SOME IMPROVEMENTS ON THE PARTICLE BEAM GENERATOR

O. Kievit, J.C.M. Marijnissen, P.J.T. Verheijen, B. Scarlett.

Delft University of Technology, Faculty of Chemical
Engineering and Materials Science, Particle Technology
Group, P.O. Box 5054, 2600 GA Delft, The Netherlands.

ABSTRACT

The development of an on-line aerosol analysis instrument, making use of laser pyrolysis and T.O.F. mass spectroscopy, requires a particle beam generator to introduce the particles in the ionization chamber. The results of previous investigators and theoretical models have been used to improve the design of the beam system. The apparatus consists of a 0.5 mm nozzle and three vacuum chambers in series (0.8 mbar, 10^{-4} mbar and 4×10^{-6} mbar resp.), separated by skimmers. To minimize the solid angle and to limit the influence of particle size a capillary nozzle was selected. The distances between nozzle and skimmer and between both skimmers were optimized taking the formation of shock waves into account. The beam diameter and particle transmission efficiency were measured by examining depositions of 2.82 μm PSL spheres with an optical microscope. A slight contraction of the beam just behind the nozzle was observed, while about 4 % of the particles behind the nozzle reached the third vacuum chamber. To reduce the solid angle the use of sheath air is recommended.

KEYWORDS

Particle beam generator; aerosol analysis

INTRODUCTION

Most techniques to analyze aerosol particles include some kind of sampling step, which implies that on-line analysis is impossible. The Particle Technology Group of the Delft University of Technology is developing an apparatus in which both size and chemical composition of individual aerosol particles are determined on-line, in real-time (Marijnissen *et al.*, 1988). The first part of the instrument is the particle beam generator, also called aerosol beam generator. A review on particle beams was published by Dahneke (1978). A particle beam is produced when an aerosol is expanded through a nozzle into a vacuum. On leaving the nozzle most of the gas molecules are scattered by intermolecular collisions and removed by vacuum pumps. The particles continue to travel at straight lines due to their higher inertia. This results in a narrow beam of particles, virtually separated from the suspending gas. The design and testing of a prototype of the particle beam generator are reported in this paper.

The aim of future work is to pass the particle beam through a low energy laser beam. The light scattered by the individual particles will provide information on the size of the particle and also triggers a high energy YAG laser. The pulse from this laser vaporizes and partially ionizes the fragments of the incident particle, while a third, UV laser should complete the ionization. A time-of-flight mass spectrometer will be used to analyze the resulting ions.

DESIGN

When designing a particle beam generator for the described instrument several requirements have to be met:

- Application of a mass spectrometer implies that end pressures lower than 10^{-5} mbar need to be achieved.
- A small solid angle of the beam is desirable as it enables a narrower laser

- beam. Focusing the laser beam to a small spot size implies a high intensity which is useful when analyzing relatively involatile substances.
- Accurate alignment must be possible in order to get high particle transmission efficiencies.

Following these requirements an apparatus consisting of a capillary nozzle and three separately pumped vacuum chambers in series was constructed. A capillary nozzle was selected because it produces a less divergent beam as compared with a convergent nozzle, and the solid angle of the particle beam is less dependent on particle size. In the first chamber a two stage rotating vacuum pump was employed (end pressure 0.8 mbar), and in the second and third vacuum chamber diffusion type pumps were used (end pressures 10^{-4} and 4×10^{-6} mbar respectively). The device was made of glass in order to save time and to make direct observation possible. The nozzle fits in the apparatus by a ball-and-cup joint making aligning rather difficult. Therefore a nozzle diameter of 0.5 mm was selected, instead of 0.1 mm which was originally chosen. The nozzle was fabricated by drawing a 1 cm i.d. glass tube capillary and grinding the tip back to the desired diameter. The vacuum chambers are separated by two metal walls in which cylindrical holes were drilled. The diameter of the skimmer was 0.3 mm, based on work by Estes *et al.* (1983). The distance between nozzle and first skimmer, as well as between the first and second skimmer were optimised taking two effects into account. A large distance creates a relatively wide channel, thus ensuring a maximum pumping capacity. However, when the distance exceeds a certain threshold value, which is determined by the pressure ratio over the aperture, shock waves will be formed (Bier and Schmidt, 1961). Although the motion of the particles will hardly be influenced by these shock waves it is still advisable to avoid their occurrence because of possible deleterious effects. These considerations led to a nozzle to skimmer distance of 4 mm; the distance between the first and second skimmer was chosen to be 6 mm. Figure 1 shows the built beam generator.

