ETUDE DE L'IMPACT DE LA NATURE DES PARTICULES SUR LA REMISE EN SUSPENSION DANS LES SYSTÈNES HVAC EN VUE D'OPTIMISER LEUR DESIGN ET LEU MANAGEMENT

INVESTIGATION OF THE IMPACT OF THE NATURE ON PARTICLE ON RESUSPENSION IN HVAC SYSTEMS FOR OPTIMIZING SYSTEM DESIGN AND MANAGEMENT

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RESUME

Cette étude porte sur le phénomène de remise en suspension de particules dans les conduites de systèmes HVAC à travers une étude expérimentale incluant la préparation de dépôts réalistes, afin de comprendre les relations entre le comportement des particules, leurs caractéristiques et leur "histoire" en termes de conditions environnementales auxquelles elles sont exposées en tant que dépôt. Cette étude vise également à développer une installation permettant de suivre les particules à différentes distances depuis le dépôt initial afin de détecter la remise en suspension des particules, depuis la paroi de la conduite jusqu'à leur forme aérosolisée. Cette étude permettra d'avancer dans la compréhension de la remise en suspension afin d'initier de futures innovations concernant les systèmes HVAC et ainsi de contribuer à des espaces de vie et de travail sains.

ABSTRACT

This study focused on the particle resuspension phenomenon in the duct of HVAC systems by conducting a series of experiments, including generating realistic deposits to understand the correlation between particle resuspension behavior, particle characteristics, and their "history" reflecting various environmental conditions. The study also creates a platform to track particles at different distances from the initial deposit to measure particle resuspension from the pipe wall to their aerosolized form. This study is expected to advance the understanding of particle resuspension to support future innovative HVAC applications and contribute to healthy living and working environments.

MOTS-CLÉS: Qualité de l'air intérieur, systèmes HVAC, ré-suspension des particules, vieillissement aérosols, chimie des aérosols **/ KEYWORD:** indoor air quality, HVAC systems, particle resuspension, aerosol aging, aerosol chemistry

1. INTRODUCTION

Indoor air pollution contributed to over 3 million deaths annually, particularly among children under 5 years old, exposure to indoor air pollution was responsible for nearly half of pneumonia-related deaths (WHO, 2022). In 26-European countries, indoor air pollution places a significant burden on the economic and health care systems, which has been estimated to cause the loss of 2 million disability-adjusted life-years annually. However, indoor air quality has not received sufficient attention, and research on the topic is limited in comparison to outdoors. One of the aspects that has received less attention is particle resuspension in the duct of HVAC systems, which is considered as a secondary source of indoor particles (Lee et al., 2019).
Particle resuspension is a phenomenon when particles deposited on a surface are detached and re-aerosolized into the air. The deposition of particles occurs when they are transported along the airflow in the duct. During the transport, particles may collide with or adhere to the duct surfaces, leading to deposition on the duct walls. When airflow resumes or accelerates (e.g., restarting after the maintenance or weekend shutdowns), the deposits can be resuspended.
In a building HVAC system, particles deposited, aerosols aggregated on deposited ones, SVOC nucleated/condensated, or microbial species can be resuspended in air, and may elevate indoor particle concentration, affecting indoor air quality and raising human health concerns. On the other hand, particle resuspension in the manufacturing environments could contaminate or damage products, such as in pharmaceutical, food or semi-conductor industry (Ben Othmane, 2011; Kato & Yang, 2008). In addition, particles resuspension in the upstream part of the duct could contribute to filter clogging and pipe fouling, leading to higher maintenance needs and affecting the HVAC system efficiency (Gonzalez, 2016)
Published studies have addressed the influence of the airflow properties (e.g., mean duct velocity) and particle size (Theron et al, 2020), for "model" deposits generally made from spherical particles. However, numerous factors have not been covered yet, including morphology and chemical characteristics of particles, and the effect of ambient environment conditions (e. g. air temperature and humidity). In addition, these studies mostly focused on the initial stage of particle resuspension, i.e., particle detachment from the duct surface, and the tracking of resulting airborne particles at specific distances from the initial deposit is still lacking in published studies. Following the particle resuspension would provide information on particle behavior in the duct, which is crucial for a better control of HVAC system performance.
Hence, this study concerns the first step of the SIROCCO project that aims to advance the understanding of particle resuspension to push forward the resuspension models and support future innovative HVAC

applications and research. The main objective is to deliver a new and more realistic experimental protocol and methodology framework to measure the impact of physical and chemical characteristics of particles, as well as their “history” as a deposit on particle resuspension dynamics. The “history” is studied by exposing the deposits directly to airflow or by keeping them at rest under controlled conditions of temperature and relative humidity, which mimic resting periods such as weekends when HVAC systems are turned off for energy saving reasons, allowing a better understand how resting conditions affect particle resuspension and behavior in real-life HVAC systems.

