1 | 68 |
| $O_2$ | vol.-% d.b. | 11.8 | 9.7 | 13.5 |
| flue gas temperature after boiler | ° C | 199 | 176 | 207 |
| flue gas temperature after SHE | °C | 68 | 58 | 117 |
| flue gas pressure | Pa | -52 | -20 | -77 |

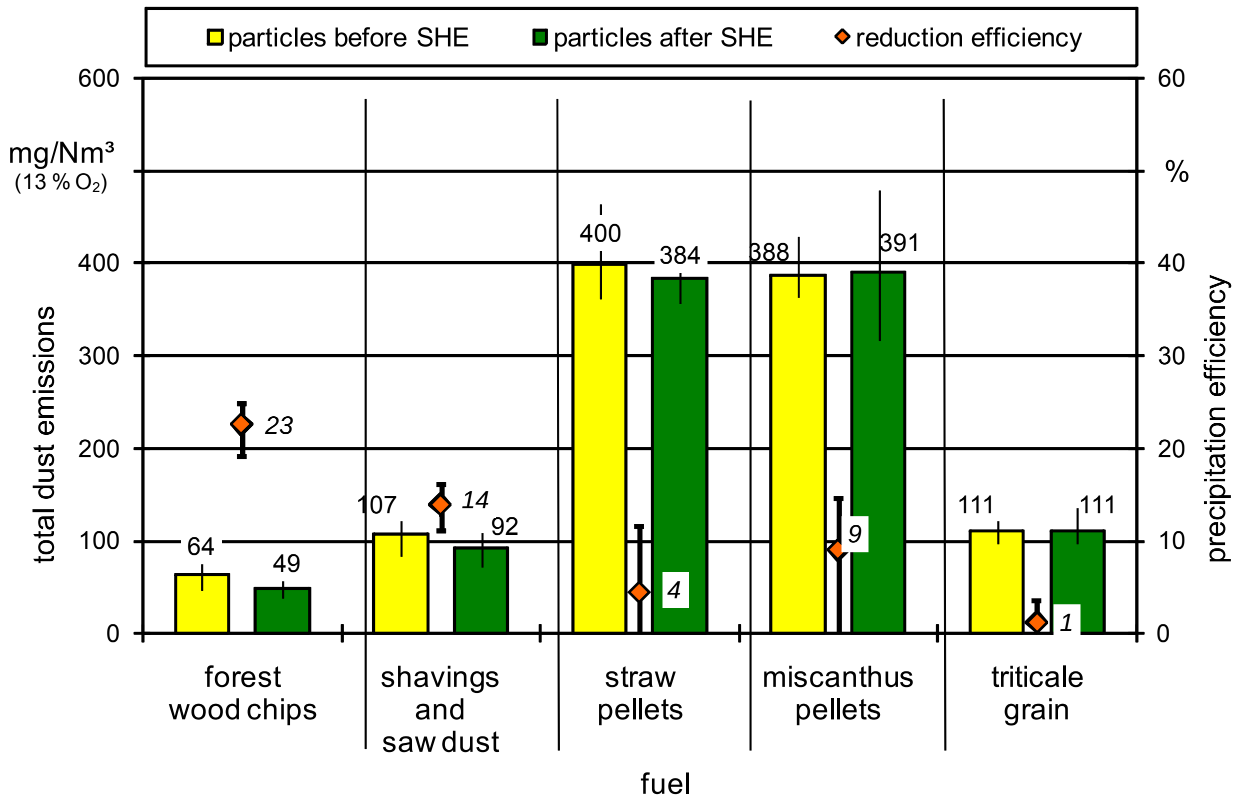



**Figure 48:** TSP precipitation efficiency of flue gas condenser Öko-Carbonizer – modern boiler

Explanations: values of 5 trials made with Öko-Carbonizer connected to biomass boiler Agroflamm Agro 40 and different biomass fuels; source: [20]

**Table 34:** Results of test runs at test stand performed by TFZ Straubing – modern chip wood boiler

Explanations: average of 11 trials made with Öko-Carbonizer connected to wood chip boiler HDG Compact 50 with different wood chip fuels; source: [21]

| parameter | unit | average | min | max |
|---|---|---|---|---|
| CO | mg/m³ (13 % $O_2$) | 179 | 77 | 291 |
| org. C | mg/m³ (13 % $O_2$) | 3 | 1 | 8 |
| $O_2$ | vol.-% d.b. | 8.7 | | |
| flue gas temperature after boiler | ° C | 132 | 115 | 141 |
| flue gas temperature after SHE | °C | 44 | 39 | 47 |

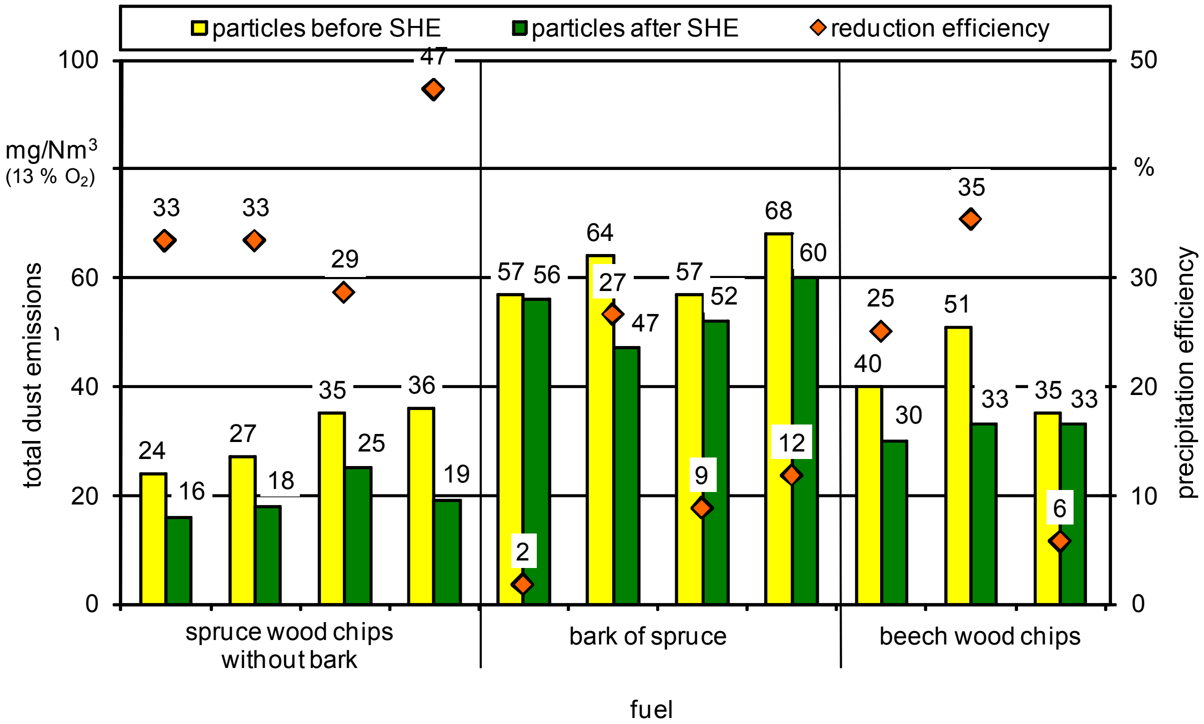



**Figure 49:** TSP precipitation efficiency of flue gas condenser Öko-Carbonizer – modern chip wood boiler

<u>Explanations:</u> average of 11 trials made with Öko-Carbonizer connected to wood chip boiler HDG Compact 50 with different wood chip fuels; source: [21]

- **Precipitation efficiency:**
    - TSP: mean 11 % precipitation efficiency (mean value) with a modern multi-fuel boiler and 23 % precipitation efficiency (mean value) with a modern wood chip boiler
    - Particle precipitation depends on condensation. Fuels with higher water content lead to higher moisture in the flue gas and more condensate. This slightly increases the particle precipitation efficiency

### *4.2.14.3 Relevant economic data*

- **Investments Costs:**
    - approx. 1,200 € (20% VAT included) for 35 kW unit
- **Annual operating costs:**
    - not specified
- **Annual maintenance and other costs:**
    - no experience available yet

#### 4.2.14.4 Summery and conclusions

The precipitation efficiency is low. The return water temperature should not exceed 35 °C. The main application of the system is to increase the thermal efficiency of the boiler rather than to reduce particulate emissions efficiently.

