TECHNO-ECONOMIC ASSESSMENT OF PARTICLE REMOVAL IN AUTOMATIC WOOD COMBUSTION PLANTS FROM 100 KW TO 2 MW

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ABSTRACT: Automatic wood combustion leads to relatively high emissions of particulate matter smaller 10 microns and even smaller 1 micron. To reduce the environmental impact and to comply with stringent emission limit values, secondary measures for fine particle removal by electrostatic precipitators (ESP) and fabric filters are needed. These techniques are common for plants greater than 2 MW, but there is an increasing interest in particle removal for plants smaller 2 MW and even smaller 1 MW. In Switzerland, experiences exist with a limited number of applications in the size range of around 500 kW. The present study describes the technical and economic consequences of utilisation of ESP and fabric filters for wood combustion plants in the size range from 100 kW to 2 MW to meet an emission limit value of 20 mg/m^3 at 13 vol.-% O_2. The economic data refer to reference plants and offers from manufactureres in Europe. The economic assessment shows, that ESP and fabric filter lead to similar total cost with higher investment cost for ESP and higher operation cost for fabric filters.

Keywords: Aerosols, electrostatic filter, flue-gas cleaning.

1 INTRODUCTION

Immission limit values on particulate matter PM10 are highly exceeded in most European countries. Together with Diesel engines, biomass combustion is one of the main source of combustion particles leading to PM10 in the ambient air. Hence, measures to reduce PM emissions will be needed in the next years. Since primary measures are not sufficient to meet strong limit values for automatic biomass combustion plants, technologies for particle separation by secondary measures are of interest. For applications in the size range between 100 kW and 2 MW, electrostatic precipitators (ESP) and fabric filters are most promising. Experiences exist from applications in larger plants since many years, while a limited number of such plants have been implemented in the size range of around 500 kW in the recent years. Although the technology is proven in principal, both systems exhibit specific advantages and disadvantages and operational limits for succesful applications. The aim of the present study is to assess the availability and application of particle removal systems for automatic biomass combustion plants in the size range from 100 kW to 2 MW and to evaluate and compare the economic impact on heat production from wood with and without particle precipitation in comparison to light fuel oil. The method and results are described in detail in the final report [1].

2 PARTICLE REMOVAL TECHNIQUES

Automatic biomass combustion plants exhibit usually particle emissions in the raw flue gas of more than 100 mg/m^3 at 11 or 13 vol.-% O_2 and in some cases up to several 100 mg/m^3, depending on fuel type and combustion type. If a target value of safely below 20 mg/m^3 is aimed at, a significant removal efficiency, i.e. at least > 90 to 95% for particles smaller 10 microns and even smaller than 1 micron is needed. For automatic biomass combustion plants up to 2 MW, the following technologies are commonly applied for particle removal which are described in detail e.g. in [2–4]:

Cyclones
Dry electrostatic precipitators (ESP)
Fabric filters.

Cyclones do not achieve a relevant removal efficiency for fine particles smaller than 5 microns. If emission limit values of e.g. 150 mg/m^3 at 11 or 13 vol.-% O_2 are aimed at, cyclones are often applied as only particle removal system. If ESP or fabric filters are applied, cyclones are often used as a pre-separators for the removal of coarse fly ash and glowing particles which might lead to a destruction of the fabric material. However, a pre-separator by cyclone causes not only additional investment cost, but also significant operation cost due to the additional pressure drop. Furthermore, in some cases a pre-separation can also lead to a reduced precipitation efficiency of the ESP.

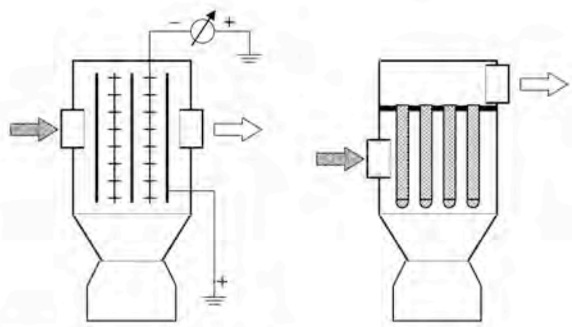

Figure 1: Investigated particle removal systems: Electrostatic precipitator (ESP) (left), fabric filter (right).

ESP exhibit a high precipitation efficiency for all particle sizes except for particles in the size range from app. 0.2 to 0.8 micron, where the precipitation efficiency exhibits a typical minimum. Due to the precipitation principle, the removal efficiency depends on the residence time or the space velocity in the ESP and hence can be improved by increasing the precipitation area, thus leading to increased size and cost of the ESP. Due to this situation, ESP are nowadays often designed to achieve e.g. 50 mg/m^3 at 11 vol.-% O_2 and hence the size and cost increase, if far lowert emission limit values are demanded.

