Particle Separator for Small Heating Appliances:Characterisation, Field Tests and Future Potential

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Abstract

In accord with efforts to deal with the problem of global warming, it is favourable to promote the use of renewable sources of energy. Generation of heat or energy by wood combustion takes advantage of a renewable and often locally available source of energy. Elevated levels of particle emissions, however, are one major disadvantage of wood combustion, especially of small wood fired heating systems. Current statistical data [1,2] leave no doubt that small wood fired furnaces are one of the major sources of particle emissions in Switzerland (fig. 1). It is well known that high concentrations of particulate matter in ambient air are responsible for a number of adverse health effects, mainly pulmonary diseases, but also cardio-vascular illnesses. Therefore the problem of particle emissions from small wood fired appliances is being discussed in several countries.

Based on the principle of electrostatic precipitation, a low cost system for the removal of particulate matter from the flue gas of small heating appliances has been developed. This presentation gives updated information on the current development. The separation characteristics were investigated with respect to flue gas velocity or particle number concentrations. The dependence of collection efficiency on particle diameter were determined. Collection efficiency was evaluated in terms of mass and number, using either a CPC or gravimetric measurements.

Additionally, particle emissions were characterised by transmission electron microscopy, and soot depositions within the particle separator were chemically analysed.

Modifications of the design have been considered. Prototypes were built and field tests have been carried out successfully. Based on these results and the statistical data mentioned above, the impact of this technology on the emission situation in Switzerland may be estimated.

Experimental Set-up

Figure 5 shows the experimental set-up that has been used for operation and testing of different designs of the particle separator. Basically, the set-up includes a heating appliance as the source of exhaust gas, the flue pipe where the actual set-up of electrostatic precipitator (ESP) was inserted, and measurement equipment for particle concentrations in the flue gas. Additionally, gaseous emissions of CO and CO_2, as well as flue gas temperature and pressure, have been monitored in order to characterise the combustion. The flue pipe offered several ports for flue gas sampling, before the ESP and at several distances behind it.

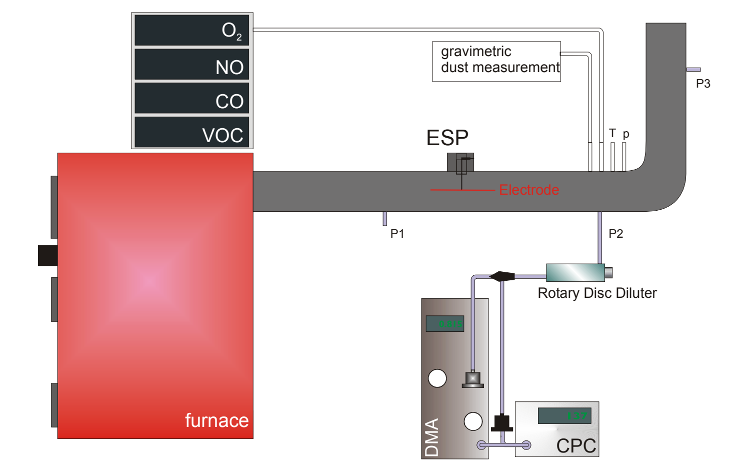

Figure 5: Experimental set-up

Laboratory experiments were carried out with several heating appliances: a pellet fired boiler and a pellet fired stove as well as a closed fireplace and stove that were fired by logs of wood. The heat output of these appliances ranged between 5 and 20 kW. Flue gas temperature was highest with the appliances fired by wood logs and could reach more than 400 °C. Flue gas velocity was generally below 1 m/s.

Different measurement techniques for the detection of particle concentrations have been used. Most of the measurements have been carried out with a condensation particle counter (CPC, TSI model 3022) which can detect small particles with diameters ranging from below 10 nm to about 3 µm. In order to observe the number size distribution (NSD) of the particles in the flue gas some measurements were performed with a scanning mobility particle sizer (SMPS) by adding an electrostatic classifier (TSI model 3071).

Furthermore, a diffusion charger (DC, Matter engineering model LQ1-DC), not shown in figure 5, was used. This device gives a signal that corresponds to the surface area of the emitted particles.

Sampling was carried out with the help of a rotary disc diluter which has been described by Hüglin et. al.[3]. The dilution unit was attached to the flue pipe via a stainless steel tube of about 10 cm length. This short tube was thermally isolated and the dilution unit was heated to temperatures of 120°C or higher in order to avoid problems related to cooling of the undiluted sample.