### 4.2.15 Pellet boiler Pellematic Plus® with integrated flue gas condensation - ÖkoFEN (Austria)

In Figure 50 a scheme of the pellet boiler Pellematic Plus® is presented.

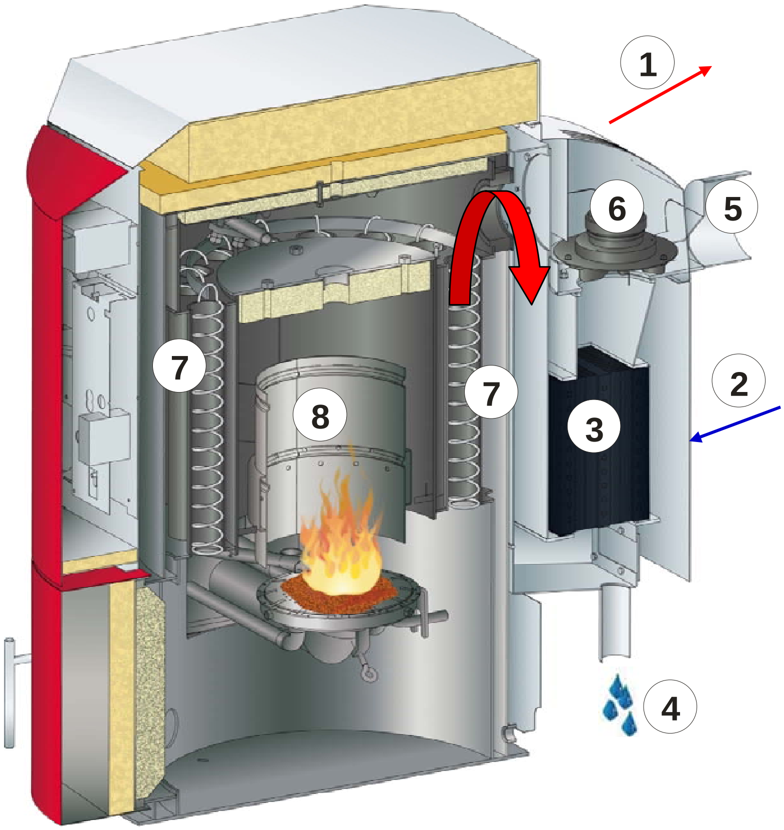



**Figure 50:** Scheme of the pellet boiler Pellematic Plus®

Explanations: 1 ... feed water; 2 ... cold return; 3 ... flue gas condenser (heat exchanger); 4 ... condensate; 5 ... flue gas; 6 ... flue gas fan; 7 … boiler; 8 ... combustion chamber; source: [45]

#### 4.2.15.1 Basic data

- **Contact:**
  ÖkoFEN Forschungs- und EntwicklungsgesmbH
  Gewerbepark 1
  4133 Niederkappe, Austria
  phone: 0043 (0) 72 86/74 50; fax: 0043 (0) 72 86/74 10
  email: info@pelletsheizung.at; web: http://www.pelletsheizung.at

- **Basic technological data**
  - **Description of technology:**
    - automatic pellet boiler with integrated flue gas condensation
    - heat exchanger (flue gas condensers) made of carbon
  - **Field of application:**
    - integrated flue gas condensation system (available only with pellet boiler)
    - nominal boiler capacity:12-32 kW

#### *4.2.15.2 Technical evaluation*

- **Operating behaviour:**
  - heating system with a return temperature of maximum 35 °C is needed
  - pressure drop of heat exchanger due to flue gas fan of pellet boiler negligible
- **Cleaning procedure:**
  - automatic cleaning system by means of water spray (once a day)
- **Installation:**
  - required space: approx. 1.13m x 1.09m x 0.999m (pellet boiler and condensation system)
  - electric connection (230V) required
  - tab and waste water connection required
  - chimney must fulfil requirements regarding fire-resistance, corrosion and moisture resistance
  - temperature of return water: 30-35 °C
- **Maintenance:**
  - condenser has to be manually cleaned one a year
- **Thermal efficiency:**
  - up to 15% related to the NCV of the fuel (according to manufacturer)
- **Results of test runs performed:**
  - Test runs performed by AUSTRIAN BIOENERGY CENTRE (Austria)
    - Test runs at test stand (measurement methodology shown in Figure 51) performed
    - Results of test runs at test stand are summarised in Figure 52

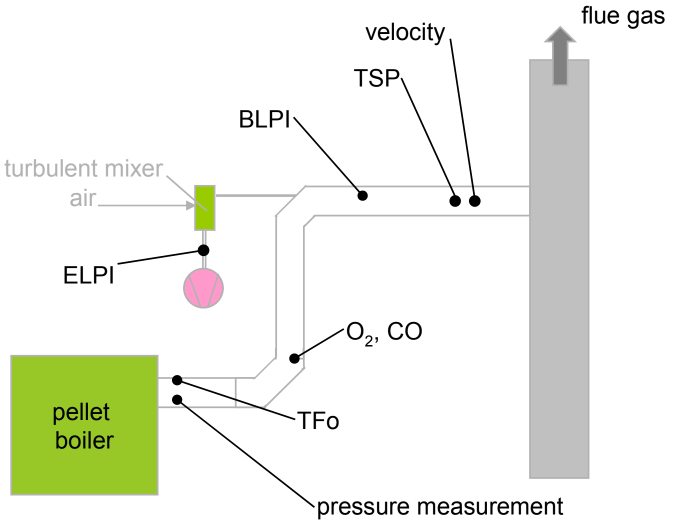



**Figure 51:** Scheme of measurement methodology of test runs at test stand performed by AUSTRIAN BIOENERGY CENTRE

Explanations: BLPI ... 9-stage Berner-type low-pressure impactor; ELPI ... electrical low pressure impactor; TFo ... temperature at boiler outlet; TSP (total suspended particulate matter) measurements according to VDI 2066

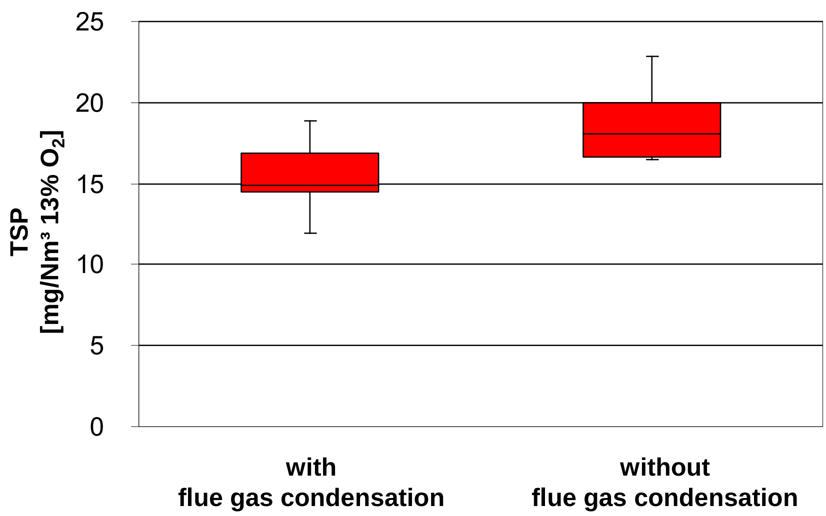



**Figure 52:** TSP emissions of pellet boiler ÖkoFEN during test runs performed by AUSTRIAN BIOENERGY CENTRE

Explanations: values of 9 trials made with flue gas condensation at full load (20 kW); values of 5 trials made without flue gas condensation at full load (18.2 kW)

- **Precipitation efficiency:**
  - TSP: 40 % reduction efficiency according to manufacturer
  - measurements performed by the AUSTRIAN BIOENERGY CENTRE showed rather small particle reduction efficiencies (>10 %)

#### 4.2.15.3 Relevant economic data

- **Investments Costs:**
  - approx. 1,200 € (20% VAT included) for flue gas condenser
- **Annual operating costs:**
  - not specified
- **Annual maintenance and other costs:**
  - no additional costs

#### 4.2.15.4 Summery and conclusions

The measured precipitation efficiency is rather low. The return water temperature should not exceed 35 °C. The main application of the system is to increase the thermal efficiency of the boiler rather than to reduce particulate emissions.

