A NOVEL PARTICLE TRAP FOR USE WITH THE GAS QUENCHING PROBE

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ABSTRACT

A novel particle trap impactor is developed for use with the gas quenching in fluidized bed combustion conditions. At room temperature, the impactor with a nozzle of 1mm in diameter, in combination with the orifice to jet diameter ratio at 1.5 and the jet-to-plate spacing ratio at 1.4 yielded sharp size cuts with a maximum collection efficiency of 92% and a cut-size ($d_{50}$) of 0.05µm.

Keywords: virtual impactor, PTI, volatile metals, gas quenching probe, fly ash.

1. INTRODUCTION

The gas quenching (GQ) probe technique has been further developed for measurement of gas species in fluidized bed combustion (FBC) conditions [1-4]. In a GQ probe sampling system a trapper solution is directly injected into the hot probe tip in order to absorb and quench the extracted hot gases. The trapper solution is then circulated back to the reservoir by a vacuum pump. The latest modification of the probe tip is presented in Fig. 1. A quartz tube holding the sintered quartz filter is added to eliminate the effects of the probe cooling water on the filter temperature and the potential losses of sampled species. The technique is however still subject to uncertainties potentially caused by the fly ashes accumulated on the filter during sampling [4]. It is therefore useful to separate the solid particulates from the extracted gas in such a manner that further contacts between the collected particles and the gas stream are minimized. This paper presents the results from the study into the design and test of a novel virtual impactor developed based on the Particle Trap Impactor (PTI) concept [5, 6], which can incorporate with the GQ probe for sampling of gas species in hot combustion gases in FBC conditions.

Fig. 1 The new modified GQ probe with detachable quartz module

2. EXPERIMENTAL

2.1. Description of the impactor incorporated with the GQ probe.

General features of the quenching and trap (QT) impactor used in this study are shown in Fig.2. The impactor, made of stainless steel, consists of three major components: an impactor...
house, a flat separating plate and an end cap. A sintered quartz filter can be added in the impactor. The impactor house is cylindrically shaped and built with a round nozzle and an impactor cavity. An orifice aligned with the nozzle is formed chiefly by a truncated hole located on the edge of the separating plate and partly by the side wall of the impactor house as can be seen in the figure.

The choices of the nozzle diameter ($D = 1\text{mm}$), the orifice diameter ($D_o = 1.4, 1.5$ and $1.6$), the jet-to-plate spacing ($S = 0.5, 1.0, 1.5$ and $2.0$), the cavity depth ($S_c = 20\text{mm}$) and the geometry of cavity are connected to the studies on the PTI [6] and virtual impactors [7]. On operation, the nozzle and the orifice are on the top side of the impactor as shown in the figure.

2.2. Experimental setup

![Fig. 3 Schematic diagram of the experimental setup](image-url)
The experimental setup is schematically shown in Fig. 3. The impactor assembly consists of an impactor holder, the impactor and a sealed transparent plastic box. The impactor is mounted to the holder and inserted into the plastic box, which is connected to an aerosol source. The impactor holder is connected to a particle differential mobility analyzer (DMA). Aerosol particulates are produced from KCl aqueous solution by means of the TSI Constant Output Atomizer Model 3075. Two vacuum pumps were used. The smaller is located after the DMA in order to extract a small portion (1 L/min) of the total aerosol flow passing the impactor assembly (11 L/min), through the DMA. The bigger is located between the impactor assembly and the DMA, from which a gas flow rate of 10 L/min was produced.

3. RESULTS AND DISCUSSION

3.1. Optimization of the Do/D ratio

For the chosen parameters, the value of Do/D, the orifice to jet diameter ratio was 1.4, 1.5 and 1.6, respectively. The ratio of jet-to-plate spacing to the jet diameter, S/D, was set at 1.0 for experiments to find the optimal Do/D, among the three values. The collection efficiency of the impactor, defined as the percentage of the collected particle number over the total number of the particle enter the impactor, is computed and presented in Fig. 4. As can be seen in the figure, the collection efficiency of the impactor slightly decreased when the ratio Do/D was increased. The maximum collection efficiency in each case is about 92%. The three data series are quite similar with a similar cut-size (d50) of about 50 nm. The Do/D value of 1.6 yielded lowest collection efficiency and the data was a little bit scattered compared to the other two. Even though, the best collection efficiency was obtained from the Do/D value of 1.4. This ratio was used in subsequent experiments.

![Collection efficiency graph](image)

Fig. 4  Effect of the orifice to jet diameter ratio on the impactor efficiency.

3.2. Optimization of the S/D ratio

Fig. 5 presents the results of experiments which were performed to determine the optimal value of the ratio of jet-to-plate spacing to the jet diameter, S/D, while the Do/D ratio was held constant at 1.4. The collection efficiency of the impactor slightly increased as the S/D ratio was increased from 0.5 to 1.0 and 1.5, but started to drop when the ratio was increased further to 2.0. The data from the last experiment was scattered especially for the fraction of courser
particles. The maximum collection efficiencies in the first three cases were quite similar and about 92%, but the data from the experiment for the S/D ratio of 1.5 yielded a much sharper size-cut and a smaller d₅₀ value as well as, about 40nm. It suggests that, in combination with the chosen parameters, the ratio of jet-to-plate spacing to the jet diameter at 1.5 is optimal.

![Graph showing collection efficiency vs particle diameter for different S/D ratios.](image)

*Figure 5. Effect of the jet-to-plate spacing to jet diameter ratio on the impactor efficiency.*

### 3.3. Comparison with sintered quartz filter

In these experiments, a sintered quartz filter used by Tran et al. [4] was added in the QT impactor as shown in Fig. 2. The filter has a diameter of 20mm, a thickness of 3mm and a porosity of 20-40µm. The collection efficiency of the impactor with the filter was compared with the impactor without filter in the same conditions. The jet-to-plate spacing to the jet diameter ratio was 1.5. The results of the experiments presented in Fig. 6 show that the impactor did not collect the particles with a diameter smaller than 20nm, while the impactor with the filter did and the overall collection efficiency increased as the particle diameter decreased from 20nm. However, no apparent advantage to the filter addition was observed in collection of the particles with a diameter larger than 20nm.

![Graph showing collection efficiency of the impactor with and without filter.](image)

*Figure 6. Collection efficiency of the impactor without and with the filter.*

The increase in the collection efficiency of the impactor with the filter as the particle diameter decreased can be explained by the filtration theory [7]. For the submicron particles with a
diameter smaller than 100nm, according to this theory, the filter efficiency is governed by diffusion regime and, therefore, increases with as the particle diameter decreases.

4. Summary and conclusions

The QT impactor designed based on the PTI concept has been constructed and tested at room temperature. With the nozzle diameter of 1 mm in combination with the ratio of D_o/D at 1.4 and S/D at 1.5 the impactor yielded very sharp size cuts with a maximum collection efficiency of 92% and a d_{50} of 50nm. Compared with the sintered filter quartz, the impactor collection efficiency is very similar. Only small difference comes from the particles smaller than 20nm in diameter. This difference is however believed to be negligible since the particles smaller than 20nm account for a very small mass portion of the total mass of fly ashes in FBC boilers [8, 9]. The results indicate that the QT impactor can be useful in combination with the GQ probe for measurement of the volatile metal species of hot flue gas, both in gas and solid phases. Further tests with the GQ probe in forms of field measurement are needed.

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REFERENCE


Conference references: 1 and 9; Book references: 7, Journals: the rest.