Gravimetric measurements were carried out in order to determine the collection efficiency in terms of particle mass concentration. In this case, the sampling was done without dilution and under isokinetic conditions. The sampling line was maintained at high temperatures and the filter assembly was heated to 150°C. The particulate matter was deposited on conditioned quartz filters which were weighed before and after exposure to a well defined amount of flue gas.

Collection efficiencies were calculated from the ratio of particle concentration with and without operation of the ESP: $\eta = 1 - C_{ESP\ on} / C_{ESP\ off}$.

Results

Figure 4 shows the current design of the ESP. The ionisation voltage is applied to the electrode that is held by a rod. The rod is inserted into the flue pipe through an insulator that is surrounded by a flow of clean air in order to prevent precipitation of dust or soot on the insulator surface.

The ionisation voltage produces a corona discharge in the vicinity of the electrode wire. This results in an electrical charging of particles in the flue gas. The charged particles are separated by electrostatic forces. The flue pipe is grounded and acts as a collector. With this design collection efficiencies of more than 80% were achieved by optimising the electrode design and the ionisation voltage.

Chemical analysis of the dust collected with the ESP on the wood log fired furnace showed a carbon content of more than 50% while it was below 40% with the pellet boiler. TEM analysis showed chain-like agglomerates for the wood log fired furnace and compact particles for the pellet boiler.

Laboratory experiments were used for the characterisation of different ESP designs. Current-voltage characterstics were measured for various electrode set-ups. Results of these measurements have been discussed elsewhere [4]. Furthermore, the dependency of the separation efficiency on parameters such as electrode dimensions (fig.2) or geometry, ionisation voltage and combustion conditions have been studied. Figure 3 shows the separation efficiency versus particle diameter for a single wire electrode of 300mm length. This result was obtained on the pellet boiler. There is a distinct minimum of the separation efficiency for particle diameters around 70 nm. This is related to a known feature of electrostatic precipitators and is attributed to the particle charging mechanisms involved. Diffusion charging is the dominating mechanism for particles of small diameter, while for larger particles, field charging plays the dominant role. Particle charging is less effective in the transition regime. Therefore, a reduced collection efficiency in that size range is to be expected.

Several tests have been carried out in order to study the behaviour during extended operating periods. Generally, a deterioration of separation efficiency has to be expected due to particle deposition on the electrode and the inner wall of the flue pipe resulting in a decrease of electric field strength. In a laboratory test, the ESP was operated with the pellet boiler continuously for a long period of time. After an initial deterioration of separation efficiency within the first day, the ESP worked stable for more than 10 days.

Several field tests showed reliable operation under real world conditions. The latest tests were done on a boiler and a closed fireplace, both fired with logs of wood. Even though the ESP set-up was not optimised and measurements were done after only one meter of flue pipe, initial separation efficiencies of nearly 60% was measured with both appliances. ESP operation was done for 138 hours with the boiler and over 50 hours with the fireplace.

Conclusions

A low cost particle separator has been characterised and tested under laboratory and real life conditions. For the situation in Switzerland it may be estimated that annual particle emissions from small wood fired appliances could be reduced by 5% per year if all new installations were equipped with such a system.

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Particle Separator for Small Wood Fired Furnaces

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INTRODUCTION

The work presented here aimed at reducing the concentration of particulate matter within the flue gas of small wood fired furnaces. With a size of typically 80 nm to 180 nm these particles are small enough to be relevant with respect to human health. Furthermore, removing the dust from the flue gas may be a prerequisite before considering other steps of after-treatment, e.g. catalytic reduction of NO_x emissions.