### 4.2.16 Wood log fired stove ECOplus with integrated ceramic filter - Hark (Germany)

In Figure 53 a scheme of the wood log fired stove with integrated ceramic filter (ECOplus) as well as a picture of are presented.

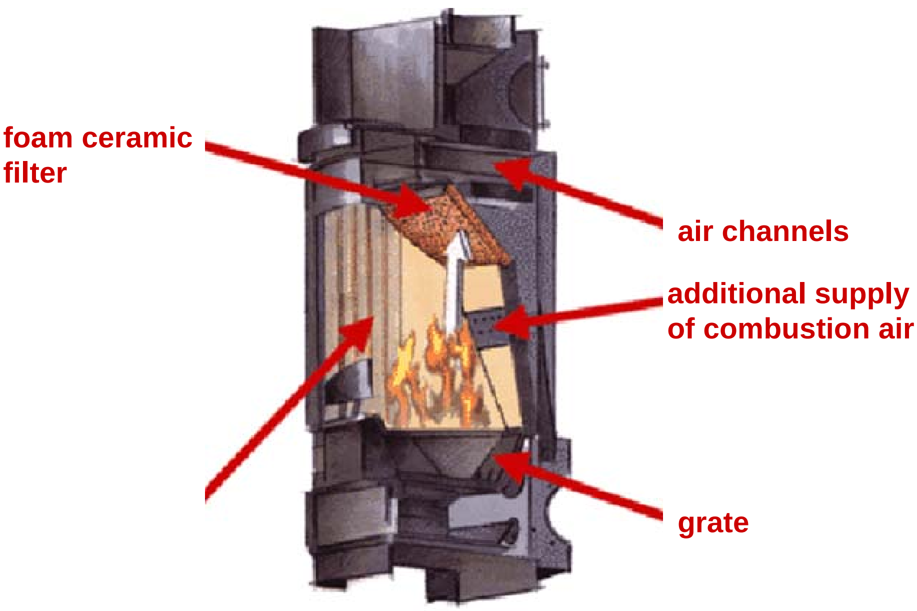



**Figure 53:** Scheme of the ECOplus technology (left) and picture of the wood log fired stove with integrated ceramic filter (right)

Explanations: foam ceramic filter was developed in cooperation with Fraunhofer Institute for Building Physics (IBP) in Stuttgart (Germany); source: [26]

#### 4.2.16.1 Basic data

- **Contact:**
O. Striegler (HARK GmbH & Co. KG)
Kastanienweg 5
04178 Leipzig, Germany
phone: 0172/260 3276
email: o.striegler@hark.de; web: http://www.hark.de

- **Basic technological data**
  - **Description of technology:**
    - wood log fired stove (4-8 kW) with integrated foam ceramic filter (for ECOplus series only)
    - unburned organic particles (soot and hydrocarbons), formed during phases of insufficient burnout conditions (start-up), are trapped in filter
    - combustion of unburned particles during intense combustion phase
  - **Field of application:**
    - ceramic filter is available only with wood log fired stove

#### 4.2.16.2 Technical evaluation

- **Operating behaviour:**
  - pressure drop of filter: ~4 Pa
  - required draught of chimney: ~12 Pa
  - bypass for flue gas during start-up due to high pressure drop (throttle has to be closed by customer)
- **Cleaning procedure:**
  - filter has to be manually cleaned periodically depending on operating time (disassembling of filter not necessary)
- **Installation:**
  - required space: approx. 0.4m x 0.5m x 1m
  - electric connection not required
- **Maintenance:**
  - stove and filter must be cleaned periodically depending on operation time
- **Results of test runs performed:**
  - test runs performed by the accredited test centre Rhein-Ruhr Feuerstätten Prüfstelle (Germany)
    - results of test runs at test stand are summarised in Table 35

**Table 35:** Results of test runs at test stand performed by the Rhein-Ruhr Feuerstätten Prüfstelle

Explanations: emissions related to dry flue gas and 13% $O_2$; CO and OGC are calculated according to EN 13240, for the calculations the mean $O_2$-values as well as the mean gaseous emission values (ppm) are considered, period of calculation: closing the door until no flame is recognisable; source:[49]

| parameter | unit | values |
|---|---|---|
| CO | mg/MJ | 583 |
| OGC | mg/MJ | 27 |
| TSP | mg/MJ | 14 |

- **Precipitation efficiency:**
  - Measurements before and after filter are not possible.
  - The stove has been optimised for an operation with the filter (operation of the stove without filter not feasible).
  - Therefore, the precipitation efficiency cannot be specified.
  - Other modern high technology stoves show similar TSP emissions. Precipitation efficiency seems not to be very high

#### *4.2.16.3 Relevant economic data*

- **Investments Costs:**
  - stove: approx. 2,500-3,500 € (20% VAT included)
- **Annual operating costs:**
  - no additional costs
- **Annual maintenance and other costs:**
  - no additional costs

#### *4.2.16.4 Summery and conclusions*

The foam ceramic filter is integrated into the combustion chamber of the log wood fired stove. The filter is only available with the stove. The stove has been optimised for the operation with the filter. The precipitation efficiency of the filter cannot be specified. Comparisons with TSP emissions of other modern high technology stoves show no differences concerning TSP emissions. Therefore, the precipitation efficiency seems not to be very high. A further evaluation in order to identify the potential of the ceramic filter is needed.

### 4.2.17 Ceramic filter – Interfocos BV (The Netherlands)

In Figure 54 pictures of the ceramic filter as well as of a wood log fired stove with integrated ceramic filter are presented.

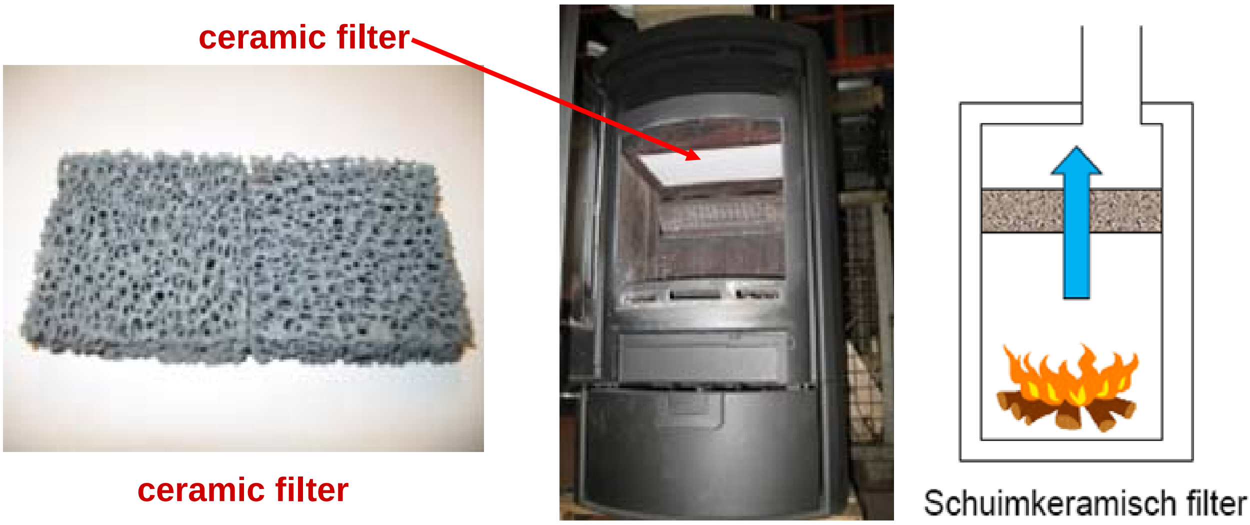



**Figure 54:** Picture of ceramic filter (left) and pictures of the wood log fired stove with integrated ceramic filter (middle and right)

Explanations: source: [31]

