Journal of Aerosol Science 52 (2012) 98–108

Contents lists available at SciVerse ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci

An experimental study on the charging of non-radioactive aerosols with and without the presence of gamma radiation

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ARTICLE INFO

Article history:
Received 2 September 2011
Received in revised form
14 May 2012
Accepted 14 May 2012
Available online 1 June 2012

Keywords:
Aerosol charging
Gamma radiation
Aerosols generation
Core disruptive accident

ABSTRACT

Electrical charging of non-radioactive aerosols was studied. The mean charge acquired by the poly-dispersed and mono-dispersed aerosols is determined for the two cases, viz. with and without the presence of additional ion pairs generated by gamma radiation. The results are separated accordingly by determining average charge acquired by the aerosols in three generation route (atomization, combustion and vaporization & condensation) and compared with the charge acquired in the presence of gamma radiation field. Using theoretical formulation developed by Clement and Harrison, the mean charge acquired by the aerosols (mono-dispersed) for a given concentration of both aerosols and ion pairs were calculated and compared with that of experimental results. The study is extended to determine the mean charge obtained for the distribution of DOP aerosols (poly-dispersed), by varying number concentration of aerosols and number concentration of ionpairs. It is found that the mean charge acquired by the aerosols increases with increase of ion pair concentration for a given concentration of aerosols.

1. Introduction

One of the important studies in the safety analysis of sodium cooled fast reactor, is the characteristics and the behavior of aerosols suspended in the Reactor Containment Building (RCB), in particular during Core Disruptive Accident (CDA)[1] condition (Abbey & Silberberg, 1979). The time evolution of the quantity of suspended mass concentration of aerosols and their leak rate from RCB determine the environmental source term (Indira et al., 2006). The environmental source term is the quantity of radioactive materials released, that would be carried away in the down wind direction and get deposited over the ground, resulting ground contamination as well as the health hazards to the public living at the site boundary (Baskaran et al., 2007). Hence, in order to undertake the aerosol studies, an Aerosol Test Facility (ATF) has been constructed

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[1] During the normal operation of the sodium cooled fast reactor, there will be a balance between the heat generated in the core and the heat removed by the coolant. When the heat balance is lost due to initiating events such as, loss of coolant, loss of coolant flow, transient over power, and subsequent failure in the removal of such heat, may lead to the following core disruptive events in the reactor core viz., (i) Core disassembly, (ii) Core meltdown, and (iii) Both Core meltdown and Core disassembly. The after effects of core disruptive events are called Core Disruptive Accident (CDA). But to prevent the initiating events, there are two safety system provided in the reactors: (a) the shutdown system and (b) the decay heat removal system. Thus in case of the occurrence of initiating events, a CDA can be expected only with the failure of safety systems. In the unlikely event of CDA in sodium cooled fast reactor, the sodium slug may impact the reactor top plug. This provides a pathway for the escape of radioactive material (fission products and fuel material) and sodium into the RCB volume. Fuel and fission product vapors will condense and form aerosols. In addition, sodium burning will give rise to various compounds of sodium aerosols.

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http://dx.doi.org/10.1016/j.jaerosci.2012.05.004

Nomenclature

N	number concentration of aerosols/cm^3
n	number concentration of ionpairs/cm^3 (n_+ and n_- are positive and negative ions) $\bar{n}-(n_+ + n_-)/2$
a	particle radius (cm)
d	particle diameter (cm)
j	magnitude of charge (number) (j_1—number of charges for a particle with radius a_1)
$\bar{J}$	average number of charges based on theoretical estimation
$\langle j \rangle$	mean change over a distribution
e	elementary charge value
ε_0	permittivity of free space
ε_r	relative permittivity
k	Boltzman constant
T	temperature (K)
μ	mobility of ions (μ_+ and μ_- mobilities of positive and negative ions)
Z	total number of particles $Z = \sum_{p=1\ to\ 12}^{p+1} N_p$ where p–collection stages 1–12.
φ	$e^2/8\pi\varepsilon_0 akT$
α	ion recombination coefficient 1.6×10^{-6} cm^3/s
β	ion attachment coefficient 1.4×10^{-6} cm^3/s
q	ion pair production rate (ionpairs/cm^3/s)

in our division and various characteristics of aerosols and their behavior have been studied. The study includes physical and chemical characteristics of sodium aerosols, behavior of aerosols in the presence of gamma radiation field and the behavior of mixed aerosols in a confined environment.