Fabric filter enable typically removal efficiencies of > 99%. The periodic cleaning of the fabric filter causes a temporary reduction of the filtration efficiency, since the filter layer is needed for a maximum precipitation of fine particles. In addition, gases substances such as HCl and PCDD/F can be removed by absorption in the filter layer. For this purpose, limestone can be added for HCl and active coke can be added for PCDD/F removal. Hence, fabric filter are advantageous in case of contaminated wood. However, fabric filters exhibit a significant energy consumption due to the relevant pressure drop and the utilisation of pressurised air for the periodic cleaning. In addition, fabric filters are well suited for dry flue gases, while high water content in the fuel and consequently in the flue gas are critical, since condensation of water vapour and other substances may lead to filter clogging and thus to a destruction of the filters, which may lead to interruption of the plant operation and to high cost. In addition, fabric filters can be destroyed by glowing particles, which need to be avoided, removed, or detected and extinguished in front of the fabric filter.

To avoid condensation in the filter, fabric filters need to be heated up to a minimum operation temperature, which can be performed by electric heating. However, fabric filters in small plants are often equipped with a bypass and hence not in use during the critical start-up phase of the combustion plant. Typically, fabric filters are only operated at temperatures higher than 120°C for dry fuels and higher than 140°C for wet fuels. In ESP, condensation should also be avoided and hence in some systems, the electric current is reduced or shut off during operation periods below a minimum temperature. Consequently, automatic combustion plants which are equipped with particle precipitation should be operated during long operation periods, while on/off operation should be avoided. Furthermore, a minimum availability for the precipitation should be claimed and the operation of the precipitation should be monitored. Since condensation is more critical in fabric filters, fabric filters are most often used for dry fuels only, while ESP are also used for wet fuels.

Beside ESP and fabric filters, flue gas condensation and wet electrostatic precipitation (wet ESP) are also used for automatic biomass combustion plants. However, flue gas condensation alone does not achieve a high efficiency (i.e., typically less than 50% if the raw gas concentrations are below 100 mg/m^3), while wet ESP with or without separate flue gas condensation is more complex and hence usually applied in larger scale, e.g. for blue haze reduction (organic aerosols) in wood industry.

3 METHOD

In the present study, an emission limit value of 20 mg/m^3 at 13 vol.-% O_2 is assumed. This target value can be safely achieved or significantly undercut by fabric filters. Dry ESP are also capable to meet this standard, if designed for this value. However, a good operation of the plant is needed for both type of separators, which is assumed in the present case. Experiences from reference plants show, that emission values below 5 mg/m^3 can be met under typcal operation conditions, if the separators are designed for a guarantee value of 20 mg/m^3, since the guarantee value needs to be met in a broad range of operation.

The economic assessment is performed according to the method of annuity by taking into account the capital cost and the operation cost. Capital cost and operation cost from automatic biomass combustion plants mostly without particle precipitation have been evaluated in an earlier investigations of 35 biomass plants in Switzerland [5]. Detailed data from similar plants in Germany and Austria have been collected for a handbook on plant planning and quality management [6]. Investment cost of reference plants in the size range close to 500 kW have been collected from three plants which were recently built in Switzerland [1]. Furthermore, detailed offers from different manufacturerers of ESP and fabric filters have been collected to receive actual data on these technologies. The detailed boundary conditions and the technologies which were respected for the economic assessment is described in [1].

Based on the investment cost and the operation cost as expected from the manufacturers and as reported from plants operated in practice, the capital and operation cost have been calculated with the following basic assumptions:

Interest rate for capital cost:	5.0% p.a.
Payback time for technique/hardware:	15 a
Payback time for buildings:	30 a
Operation of heating plants:	2000 h/a
Life time of filter for fabric filters:	5 a
Fuel price for wood chips at the gate:	3 Ct./kWh
Fuel price for light fuel oil:	6 Ct./kWh

The fuel price for light fuel oil is used for the calculation of a reference scenario for heat production with fossil fuels. The assumed fuel price of 6 Ct./kWh corresponds to app. 60 Euro per 100 Liter, which was an average light fuel oil price in 2006 in Germany.

In Germany, the price for commercially available wood chips with a water content of app. 35% in 2006 varied between Euro 35.– and Euro 90.– per ton [7], which corresponds to approximately 1.2 to 3.0 Ct./kWh. In the present study, a wood fuel price of 3 Ct./kWh is assumed. Hence for cheaper wood fuel, wood is more economic in comparison to light fuel oil, while the relative increase of the heat production cost caused by particle precipitation also increases. However, the assumed wood fuel price is regarded as fairly low since it is assumed, that the ratio between the cost for light fuel oil and for wood chips will be significantly > 1 but might also decrease to a level significantly < 2 in the long term.