### 4.2.17.1 Basic data

- **Contact:**
  Interfocos BV,
  Eric Smit, product development engineer
  phone: + 31 497-339284
  email: esmit@interfocos.com

- **Basic technological data**
  - **Description of technology:**
    - Open ceramic structure of non-catalytic filter material captures larger particles with a very low pressure drop
    - Ceramic filter is also in operation at start-up when the highest emissions occur.
    - The trapped particles experience a longer residence time and burnout later at high temperature when the stove heats up.
  - **Field of application:**
    - wood fired stoves
    - because of low pressure drop suitable for natural draught systems

### 4.2.17.2 Technical evaluation

- **Operating behaviour:**
  - only limited influence on stove operation
  - Pressure drop over the filter is 1 – 3 Pa.
  - increased heat radiation to the fuel, causing more rapid degasification

- **Cleaning procedure:**
  - cleaning not required, dust burns and fine ashes are not sticky and leave with the flue gas
  - any deposits can easily be removed from the surface with a soft brush
- **Installation:**
  - installation directly in upper part of combustion chamber
  - electric connection not required
- **Maintenance:**
  - stove and filter must be cleaned periodically depending on operation time
- **Results of test runs performed:**
  - Laboratory tests have been performed by the manufacturer in a freestanding woodstove and an inset appliance. Firing and flue gas sampling have been done according to the procedure described in EN 13240
  - Particle precipitation efficiency ranged from less than 10 % to more than 70 %. The results are very dependent on the geometry of the filter in the stove and the pore size of the filter.
- **Precipitation efficiency (according to manufacturer):**
  - The filter reduces emissions from about 34 down to 10-17 mg/m³ (related to 13% $O_2$ and dry flue gas), depending on the filter material chosen and the position in the stove.

#### *4.2.17.3 Relevant economic data*

- **Investments Costs:**
  - approx. 100 € (19% VAT included)
- **Annual operating costs:**
  - no additional costs
- **Annual maintenance and other costs:**
  - no additional costs

#### *4.2.17.4 Summery and conclusions*

Market introduction is foreseen for 2011. The ceramic filter is basically an interesting low-cost technology that could have a great impact on dust emissions from stoves. It can be built in new stoves without causing inconvenience to the end user. Technology principle and variables need to be better understood and optimised. Extensive research is necessary. Seems mostly suitable for stoves that show high dust emission due to unburned particles, not suitable for boilers that have low dust emissions (and unburned hydrocarbons) already, as these are not affected by the filter. Longer duration test runs and optimization of the filter still to be performed.

## 4.2.18 Catalytic converter KLIMA-KAT - CAMINOS (Germany)

In Figure 55 pictures of the catalytic converter as well as schemes of the installation of the catalytic converter in the upper part of the combustion chamber of a wood stove are presented.

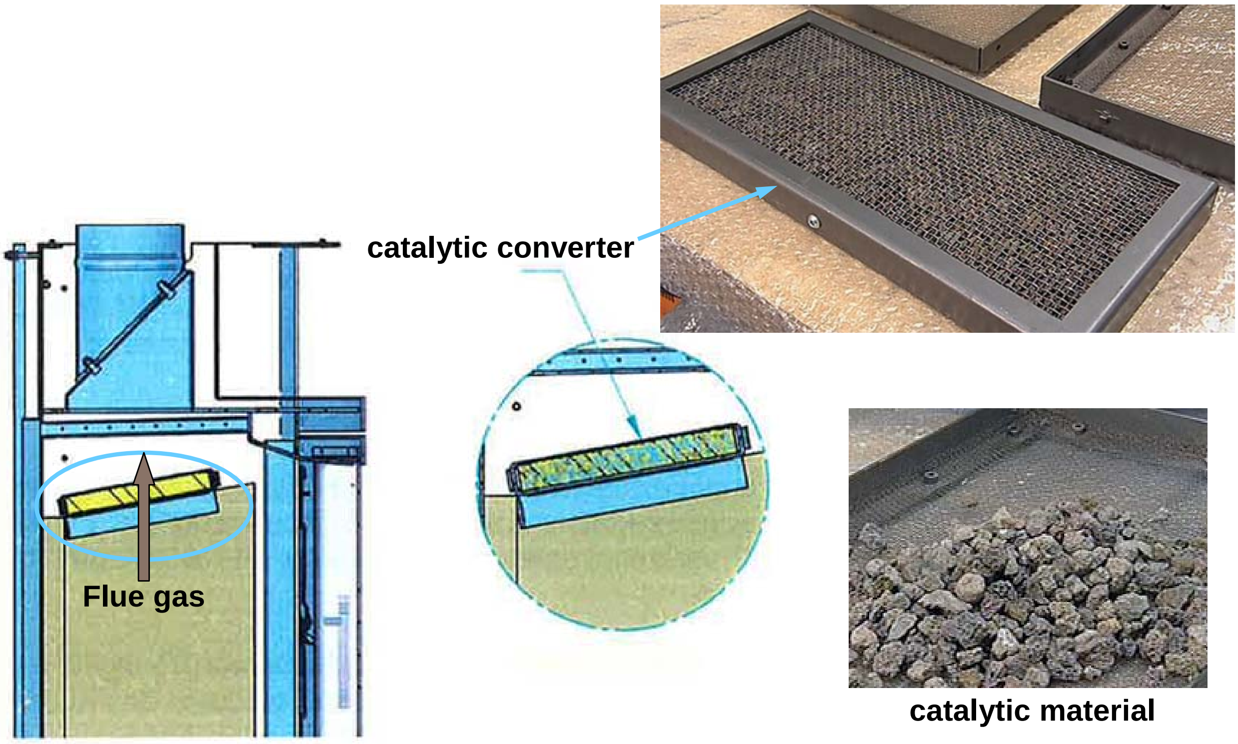



**Figure 55:** Pictures and scheme of the catalytic converter KLIMA-KAT

Explanations: catalytic converter is installed in upper part of combustion chamber; source: [38]

### *4.2.18.1 Basic data*

- **Contact:**
  CAMINOS Kaminöfen Produktions- und Vertriebs GmbH & Co.KG
  Weidengrund 10
  32584 Löhne, Germany
  phone: 05732994-0; fax: 05732994-450
  email: mail@caminos.de; web: http://www.caminos.de
- **Basic technological data**
  - **Description of technology:**
    - filter with absorbing and catalytic NANOlapilli to combust organic particles and also to convert CO into $CO_2$
  - **Field of application:**
    - only for CAMINOS wood stoves

#### *4.2.18.2 Technical evaluation*

- **Operating behaviour:**
  - no data available
- **Cleaning procedure:**
  - cleaning not necessary
- **Installation:**
  - installation directly in upper part of combustion chamber
- **Maintenance:**
  - not necessary
- **Precipitation efficiency:**
  - TSP: up to 85 % reduction efficiency (according to manufacturer)
  - no measurements from independent test institutions available

#### *4.2.18.3 Relevant economic data*

- **Investments Costs:**
  - no data available
- **Annual operating costs:**
  - no data available
- **Annual maintenance and other costs:**
  - no experience available yet

#### *4.2.18.4 Summery and conclusions*

The unit fits in almost all CAMINOS wood stoves, other stoves are not mentioned. No additional space is necessary due to the installation directly in the upper part of the combustion chamber of the wood stove. The pressure drop could be a problem, especially if the filter gets loaded with particles. The cleaning procedure is not mentioned. The precipitation efficiency is high according to manufacturer, but test results of independent institutions are missing.

### 4.2.19 Catalytic converter MEKAT – moreCat GmbH (Germany)

In Figure 56 a picture of the catalytic converter MEKAT as well as schemes of typical application of the catalytic converter are presented.