In this context, one of the key studies is the behavior of sodium aerosols under the gamma radiation field. It is noted that in the event of CDA, the entire RCB volume is occupied by the bi-polar ions that are generated due to the prevailing gamma radiation. When the sodium and other fission product aerosols are made to suspend in the volume of RCB, i.e. in the sea of bi-polar ions, the aerosols acquire charges. When these aerosols undergo coagulation with the acquired charges, the Brownian coagulation is found to be enhanced. Experimental results at ATF showed that the coagulation enhancement of 5–8 times for the mono-dispersed sodium aerosols in a confined environment at the dose rate of the order of few mGy/h (Subramanian et al., 2008). It is further reported that, by using general theory derived by Zebel (1966) and by Williams and Loyalka (1991),[2] in order to get the coagulation enhancement factor of 5 times the modest charging required by the aerosol particle is about 8 charges for the particles of radius 0.5 μm in a given ion concentration (radiation field of 4 mGy/h) (Subramanian et al., 2011). Thus it is understandable that the electrical forces caused by the Coulomb interaction between the charged aerosol particles are responsible for the enhanced coagulation. Hence it is customary to get the number of elementary charges acquired by the aerosols in the presence of given concentration of bi-polar ions. Thus the study has been extended to determine the charge-size distribution of aerosols for a given concentration of bi-polar ions and aerosols number concentration.

Before getting into the measurement of charges on the aerosols, it is imperative to consider the charges acquired by the aerosols during generation process besides during the presence of gamma radiation. Understanding the mechanism of aerosol charging during generation of aerosols is important in aerosol science, particularly to understand the aerosol process like particle deposition, electrical migration, sampling & transport and coagulation, etc. Hence our experimental study includes determination of charging of aerosols in three generation process viz. (i) combustion route (generating sodium compound aerosols), (ii) vaporization and condensation route (SrO_2 aerosols) and (iii) atomization route (polystyrene latex and DOP aerosols) and by comparing the average charge acquired by a particular sized aerosols generated in all the three process.

Interaction between energetic radioactive particles and molecules in the air results in the formation of ions. The interaction may be direct collision or by electrical interactions. The direct collision results in ionization which produces showers of ions whereas gamma radiation interacts mainly in the form of photoelectric effect, Compton scattering and pair production. The principle positive ion formed in the atmosphere is the hydronium ion $H^+(H_2O)_n$ where n is between one and ten. The negative ions are formed by the attachment of low energy electron to an oxygen molecule (O_2^-). Then they attach to produce hydrate $O_2^-(H_2O)_n$. There also exists formation of secondary chemical species ions like $NO^+(H_2O)_n$ or $NO^-(H_2O)_n$. Increasing levels of hydration increase the mass of an ion which correspondingly reduces its mobility. It is also understood that ion mass and its mobility has the influence in charging of aerosols. The background ion concentration is expected to be between 500 and 700 cm^{-3}, while with gamma source it is calculated to be 10^6–10^8 cm^{-3} (in our experimental condition). The mobilities of the positive and negative ions are considered to be 1.14 cm^2 V^{-1} s^{-1} and 1.25 cm^2 V^{-1} s^{-1} respectively. Then, charges acquired by the aerosol in the presence of gamma radiation are due to the interaction of ions and aerosols, by exposing the aerosols with a given concentration of bi-polar ions. At this juncture, the aerosol charging is considered to be a steady state charging (Clement & Harrison, 1992). A collision between the aerosol and a small ion will cause the aerosol's charge to increase or decrease by one charge unit depending upon the polarity of

[2] The coagulation enhancement factor $f = K'/K$ where K' and K are coagulation kernels for the charged and uncharged particles respectively. The coagulation enhancement factor particles in the presence of bi-polar ions concentration is calculated by using formula: The coagulation enhancement factor $f(Y) = Y/\exp(Y)-1$where $Y = j_1 e j_2 e/4\pi\varepsilon_0 kT(a_1 + a_2)$.