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Influence of electric charges on the washout efficiency of atmospheric aerosols by raindrops

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ABSTRACT

Latest investigation completed at IRSN has revealed the substantial influence of flow morphology around the drops, in atmospheric washout of fine aerosol particles by precipitations, in complement to classical mechanisms. Moreover, several authors have claimed that rain drops during stormy rainfall carry millions of elementary electric charges which could increase by couple orders of magnitude the collection efficiency as a consequence of electrostatic forces. In non-thunderstorm clouds, model calculations indicate that the image charge effect resulting from aerosol charging can significantly affect their washout, even by uncharged raindrops.

However, investigations on the influence of electric charges on aerosol washout (or collection efficiency) by simulated raindrops are very fragmented and contradictory.

In this article, we report results of self-charged water drop generated by hypodermic needle over charge values comparable to those reported in the literature during stormy rainfall. We also controllably charged aerosol particles by corona discharge and evaluate how it affects their collection efficiency. Electric charges on drops and aerosols are precisely monitored by high resolution electrometers. Our preliminary results tend to accredit the impact of electric charges in collection efficiency.

1. Introduction

In case of a Fukushima-like nuclear severe accident, soils contamination will likely result from the washout of radionuclides by precipitations. This was confirmed by measurements of soils cesium contamination in the first days following the Fukushima accident which have shown higher activities downwind of the radioactive plumes after snow and rainfall events (Katsumi, 2012). The monitoring of cesium deposits is particularly important because contamination measurements of Cs-137 after the Chernobyl accident revealed that this radionuclide may remain adsorbed on the surface of the soils for decades making their use impossible (Giani and Helmers, 1997). In France, given the pluviometry, the probability of occurrence of rainfall coupled to a nuclear accident is real. To better protect people against high exposure to radionuclides, it is essential to understand the interactions between the fine aerosol particles suspended in the atmosphere and precipitations that determine their removal.

The washout of aerosol particles by precipitations has been studied for several decades, both in laboratory under simulated stormy conditions (Beard, 1974; Lai et al., 1978; Quérel et al., 2014), and by modeling (Grover et al., 1977; Wang et al., 1978; Carstens and Martin, 1982). To add its contribution to the topic, IRSN has developed an experimental facility (BERGAME "French acronym for facility to study aerosol scavenging and measure collection efficiency") to investigate in laboratory the washout mechanism by drops simulating rainfalls. However, to date there are several discrepancies on the estimation of the aerosol collection efficiency between laboratory studies and model outputs. Part of these discrepancies could be related to an underestimation of electrostatic forces contribution in the calculation of aerosols collection efficiency. Indeed, it is well recognized that raindrops naturally and systematically carry electric charges through various mechanisms in the atmosphere (Williams, 2009), which could leads to strong electrostatic interactions. For electrically charged drops, Barlow and Latham (1983) in their laboratory experiments on sub-micron aerosols exhibit significant increase in the washout efficiency. More recently, Tinsley et al. (2000) model calculations in the same size range pointed out that image charge effect due to aerosol particles charging can significantly affect their collision with raindrops compared to uncharged particles, even if the particles and drops carry electric charges of same polarity. Indeed, radioactive aerosols positively self-charge because of emission of electrons during decay (Gensdarmes et al., 2001). Moreover, the radioactivity (η) measured on spherical Cs-137 bearing particles

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Nomenclature

E	collection efficiency	τ	particle characteristic relaxation time (s)
v_t	drop terminal velocity (m s^{-1})	μ_w	dynamic viscosity of water (kg m^{-1} s^{-1})
Re	Reynolds number	μ_a	dynamic viscosity of air (kg m^{-1} s^{-1})
S	particle Stokes number	ρ_a	air density (kg m^{-3})
S^*	particle critical Stokes number	ρ_w	water density (kg m^{-3})
d_P	particle diameter (m)	C_c	Cunningham correction factor
d_D	drop diameter (m)	λ	mean free path of air molecules (m)

of 2 μm diameter, 3 days after the Fukushima accident, a hundred kilometers from the emission area of $\sim 10^{-2} < \eta < 10$ Bq/m^3 (Adachi et al., 2013), is equivalent to a number of elementary charges (j) on the particles of $\sim 10^{-3} < j < 10^3$ according to Clement and Harrison model calculations (Clement and Harrison, 1991). Non-radioactive aerosol get electric charges by adsorption of atmospheric ions resulting from cosmic radiations (Fuchs, 1963).