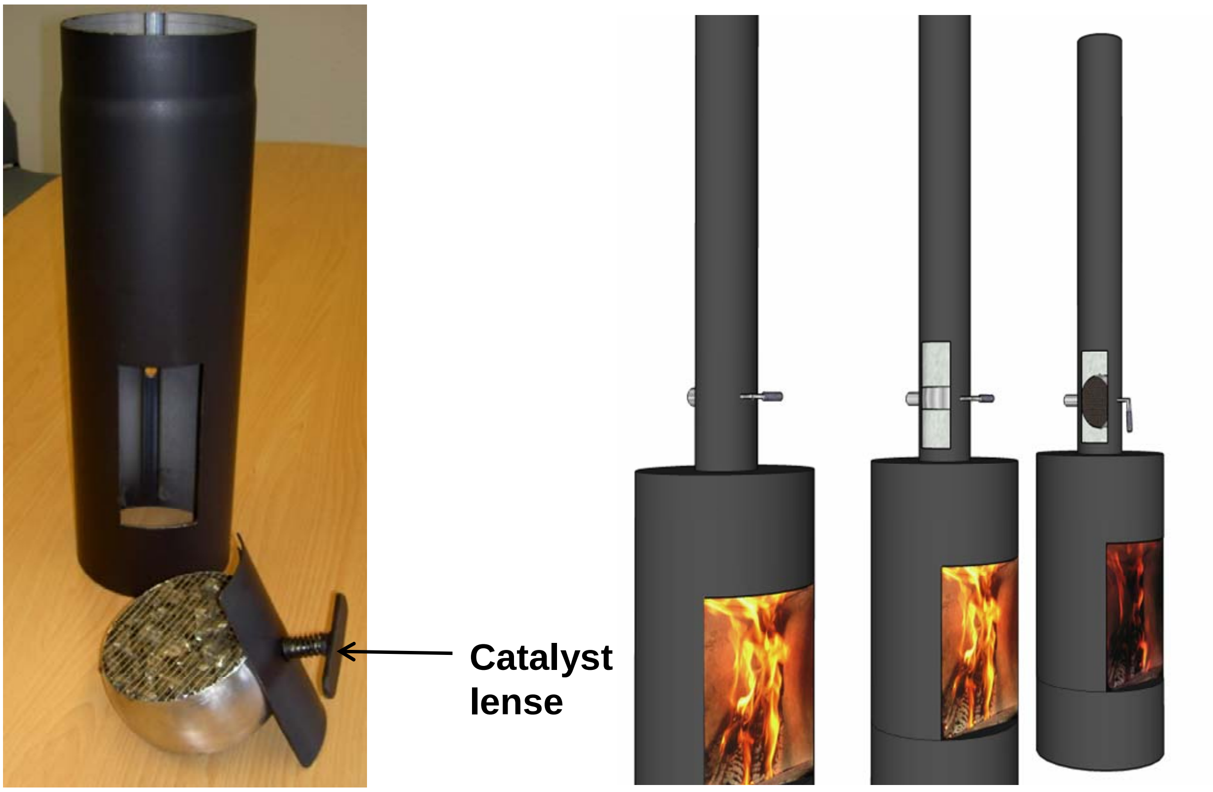



**Figure 56:** Picture of the catalytic converter MEKAT (left) and schemes of typical applications (right)
Explanations: source: [23]

#### *4.2.19.1 Basic data*

- **Contact:**
  E. Erich (moreCat GmbH)
  Asdonkstraße 33, Industriegelände Rossenray
  47460 Kamp-Lintfort, Germany
  phone: 02842-9032201; fax: 02842-9032209
  email: info@morecat.de; web: http://www.morecat.de
- **Basic technological data**
  - **Description of technology:**
    - Pd containing catalyst placed in a lense to convert CO, soot and unburned hydrocarbons to $CO_2$ and steam
    - converter can be turned into flue gas pipe after start-up as soon as flue gas temperature exceed 250 °C
  - **Field of application (according to manufacturer):**
    - for pellet stoves, wood log stoves and lignite briquette stoves

#### 4.2.19.2 Technical evaluation

- **Operating behaviour:**
  - temperatures between 350 and 550°C required for oxidation processes
  - no reduction of emissions during start-up due to low flue gas temperatures possible → filter in bypass position
  - pressure drop over catalytic bed increases during operation due to ash and particle deposition
  - cleaning after 8 h of operation recommended (5 - 26 h during test runs)
- **Cleaning procedure:**
  - manual cleaning by taking out the lense and washing with water
- **Installation:**
  - installation in flue gas duct directly on top of wood stove
  - no additional space required
- **Maintenance:**
  - manual cleaning of converter every 8 h
- **Precipitation efficiency (according to manufacturer):**
  - TSP: above 35 % precipitation efficiency
  - hydrocarbon reduction up to 75 %
  - CO reduction up to 82 %
  - soot reduction up to 95 %
- **Results of test runs performed:**
  - Test runs performed by Graz University of Technology (Austria)
    - Field test runs (measurement methodology shown in Figure 57) performed with chimney stove, total operating time: 134 h
    - Results of field test runs are summarised in Figure 58, Figure 59 and Figure 60

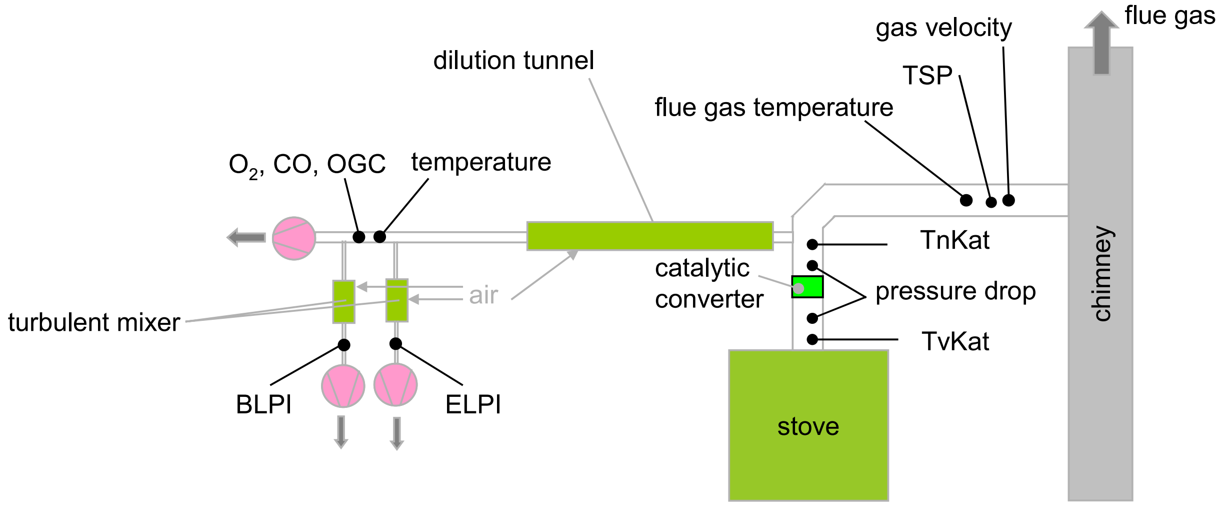



**Figure 57:** Scheme of measurement methodology of field test runs performed by Graz University of Technology

Explanations: BLPI ... 9-stage Berner-type low-pressure impactor; ELPI ... electrical low pressure impactor; TvKat ... temperature at filter inlet; TnKat ... temperature at filter outlet; TSP (total suspended particulate matter) measurements according to VDI 2066; test runs performed with chimney stove Jydepejsen Fine-line (2003 model); source: [43]

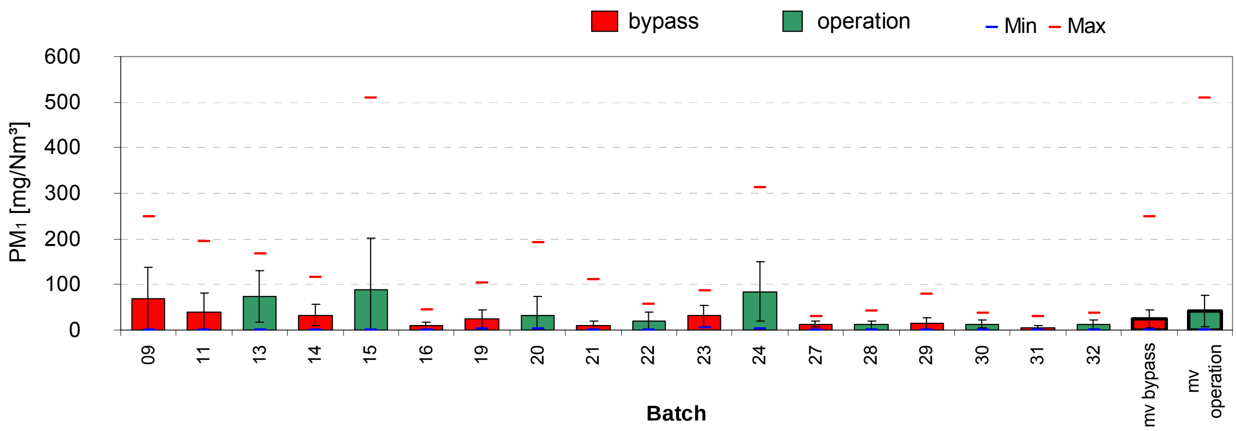



**Figure 58:** $PM_1$ emissions of chimney stove during field test runs with catalytic converter performed by Graz University of Technology