Fig. 1. Photograph of the built beam generator.

EXPERIMENTS AND RESULTS

To investigate whether the designed beam generator is suitable to introduce aerosol particles into the ionization chamber of a mass spectrometer several experiments have been performed. Polystyrene latex (PSL) spheres of $2.82 \mu\text{m}$ diameter were dispersed with a Dautraban type nebulizer. The water was removed from the droplets by passing the flow through a silica gel diffusion dryer and a heated expansion chamber. The resulting aerosol was led directly to the nozzle tube. In the experiments to determine the beam diameter 3 ml of a 0.1 volume

percent PSL suspension was nebulized. The beam was sampled by placing a glass slide in the beam path perpendicular to the main axis, just behind the nozzle. To ensure adequate capture of the particles the slides were coated with a thin layer of vacuum grease, about $0.6\text{ }\mu\text{m}$ thick. The resulting depositions (of which Fig. 2 is an example) were studied with an optical microscope. As can be seen from Fig. 3, most particles (i.e. 98 %) are confined to the core of the deposition. Reentrainment probably caused some particles to deposit outside this area. The diameter of the deposition is defined as the width of the core, measured perpendicular to its maximum length. Solid angles were calculated using this diameter and under the assumption of radial symmetry. The results of the experiments are summarized in table 1.

Figure 2. Example of a particle deposition, produced at a distance of 1.8 mm from the nozzle.

Figure 3. Detail of the deposition shown on the left hand side.

Table 1. Deposition diameters measured at various distances from the nozzle; solid angles are calculated assuming a beam source located 2.8 mm behind the nozzle exit.

distance from nozzle (mm)	deposition diameter (mm)	solid angle (sr)
1.0	0.43	1.0×10^{-2}
1.8	0.48	8.6×10^{-3}
2.0	0.53	9.6×10^{-3}
3.0	0.62	9.0×10^{-3}

In order to calculate the efficiency at which particles are transmitted to the final vacuum chamber samples were taken directly behind the nozzle, in between the two skimmers and behind the second skimmer. The experiments have been carried out with the same setup as described above, although a much lower particle concentration was used (0.001 volume %). An image processor connected to an optical microscope was used to count the deposited particles. To get an indication of the reproducibility all three experiments were duplicated. Transmission efficiencies were also calculated based on a solid angle of 9.2×10^{-3} steradians (found by extrapolating the measurements) and on the assumption of an even distribution of particles across the beam cross section. The results are listed in table 2.

Table 2. Absolute and relative numbers of particles as a function of the sampling location. The calculated values are based on geometrical grounds, assuming a solid angle of 9.2×10^{-3} sr.

Sampling location	number of particles (-)	relative number of particles (%)	
		measured	calculated
behind nozzle	951	100 *	100
" "	912		
between skimmers	102	11	17
" "	105		
behind 2nd skimmer	39	4.0	4.7
" " "	36		

* The average number of particles from the first two experiments (i.e. 932) was designated the value of 100 %

DISCUSSION AND CONCLUSIONS

The diameters listed in table 1 seem to indicate a light constriction of the particle flow just behind the nozzle. Similar effects were found by Israel and Whang (1971) and are, probably, partly caused by the shape of the nozzle and partly by friction with the nozzle walls. The measured solid angle (9.2×10^{-3} sr) is relatively small as compared to values reported by Estes *et al.* (1983), who found 4×10^{-2} sr using $2.77 \mu\text{m}$ PSL spheres. A different nozzle geometry might be the cause of this smaller solid angle. The nozzle which was used in the present studies has a converging section due to the construction method. Dahneke and Cheng (1979) showed that surrounding the aerosol flow by a sheath of filtered air has a favourable effect on the solid angle of the particle beam. Reducing the aerosol flow to a core of 1 % of the total flow results in a smaller solid angle by a factor 100. Because of the smaller solid angle a higher particle transmission will be feasible. The measured efficiency of 4 % corresponds well with the calculated value, but it is too low to enable the analysis of dilute aerosols.

The experimental results show that the beam generator comes up to the requirements. Future work will focus on the design of a stainless steel version of the beam generator, with an improved alignment mechanism. The possibility to apply sheath air will be implemented.

ACKNOWLEDGEMENTS

The authors would like to thank the Dutch foundation for chemical research (SON) for sponsoring this project. Financial support was also provided by the foundation of technical sciences (STW).

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