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Computational fluid dynamics simulation of a rectangular slit real impactor's performance

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Abstract

The performance of a rectangular slit impactor was simulated using the three-dimensional computational fluid dynamics (CFDs) computer program CFX-4.4. The characteristic impactor efficiency curve obtained from the simulations was compared with the experimental results. A sensitivity study was carried out to investigate the effect of (a) the total number of particles used for the simulation, (b) gravity in the simulation, and (c) ultra-Stokesian drag on the efficiency curve predictions. The simulation predictions for each of the above cases are presented along with the experimental data and the results are discussed. Results obtained from the simulation are seen to be in good agreement with experimental data, validating the particle transport model implemented in CFX-4.4, for laminar flow conditions.

1. Introduction

Impactors (Hinds, 1999; Fuchs, 1964) are the most primitive of the devices that have been extensively used for the collection and measurement of aerosol particles. Impactors have also been used for classifying particles based on size (aerodynamic diameter); they work on the principle of inertial impaction. They have been, and are being used in a wide variety of disciplines from occupational health to environmental assessment. It would not be improper if it were mentioned that, as of this date, inertial impaction is more thoroughly studied than any other aerosol separation process.

In particular, in the nuclear field, inertial impactors are widely used in devices employed to monitor the concentration of radioactive aerosol in various facilities ranging from nuclear fuel fabrication facilities to nuclear waste management and spent-fuel reprocessing facilities. Moreover, continuous air monitors (CAMs)

Abbreviations: NPP, nuclear power plants; CAM, continuous air monitor; CFD, computational fluid dynamics; ATL, Aerosol Technology Laboratory; TAMU, Texas A&M University; HDS, hybrid differencing scheme; CDS, central differencing scheme; AD, aerodynamic diameter; EXP, experiment; ICCG, conjugate gradient solver

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Nomenclature

C_c	Cunningham slip correction factor
d_p	particle diameter
F_B	Buoyancy force
F_D	drag force
F_L	lift force
F_{PG}	pressure gradient force
F_{VM}	virtual mass force
m_p	particle mass
n_{in}	total number of particles specified at the inlet patch
n_w	number of particles deposited on the wall
Re	fluid Reynolds number
Re_p	particle Reynolds number
S	stopping distance
Stk	Stokes number
T	throat length
u, v, w	velocity components
V	fluid velocity
V_0	average velocity at the throat
V_p	particle velocity
V_R	relative velocity = $V - V_p$
W	throat width (nozzle diameter)

Greek letters

η	collection efficiency on the wall
λ	mean free path of the fluid
μ	dynamic viscosity of the fluid
ν	kinematic viscosity of the fluid
ρ	fluid density
ρ_p	particle density

that monitor vent exhausts from various regions of the nuclear power plant (NPP) utilize inertial impactors as the particulate aerosol detecting device. From a more general viewpoint, there are several other applications involving the transport of radioactive aerosols under laminar flow conditions. A typical example in this regard is the transport of a radioactive aerosol inhaled by personnel through the human system, and a more novel application is the delivery of aerosols using nebulizers for asthma therapy.

Inertial impactors can be classified into two types, namely, the real and the virtual impactor. The real impactor removes particles by impaction on a coated solid surface, whereas, the virtual impactor redirects the particles into two different streams based on their size. Based on the geometry of the nozzle section, the real impactor can further be classified as a slit (rectangular nozzle) impactor and axy-symmetric (round nozzle) impactor.

In the past, a lot of work has been devoted to studying the performance of inertial impactors, theoretically and experimentally. Marple and Liu (1974) were the first to undertake the theoretical study of the design and development of inertial impactors. They numerically obtained the characteristic impactor efficiency curves for both rectangular-and-round-jet real impactor with different characteristic geometrical configurations. Subsequently, Rader and Marple (1985) refined the previous study by using a finer grid and including appropriate models for ultra-Stokesian drag and interception, for the particulate phase. The results of the above study are treated as a standard in handbooks on aerosol measurement (Baron and Willeke, 2001).

More numerical studies on the performance of round-nozzle real impactors are available in literature. Jurcik and Wang (1995) used the FIDAP code (Fluent USA Inc., 2002) to study the performance of a flat-plate orifice round nozzle impactor and compared their results against experimental data and the numerical results of Rader and Marple (1985) for an angled nozzle configuration. More recently, Collazo et al. (2002) reported the design, calibration, and experimental validation of round-nozzle single-and-multi-stage impactors for the size measurement of man-made organic fibers. They reported using the computational fluid dynamics (CFD) code FLUENT (Fluent USA Inc., 2002) in their design stage. Huang and Tsai (2002) performed a numerical study in which the influence of impaction plate diameter and particle density on the collection efficiency of a round-nozzle inertial impactor was investigated.

A study was performed to assess the capability of the CFD code CFX-4.4 (ANSYS Canada Ltd., 2003) for modeling aerosol transport. In this study, the performance of a slit (rectangular) nozzle real impactor was numerically simulated using the CFD code CFX-4.4. The sensitivity of obtained results was analyzed with respect to the total number of particles used in the simulation. The effect of including the buoyancy force (gravity) in the simulations was also explored.