The influence of electric charges on both raindrops and aerosol particles on washout efficiency is still an unsolved problem. And, as long as the subject is not treated comprehensively, it might be unrealistic to properly model aerosol washout by rain, even by empiric methods.

We are currently investigating the influence of electric charges on both water drops simulating rainfalls and aerosol particles of micron size range on the washout efficiency in BERGAME.

This article focuses on our first results on the evolution of washout efficiency when aerosol particles are controllably charged by a bipolar corona charger. The initial charge state of the drops is monitored with a Faraday pail but it is not intentionally charged. Other experiments on the influence of drops charge on washout efficient for neutralized aerosols are presently explored but the outcomes are not within the scope of this paper.

2. Washout investigation facility

BERGAME has been designed specifically to assess the washout efficiency of aerosol particles by raindrops. It consists of a shaft of 10 m high with a square cross section of 0.45 × 0.45 m^2 through which millimeter drops free fall toward their terminal velocity before entering in a seeded aerosol atmosphere, and collected beneath.

Drops are generated at ambient temperature from a hypodermic needle filled with water in a constant level that shapes them uniformly. Drop diameter and velocity are measured inside the aerosol chamber by shadow imaging and image velocimetry (PIV) respectively. A drop of 2.5 ± 0.1 mm reaches the aerosol chamber every 10 ms at it terminal velocity of 7.3 ± 1 m/s. The aerosol chamber is a stainless steel rectangular cube of 1 m height with a cross section of 0.8 × 0.8 m^2. It is equipped with two apertures

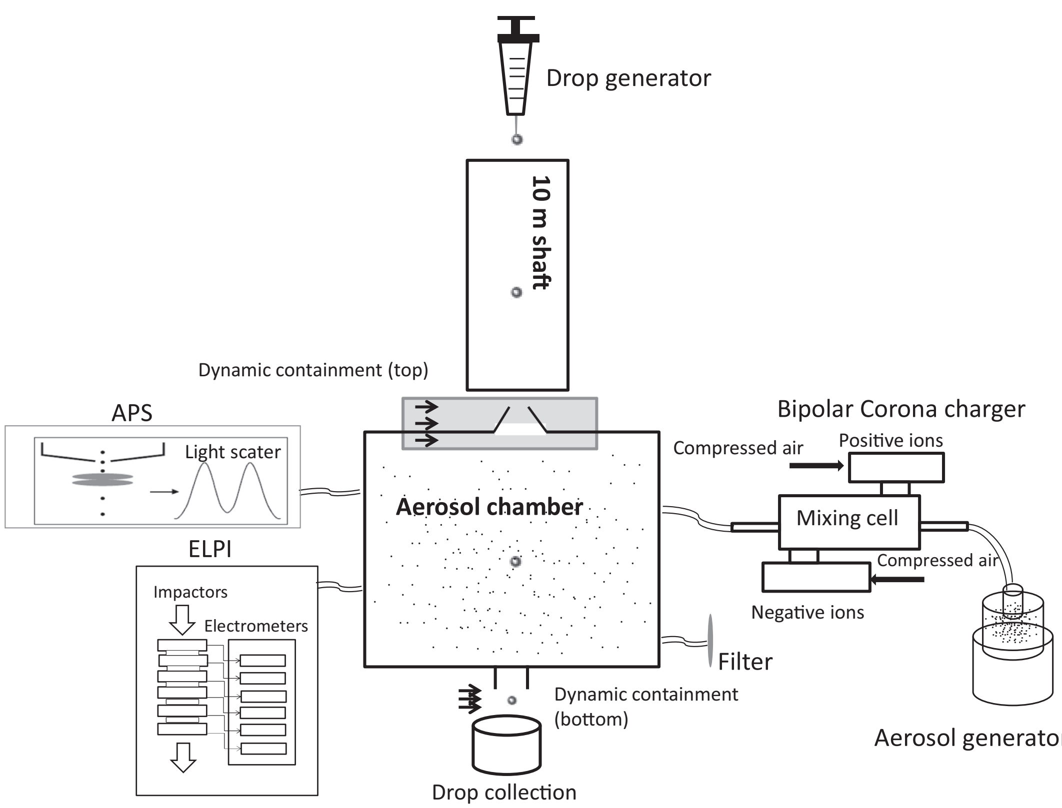

Fig. 1. BERGAME experimental set up.