Journal of Aerosol Science 100 (2016) 73–87

Contents lists available at ScienceDirect

Journal of Aerosol Science

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

Experimental investigation of a turbulent particle-laden flow inside a cubical differentially heated cavity

J. Kalilainen [a,*], P. Rantanen [b], T. Lind [a], A. Auvinen [b], A. Dehbi [a]

[a] Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland
[b] VTT Technical Research Centre of Finland, P.O. Box 1000, BI7, FI02044 VTT Espoo, Finland

ARTICLE INFO

Article history:
Received 8 July 2015
Accepted 1 June 2016
Available online 8 June 2016

Keywords:
Deposition
Enclosure
Natural convection
Experiment

ABSTRACT

The depletion dynamics of 1 μm and 2.5 μm SiO_2 aerosol particles inside a differentially heated cavity was investigated experimentally using a cubical DIANA cavity with two opposing isothermal vertical walls and adiabatic top, bottom, front and back walls. The top, front and back walls are made of glass to allow optical access for different laser devices. The cavity atmosphere consisted of air and the isothermal wall temperatures were set to approximately 330.6 K and 291.3 K. The Rayleigh number of the flow was approximately 10^9, indicating turbulent conditions. The particle deposition rates were investigated by measuring the intensity of the reflected light from the particles and by using tapered element oscillating microbalance to measure the change in airborne particle mass concentration. The flow field in the mid-plane joining the isothermal walls was investigated using particle image velocimetry. Gas temperature measurements were collected using K-type thermocouple. The flow field and temperature measurements described turbulent flow near the isothermal and horizontal walls encircling the cavity stagnant core region with a stratified temperature distribution. Measurements indicated that the particle concentration at any time was approximately uniform throughout the cavity atmosphere. The measured depletion rate were compared to the theoretical "stirred settling" model predictions. While the decay rate of 2.5 μm particles was close to that predicted by the theoretical "stirred settling" model, it was found that 1 μm particles deposited two times faster than the theory predicted.

1. Introduction

The particle depletion in an enclosure has been widely studied and has application in many fields, for example, in indoor air ventilation and in nuclear safety. In the nuclear safety field, the deposition of radioactive aerosol particles in the containment building has potential to mitigate the possible source term from the power plant in severe accident conditions, hence limiting the release of radioactivity to the environment. In this work, the effect of turbulent natural convection inside an air filled enclosure on the depletion rates of micron size silica particles was experimentally investigated.

A large part of earlier experiments on particle deposition onto enclosure surfaces involves different shaped cavities with varying flow conditions. Liu (2009) provided recently an extensive review on the experiments of particle deposition in an enclosure. In their studies with cavities under forced convective flow produced using a fan or an external injector, Cheng (1997), Nomura, Hopke, Fitzgerald, and Mesbah (1997), Okuyama, Kousaka, Yamamoto, and Hosokawa (1986) and Shimada,

* Corresponding author.
E-mail address: jarmo.kalilainen@psi.ch (J. Kalilainen).

http://dx.doi.org/10.1016/j.jaerosci.2016.06.001
0021-8502/

Okuyama, and Kousaka (1989) showed that the deposition rate on cavity surfaces was dependent on the particle size, as well as other aspects such as fan rotation speed or injection flow rate into cavity. With increased injection flow rate or fan rotation speed, the deposition rate was seen to increase. When the cavity flow is not generated by external means, the fluid movement is caused by natural convection induced by temperature differences ΔT between different cavity boundaries. Chen, Yeh, and Cheng (1992) conducted experiments using a chamber with temperature difference between the top and bottom walls. They reported that the increase in ΔT also increased the deposition rates of particles with diameters smaller than 1 μm.

Thatcher, Fairchild, and Nazaroff (1996) experimentally studied removal of particles with diameters in the range of 0.1–2.5 μm inside an air-filled cubical cavity (1.2 m on each side) where natural convection was induced by temperature differences between the walls. The front and back walls were insulated, and while the bottom and right vertical cavity walls were heated, the top and left vertical walls were cooled, resulting in a counter-clockwise convective motion. The temperature difference between heated and cooled walls was 20 K. As a result, the *Ra* number was about 4×10^9, which, as the authors note, is typical of a full scale room with a wall-to-air temperature difference of ± 1.25 K. The tests provided useful information on the particle deposition velocities on the various walls, but unfortunately velocity and turbulence distributions were not measured, which makes it difficult to use the data for any validation of computational fluid dynamics (CFD) simulations.