In Switzerland, wood chips at the gate have been traded for 3.0 Ct./kWh (at an exchange rate for 1 Euro = 1.65 CHF), while ligth fuel oil was available at 4.8 Ct./kWh. Thus the ratio between light fuel oil and wood chips is 1.6 in Switzerland, which makes wood energy economically less attractive than in Germany. The results for Switzerland are given in [1].

4 RESULTS

4.1 Investment cost

The specific investment cost for the heat production plant without precipitation exhibit the typical economy of scale as shown in Fig. 2. The same is true for the total cost for a plant with particle precipitation. However, ESP and fabric filters available on the market nowadays exhibit a stronger economy of scale than the boiler for applications smaller than 500 kW, since for this size range, the same parts are applied independently of the size. Consequently, the relative increase in investment costs sharply increases in this size range as is shown in Fig. 3. ESP exhibit higher investment cost than fabric filters, as can be seen from Fig. 4.

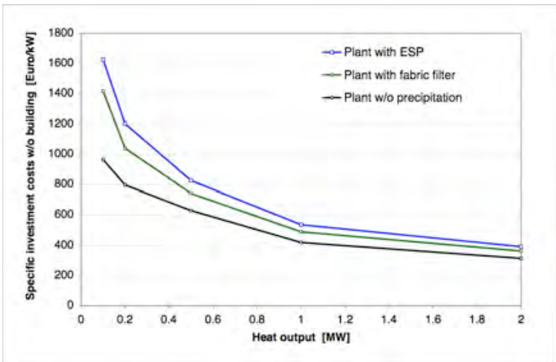

Figure 2: Specific investment cost for hardware (technique without building) with and without precipitation.

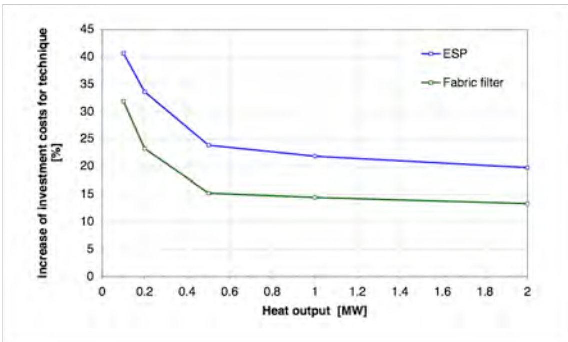

Figure 3: Increase of investment cost for hardware caused by an ESP or a fabric filter.

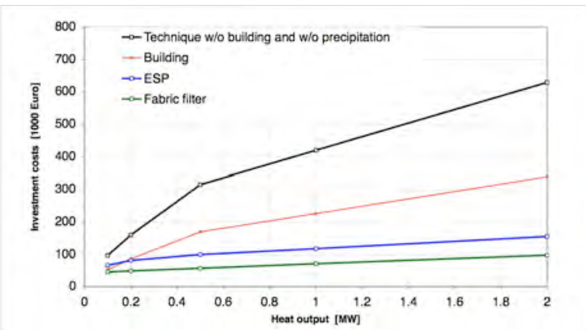

Figure 4: Investment cost for hardware (technique), building, ESP, and fabric filter as function of heat output.

4.2 Heat production cost

Fig. 5 and 6 show the additional cost caused by application of an ESP and a fabric filter respectively to an automatic biomass heating plant indicates in Cents per kWh produced heat. Due to the relatively high investment cost and fairly low operation cost, the total cost for the ESP are mainly caused by the capital cost. The fabric filter exhibits significantly higher operation cost and lower capital cost. Consequently, the total cost for ESP and fabric filter are fairly similar with slightly lower cost for the fabric filter for the investigated application. However, this comparison does not take into account different restrictions for the fuel and the plant operation for the two types of separators. Since fabric filters are not suited for fuels with high water content and need to meet stronger restrictions with respect to the burn out quality of the fly ash, ESP might also be economically more favourable in practice.

For an interest rate of 5% p.a. and wood fuel prices of 3 Ct./kWh, the application of particle removal systems influences the total heat production cost for new plants as shown in Table 1, Fig. 7 and Fig. 8 as follows:

- For 2 MW, the heat cost increase by 6%,
- for 1 MW by 7% to 8%,
- for 500 kW by 9% to 12%,
- for 200 kW by 17% to 21% and
- for 100 kW by 28% to 30%.

The lower values are valid for fabric filters, while the higher values refer to electrostatic precipitators without considering the above mentionned restrictions.

A comparison with the heat production cost from light fuel oil at 6 Ct./kWh, the size for equal heat cost for wood and light fuel oil is shifted from 0.7 MW to 0.9 MW. However, the comparison between wood and light fuel oil does not take into account the heat distribution cost in case of district heat or the higher specific heat production cost in case of residential heating instead of district heating and hence can be used as a qualitatively only.