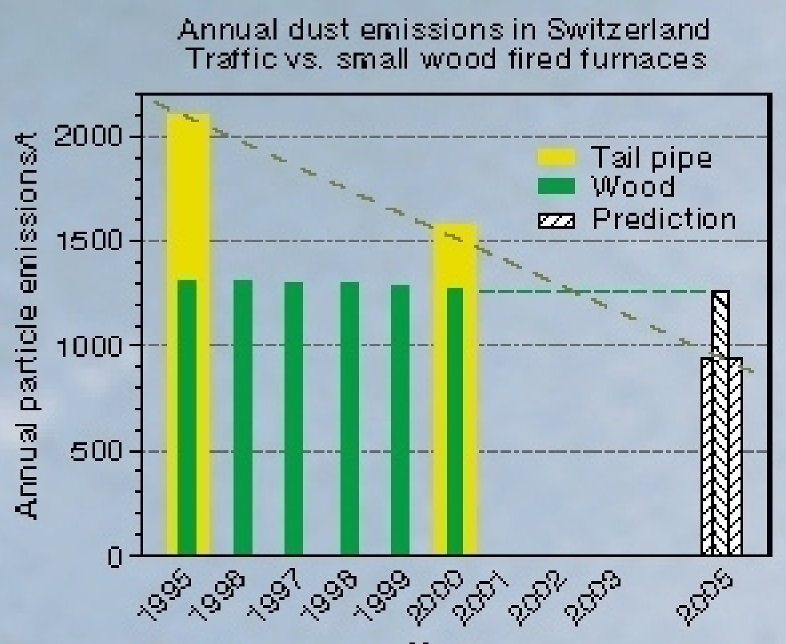

Fig.1

TECHNICAL DATA

Principle: electrostatic precipitation
Energy consumption: < 10 W
Efficiency: 70 % to 90 %
Electric feed through: Polyetheretherketone (PEEK)
Electrode: Tungsten wire ø 0.1 mm, length 240 mm
Secondary Voltage: approx. 15 kV
Air consumption: approx. 5 m³/h