The effect of surface roughness on the deposition rate has been experimentally investigated, for example, by Abadie, Limam, and Allard (2001), Lai, Byrne, and Goddard (2002) and Thatcher and Nazaroff (1997). They reported that for larger than 1 μm sized particles the deposition rate increased as the surface material was changed from smooth to rough.

The flow characteristics in the cavity determine the movement of particles, and therefore, in order to characterize the particle transport it is also important to determine the fluid velocity and temperature in the cavity. In this study, we used a cubic cavity with two isothermal vertical walls between which a temperature difference ΔT was applied. This type of installation is throughout this text referred to as a cubic differentially heated cavity (DHC). The previous experimental work on air filled DHC consists of e.g., Ampofo and Karayiannis (2003) and Tian and Karayiannis (2000a, 2000b), who measured two dimensional flow field and temperature quantities from center plane of a cavity with depth to height ratio of two and *Ra* approximately 10^9. Tian and Karayiannis used E-type thermocouple for the gas temperature and 2D Laser Doppler Anemometer (LDA) for the flow measurements and reported the mean and turbulent temperature and velocity quantities. Ampofo and Karayiannis (2003) extended the investigation by measuring the velocity and temperature simultaneously, thus obtaining also values for Reynolds stresses and turbulent heat flux. Salat et al. (2004) investigated rectangular DHC with depth to height ratio of 0.32. They used K-type thermocouples for the temperature measurements and LDA for flow field determination. The experimental results were compared against 2D and 3D Large Eddy Simulation (LES) and 3D Direct Numerical Simulation (DNS) using both adiabatic conditions and measured temperatures at the horizontal walls. A thorough review of previous work done with enclosures with natural convection, mostly focusing on the fluid heat and mass transfer aspects in cavities with different geometries and flow properties, is given for example by Baïri, Zarco-Pernia, and García de Maria (2014) and Ostrach (1988). A theoretical background on internal natural convection can be found from Bejan (2013).

In this study, deposition rate of two monodisperse aerosols was determined in a cubic DHC. The particle removal rate was investigated by measuring changes in the intensity of light reflected by the airborne particles as well as by measurement of particle mass concentration at different points inside the cavity. To the authors' knowledge, this is the first experimental study on particle depletion in a DHC with turbulent natural convective flow.

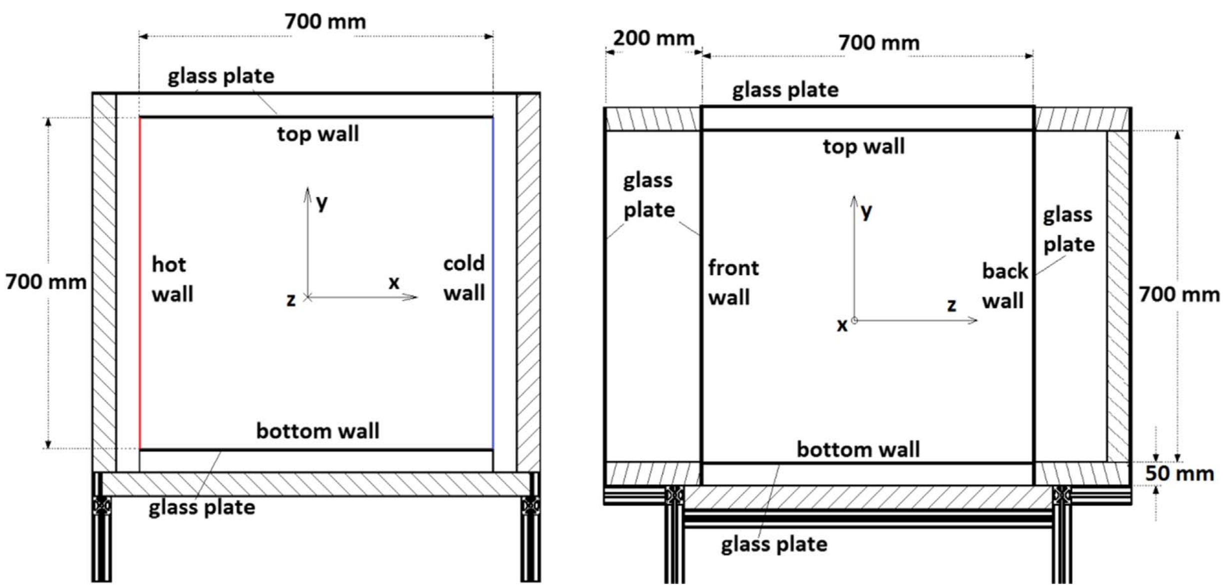

Fig. 1. A schematic of the DIANA cavity.