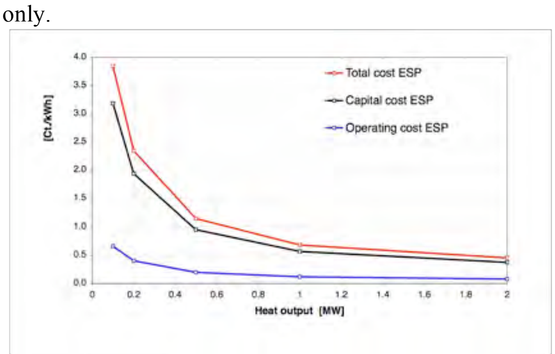

Figure 5: Increase of heat production cost by an ESP

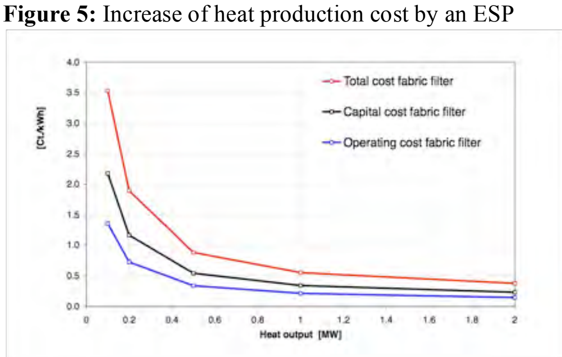

Figure 6: Increase of heat cost by a fabric filter.

Table 1 Heat production cost for light fuel oil and for wood with and without particle removal and cost increase resulting from particle precipitation in %. Fuel prices: 3 Ct./kWh for wood and 6 Ct./kWh für light fuel oil. Interest rate: 5% p.a..

Heat Output	Light fuel oil	Wood w/o precipitation	Wood with electrostatic precipitator		Wood with fabric filter	
	[Ct./kWh]	[Ct./kWh]	[Ct./kWh]	[%]	[Ct./kWh]	[%]
100 kW	11.0	12.5	16.3	30	16.0	28
200 kW	10.0	11.0	13.3	21	12.8	17
500 kW	9.1	9.5	10.6	12	10.3	9
1 MW	8.6	7.6	8.2	8	8.1	7
2 MW	8.2	6.6	7.1	6	7.0	6

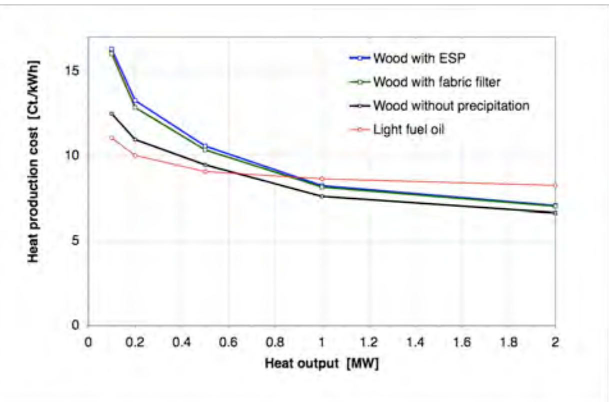

Figure 7: Total heat production cost for light fuel oil and for wood with and without particle removal. Fuel prices: 3 Ct./kWh for wood and 6 Ct./kWh für light fuel oil. Interest rate: 5% p.a..

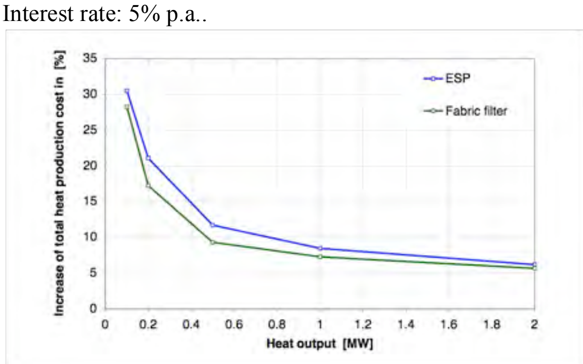

Figure 8: Percentage increase of the heat production cost

5 CONCLUSIONS

Particle removal technologies for automatic biomass combustion from 100 kW to 2 MW is in principal available. However, stronger quality requirements will be needed for the plant planning and plant operation to ensure highly efficient flue gas cleaning in practice and to avoid damages of the particle removal system or increased operation cost. On/off operation should be avoided and a high burnout quality of the fly ash needs to be guaranteed. Depending on the specific applications, electrostatic precipitators or fabric filters can be favourable, since ESP exhibit higher investment cost, while fabric filter lead to higher operation cost. For applications smaller than 500 kW, nowadays particle precipitation exhibit a much stronger economy of scale than the combustion plant. Hence developments of adopted particle removal systems for small and medium scale combustion plants is regarded as an interesting option.

6 LITERATURE

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