RESULTS

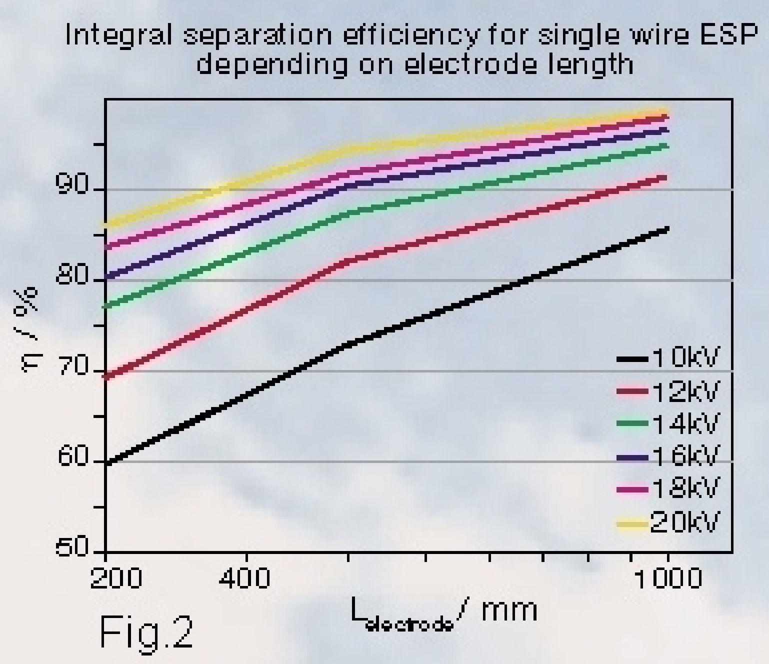

Fig.2

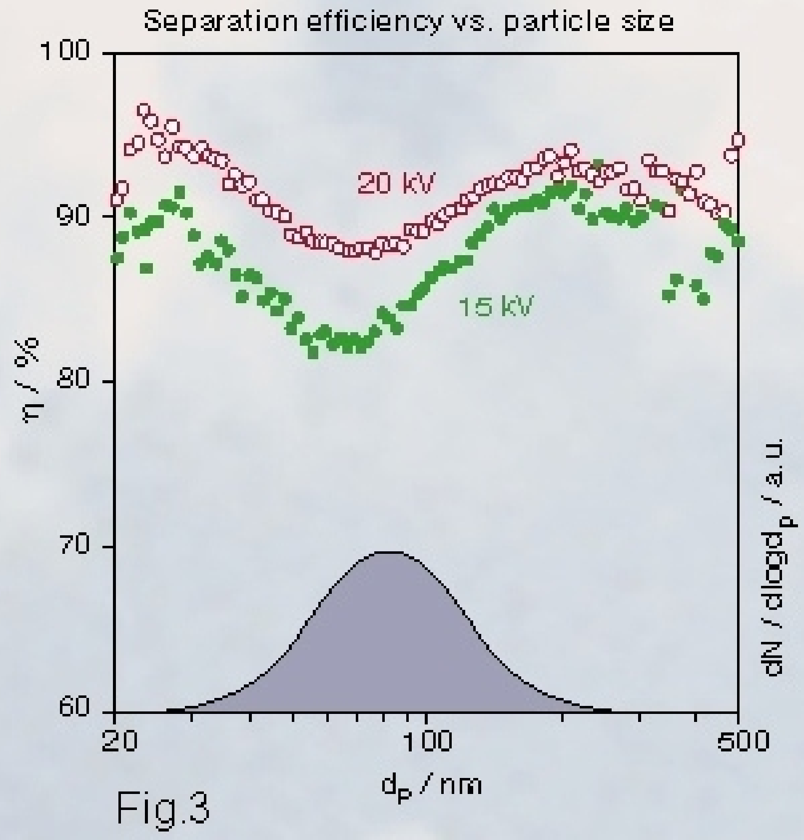

Fig.3

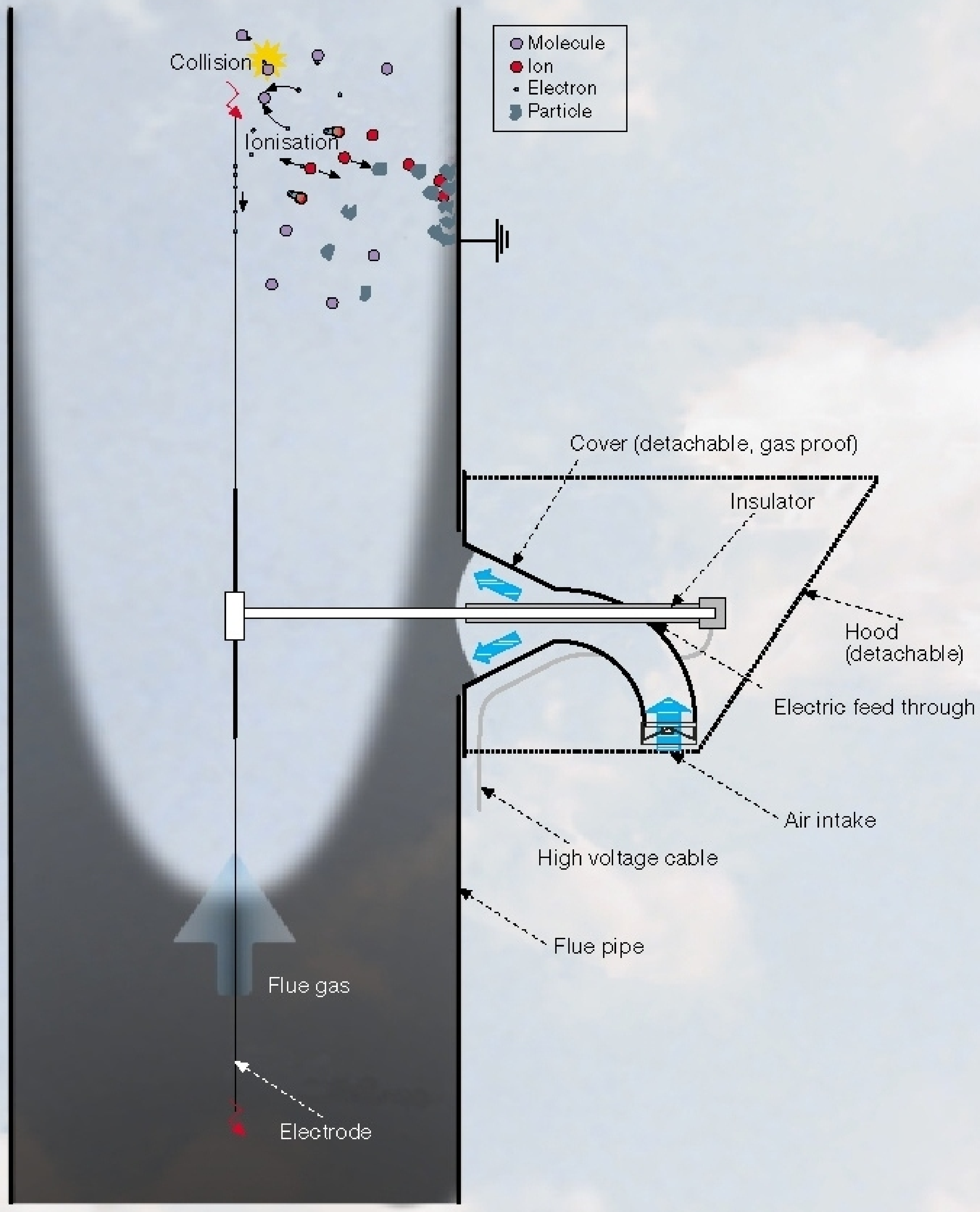

Fig.4

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