Explanations: emissions related to dry flue gas and 13% $O_2$; $PM_1$ measured with ELPI; mv ... mean value; max ... maximum value; min ... minimum value; field test run with chimney stove Jydepejsen Fine-line (2003 model); fuel: beech log wood; source: [43]

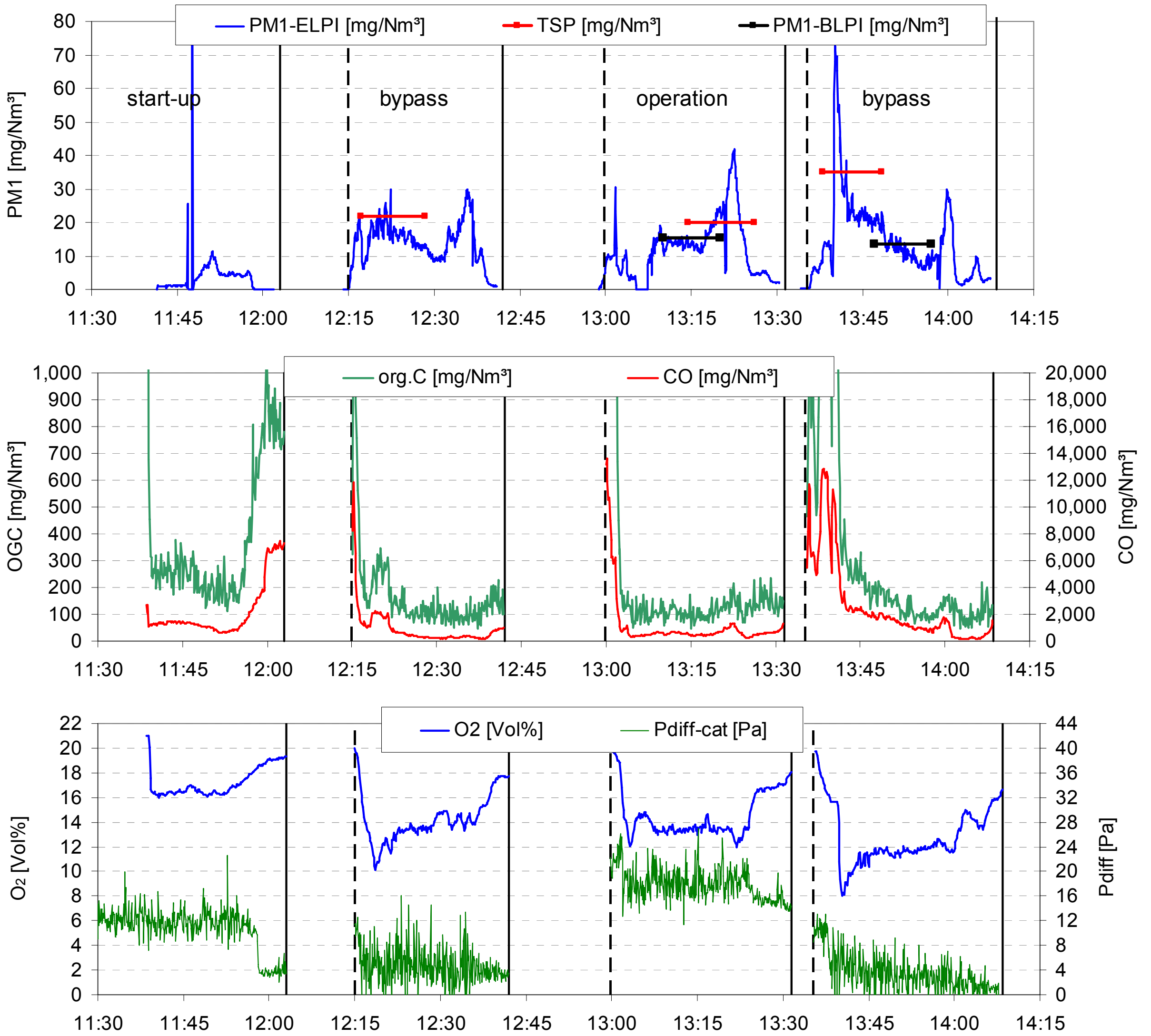



**Figure 59:** Results of field test runs performed by Graz University of Technology

Explanations: all emissions related to dry flue gas and 13% $O_2$; field test run with chimney stove Jydepejsen Fine-line (2003 model); TvKat ... temperature at filter inlet; TnKat ... temperature at filter outlet; fuel: beech log wood; source: [43]

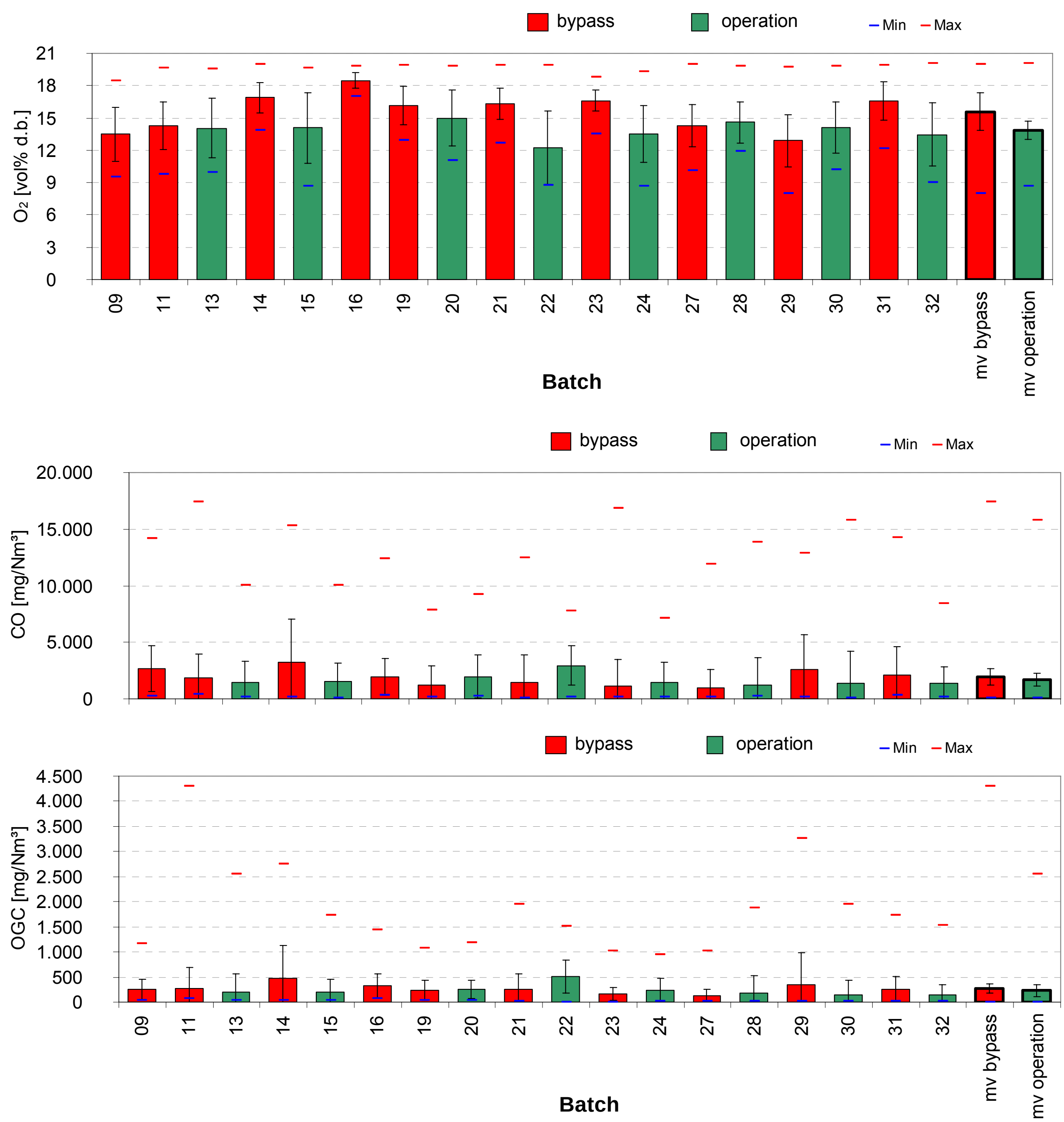



**Figure 60:** Mean $O_2$, CO- and OGC-emissions of chimney stove during field test runs with catalytic converter performed by Graz University of Technology