2. METHODOLOGY

2.1. Particle deposits preparation

Realistic particle deposits are prepared to be exposed to the airflow, which are particles sampled on flat plates to be inserted in the experimental wind duct. These deposits are made from:

- Soots and/or particles from tire wear or engines/breaks representing traffic emissions in urban areas
- Biomass burning particles representing rural environments
- Spores or pollens representing bioaerosols

For each type of particle, each airflow condition (in terms of mean velocity at steady state and mean acceleration), is repeated at least three times.
The chemical characteristics of particles are also involved in this step by simultaneously collecting particles by an Andersen Cascade Impactor (ACI), which is allowed to collect particles in 8 size fractions, including <0.4, 0.4–0.7, 0.7–1.1, 1.1–2.1, 2.1–3.3, 3.3–4.7, 4.7–5.8, 5.8–9.0 and > 9.0 µm. Quartz fiber filter (2500 QAT-UP, Pall Corp., USA) is used to collect particles in different stages. Filter samples are then measured organic carbon (OC), elemental carbon (EC) by carbon analyzer, water-soluble inorganic ions by an ion chromatography (ICS, Dionex Corp., Sunnyvale, CA, USA), and levoglucosan by a GC-MS.

2.2. Experiential setup

The experiments are set up in a lab-scale model of the actual HVAC system duct (Fig. 1). The test section is 2 m length, and of 20x4 cm^2 rectangular cross section. A fan is located at the tunnel outlet, programmed by a flow controller, allowing to set the mean flow velocity at steady state and the mean flow acceleration in the 3-10 m/s and 0.1-3.0 m/s² respectively to be representative of real HVAC systems. The CCD camera (Speedsense 1020, Dantec Dynamics) of 2320 x 1750 pixel^2 resolution and 270 Hz acquisition frequency equipped with a zoom lens (La Vision Lens) is installed in the duct, allowing us to visualize particles moving in the airflow, track particle trajectories and detect resuspension areas where particles accumulate. The duct is also set up with a thermo hygrometer to measure temperature and relative humidity with a 1-second interval.

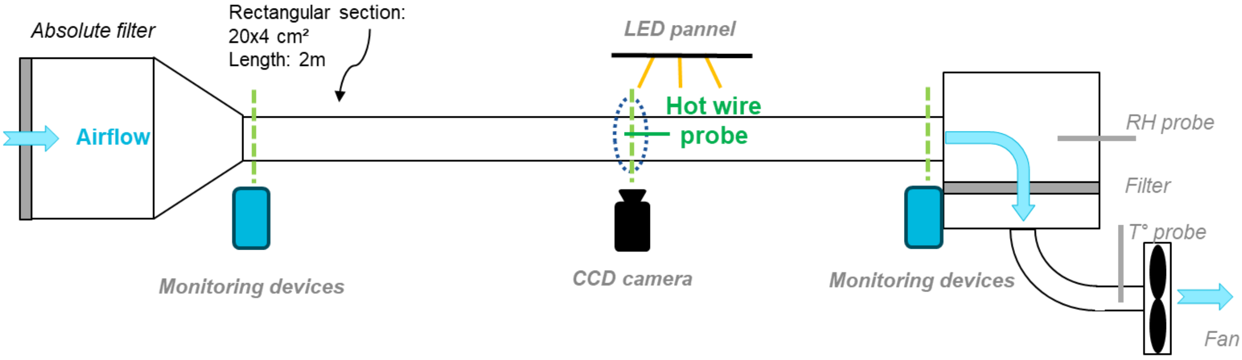

Figure 1. Experimental setup

2.3. Experimental process

For this first part of the study, in order to realize a screening of realistic particles that exhibit a significant tendency to resuspension, deposits are prepared and directly exposed to the airflow. The airflow condition applied in this study is based on previously identified parameters (Theron et al. 2020), which potentially lead to resuspension for spherical particles in the size of 10-30 µm, e.g., the mean velocity at steady state of 7.6 m/s and a mean acceleration of 2.1 m/s². The deposit of particles is monitored during the airflow acceleration followed by a given time period of steady state using the CCD camera. This experiment enables evaluation of whether the deposits are resuspended under the studied conditions. If possible, a particle counting algorithm previously developed by Cazes et al. (2023) for spherical particles will be adapted to quantify the temporal evolution of the fraction of particles remaining on the duct wall. For particle types for which resuspension was observed in the experiments, the physical and chemical characterization will be further carried out, such as

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particle size and morphological properties (using the Malvern Morphologi apparatus), OC and EC by carbon analyzer, water-soluble inorganic ions by an ion chromatography, and levoglucosan by a GC-MS.

3. EXPECTED RESULTS

The expected results of this study consist of the first elements of a database to reach a comprehensive understanding of particle resuspension behavior in the duct wall of HVAC systems under different airflow conditions. The study investigates how particle size, emission sources, and chemical characteristics influence resuspension dynamics in the duct from upstream to downstream and finally indoor air quality. By integrating a CCD camera, particle counter and sensor together with chemical characteristics, the study is expected to quantify particle number concentration, mass at various distances from the initial deposit and identify key factors influencing the resuspension. Overall, the findings are expected to contribute valuable insights into particle resuspension behavior and influencing factors, therefore, contributing to optimizing the HVAC system design and operation

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