Explanations: emissions related to dry flue gas and 13% $O_2$; $PM_1$ measured with ELPI; mv ... mean value; max ... maximum value; min ... minimum value; field test run with chimney stove Jydepejsen Fine-line (2003 model); fuel: beech log wood; source: [43]

- **Precipitation efficiency:**
  - CO: 0 - 14% reduction
  - hydrocarbons (OGC): 0 - 15% reduction
  - $PM_1$-emissions increased due to poor combustion behaviour of stove caused by high pressure drop of catalytic converter

#### *4.2.19.3 Relevant economic data*

- **Investments Costs:**
  - no data available
- **Annual operating costs:**
  - no data available
- **Annual maintenance and other costs:**
  - no data/experience available yet

#### *4.2.19.4 Summery and conclusions*

The temperature of the flue gas has to exceed 350°C for efficient operation. Therefore, the catalytic converter is not suitable for modern stoves. There is no reduction of emissions during start-up (bypass). Manual cleaning is recommended every 8 h (every 5 - 26 h during test runs). An additional air fan is possibly necessary due to the high pressure drop of up to 30 Pa. The catalytic converter MEKAT is no promising technology due to its inconvenience, low reduction efficiency and high pressure drop.

### 4.2.20 Flue-gas well (Sweden)

In Figure 61 a picture of the home-built system Flue-gas well and a scheme of the installation are presented.

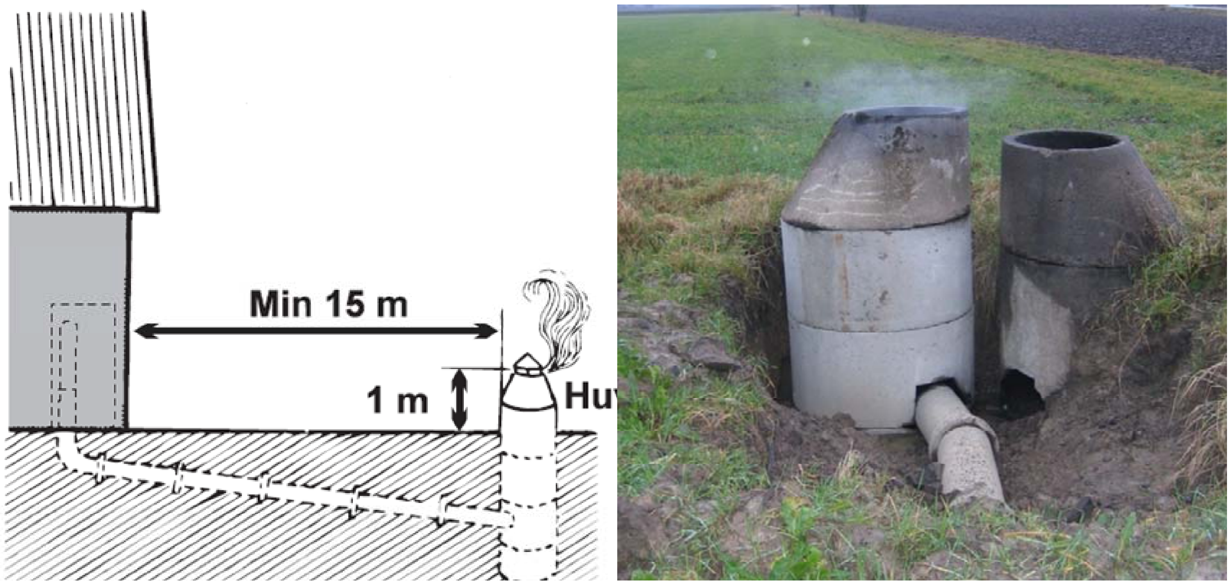



**Figure 61:** Scheme (left) and picture (right) of the home-built system Flue-gas well

Explanations: source: [51]

#### *4.2.20.1 Basic data*

- **Contact:**
  no commercial product, home-built by farmers**.**

- **Basic technological data**
  - **Description of technology:**
    - Flue gases are lead through a flue gas channel in the ground to a well.
    - The flue gas temperature is lowered, moisture is condensed and some of the acid species and the fly ash get also condensed and gather in the well.
  - **Field of application:**
    - boilers for combustion of cereals, simultaneous reduction of particles, HCl and $SO_2$

#### 4.2.20.2 Technical evaluation

- **Operating behaviour:**
  - The condensate becomes acid and needs to be neutralised, limestone is used.
- **Cleaning procedure:**
  - cleaning not necessary
- **Installation:**
  - outdoors in the ground
- **Maintenance:**
  - risk for corrosion on concrete piping
- **Results of test runs performed:**
  - test runs performed by SP (Sweden)
    - field test runs performed with Stoker Säätotuli and boiler Tulimax (80 kW) with oat energy grains
- **Precipitation efficiency:**
  - TSP: 42 % reduction efficiency (particle concentration in flue gas after boiler: 342 mg/Nm³ (related to 10% $O_2$ and dry flue gas)

#### 4.2.20.3 Relevant economic data

- **Investments Costs:**
  - 500 – 1,000 euro + cost for digging and for the pressure sensor
- **Annual operating costs:**
  - no additional costs
- **Annual maintenance and other costs:**
  - no data/experience available yet

#### 4.2.20.4 Summery and conclusions

The home-built flue-gas wells are in operation in Sweden. The concept of the device is simple, but the concrete pipings are susceptible to corrosion. Further improvements are needed to avoid corrosion of pipes. The home-built system l is no promising technology due to the low particle precipitation efficiency and is only relevant for Sweden.

# 5 Conclusions and recommendations

Solid biomass combustion is increasingly criticised as a major source of PM emissions. With the introduction of the EU directive 1999/30/EC, which limits $PM_{10}$ concentrations in the ambient air, it had to be recognised that in many European regions these limiting values are frequently exceeded. As the main sources for PM emissions traffic, industry and domestic heating have been identified. The contribution of residential biomass combustion to the total PM emissions of the residential heating sector exceeds in some European countries 80%.

Emission limit values in IEA countries are referred to total particle mass. There are no specific $PM_1$ emission limit values existing for biomass fired combustion systems in the IEA Bioenergy Task32 member countries. Significant differences exist regarding the present dust emission limit values for small-scale combustion systems in the IEA Bioenergy Task32 member countries. Rather strict emission limit values are valid for Austria, Germany and Switzerland. On the contrary, there are no dust emission limit values existing for biomass fired combustion systems in Finland, the Netherlands and Sweden, apart from voluntary schemes. This is of great relevance as stricter emission limits accelerate the technological development and the market introduction of particle precipitation devices.

There is no common international approach regarding PM emission measurements. Usually gravimetric methods, as for example the method according to VDI 2066 are applied. However, the different national regulations on residential combustion which include requirements for maximum particle matter (or dust) emissions do not define or refer to a specific method on how to determine particle matter emissions. A common European method to determine PM emissions has been made within CEN during the last years. However, a common European method could not be brought to a European Technical Specification or a European standard yet. Nevertheless, the urgent need for a common European method is clearly endorsed by the standardisation groups CEN/TC 57 and CEN/TC 295.

Moreover, also for the determination of filter efficiencies so far no common international approach exists. Regarding measurements downstream ESP for instance the influence of charged particles on particle precipitation in the sampling lines of measurement instruments is still unclear and needs some further investigations. But in this respect not only the dust emission measurement itself but also the process conditions of the stove respectively boiler connected to the filter as well as the position of the filter (directly connected to the stove/boiler or placed on the top the chimney) have to be considered due to possible particle formation due to condensation of condensable organic compounds (COC) which result from poor burnout conditions.

This particle formation due to COC condensation may significantly influence the results of measurements regarding the filter efficiency, especially when the filter is applied at an old technology boiler or a stove, where phases with poor burnout conditions and rather high flue gas outlet temperatures frequently occur. If a filter is designed to be mounted on the top of the chimney, the flue gas will cool down in the section between stove/boiler outlet and filter and COC condensation will take place. Therefore, also at a filter test stand the filter should be tested at inlet temperatures as they prevail in the field application. Moreover, in the filter a further cooling of the flue gas could take place due to for instance purge air flows which are applied to protect the isolator of an ESP electrode. Therefore, in the ESP particle formation may take place downstream the charging electrode which in the worst case could lead to a higher aerosol load at filter outlet compared to filter inlet. Consequently, in order to determine the precipitation efficiency of a filter, the flue gas at filter inlet and filter outlet should be kept at about the same temperature or at least information about the temperatures up- and downstream the filter should be provided. Furthermore, parallel measurements before and after filter are crucial, especially for stoves.

Moreover, it has to be considered that although with the strategy proposed above the filter efficiency can be evaluated, no information on the full potential of PM emissions is provided as a fraction of COCs may remain in the flue gas at sampling temperature and may form particles when mixing with the ambient air at chimney outlet. In order to also assess this particle emission potential for instance flue gas dilution to temperatures below 50°C prior to particle measurement could be an option but also a combination of dust measurements based on gravimetric filter methods followed by a set of impinger bottles containing different solvents could be applied. In both cases not only the aerosols already present in the flue gas but also the fraction of volatile COCs can be considered. From this point of view filters operating at as low as possible flue gas temperatures (e.g. roof top applications) are preferable. However, for roof top applications field testing is hardly possible and therefore, test stand procedures which provide conditions comparable with the field application have to be developed. Moreover, it has to be secured that relevant operation parameters which influence the performance of ESPs (e.g. ESP voltage and current) are the same during test stand and field operation. These parameters should generally be displayed and monitored in order to have indications regarding the filter performance during real-life operation.

The market for small-scale biomass combustion systems in Europe is extremely dynamic. Its development strongly depends on external factors such as development of fossil fuel prices, supply security and costs for biomass fuels and changing national regulations regarding emission limits and subsidies. Due to that fact, intense R&D activities regarding the development of particle precipitation devices are especially ongoing in Austria, Germany and Switzerland as in these countries the strictest dust emission limits exist.

Subsidies or incentives for small-scale particle precipitation devices are only available in Germany. There are no certificates for particle precipitation devices foreseen in the other IEA Bioenergy Task32 member countries.

A survey on the present European state-of-the-art concerning particle precipitation devices for residential biomass combustion systems (<50 kW) has been conducted. The survey involved the evaluation of 12 electrostatic precipitators, 2 catalytic converters, two ceramic filters, three condensing heat exchanger and one additional device (flue gas well).

The ESP technology seems to be the most promising technological approach for small-scale biomass combustion. Till 2011 3 ESPs for residential biomass combustion systems have been introduced into the market:

- Zumik®on/Switzerland (K+W)
- OekoTube/Liechtenstein (OekoSolve)
- Airbox/Switzerland (Spartherm)

The ESPs for residential biomass combustion systems of the following manufacturers can be expected to enter the market soon:

- RuFF-KAT/Germany

- Spanner/Germany
- TH-AE/Germany
- Windhager/Austria

A considerable number of devices is presently under development and can be expected to be demonstrated within the next years.

With the ESPs generally mean total dust precipitation efficiencies of 50 to 85% can be achieved. The particle precipitation efficiency strongly depends on the utilised fuel and the combustion technology (old/new system). The ESP is installed in the flue gas pipe between furnace and chimney or is mounted on the top of the chimney. Most ESPs are equipped with an automatic cleaning system. Cleaning of the ESP is achieved with vibration, with a brush or with water spray. Some ESPs have to be cleaned manually by the customer or the chimney sweep in regular visits. The maintenance has to be done by the customer or the chimney sweep. Usually, the filter ash has to be removed manually. The frequency of cleaning and maintenance procedures depend on operating time and type of furnace connected. The power consumption of the ESPs varies between 10 and 100 W (mostly 10-30 W).

The investment costs (incl. VAT) for an ESP are in the range of 1,000 to 3,000 € (mostly 1,200-1,500 €). Additional costs for the installation of the device have to be considered. The annual operating costs depend on the operating time of the ESP as well as local electricity prices. The annual maintenance costs depend on local chimney sweep tariffs yet.

Most of the ESPs have been developed and tested under good or acceptable combustion conditions at test stands. Furthermore, up to now only a few long term field test runs have been performed. Therefore, sufficient data concerning the applicability and availability of the investigated devices are not available.

The influence of condensable and sticky particles, which result from poor combustion conditions (typical for old stoves/boilers as well as start-up conditions) on the efficiency and the availability of the ESPs is still not sufficiently clarified. Ongoing and future projects are focusing on these issues as they will be crucial for a broad market introduction of a specific technology.

Up to now no promising results have been achieved with catalytic converters for wood boilers/stoves. Due to the required high flue gas temperatures for catalytic oxidation, these devices are not available during start-up and phases of incomplete burnout of the flue gas due to low temperatures. The device KLIMAT KAT should possibly be considered for further investigation as the catalytic filter is installed in the combustion chamber, where temperatures are sufficiently high to burn absorbed particles.

The wood log fired stove ECOplus (Hark/Germany) is equipped with a foam ceramic filter that is installed in the upper part of the combustion chamber. The stove has been optimised for the operation with the filter. The precipitation efficiency of the filter is unknown. Comparisons with TSP emissions of other modern high technology stoves show no relevant differences regarding TSP emissions. Therefore, the precipitation efficiency seems not to be very high. A further evaluation of the ceramic filter is needed.

The specially developed high temperature condensing heat exchanger from UEF (Finland) should achieve a satisfying particle precipitation efficiency according to theoretical calculations. The technology has potential, but needs further research on thermal and precipitation efficiency, design, implementation in heating systems, economic aspects, maintenance and long-term stability. The condensing heat exchanger could be applied in various systems where the need for low-cost precipitation overrules the need for high precipitation efficiencies.

The precipitation efficiency of the condensing heat exchanger Öko-Carbonizer (Germany) and the pellet boiler with integrated flue gas condensation (ÖkoFEN/Austria) is low. The main application of these systems is to increase the thermal efficiency of the boiler rather than to reduce particulate emissions.

The home-built system Flue-gas well is no promising technology due to the low particle precipitation efficiency. It is of a certain relevance only for Sweden.

In general particle precipitation devices are secondary measures and therefore could especially be attractive for old systems which show the highest particulate emissions. But these systems also show the most difficult framework conditions in terms of PM load, burnout quality of the particles and stickiness of particles. Thus, for these conditions the filters must really show a robust behaviour and must also be equipped with an efficient and automatic cleaning system. Therefore, the applicability of filters for old systems where really great particle reduction potentials are given should be a special focus of future work.

A second possible application for filters are stoves as the burnout quality of batch combustion systems with natural draft is not as good as of continuously operated systems. For stoves filter which are directly implemented in the chimney or top of the chimney are of special interest.

For modern biomass boilers the main focus should be on the reduction of particulate emissions by primary measures and filters should only be applied if additionally necessary.

In order to really introduce new residential filters in the market, the filters must be well tested and reliable. Furthermore, the filters must operate automatically over a whole heating period and must work efficiently. Besides the technological requirements, which still have to be proven for most applications, also legal and financial incentives will be needed to really achieve an effective market introduction which should, according to the present state of development, take place within the next 5 years in mid Europe (Germany and Austria).

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