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EFFECT OF AIR FLOW ON DUST PARTICLES RESUSPENSION FROM COMMON FLOORING

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ABSTRACT

Particle resuspension from flooring in connection with increased indoor air pollution was studied. Earlier efforts hypothesized that during the gait cycle, high speed airflow is generated at the floor level that would lead to particle resuspension. The details of the mechanism of the particle resuspension, however, are not well understood.

Earlier models were mainly developed for spherical particle detachment from smooth surfaces, but in reality, dust particles are irregular in shape and have a wide size distribution. The resuspension of dust particles thus depends on their shape and size and the nature of their contact with the surface.

In this work, a wind tunnel study of dust particle resuspension from common flooring was performed and the critical air velocities for particle detachment were measured. The main goal of the present experimental work is to understand the main mechanism of dust particle resuspension under real conditions by systematically investigating a range of airflow speeds. The other goal of the study is to provide information on the role of the airflow on dust particle detachment from common floorings.

Keywords: Particle Resuspension; Dust Particles; Wind Tunnel; Critical Velocity.

INTRODUCTION

Resuspension is referred to the process that the particles that are settled on the surface (flooring) are entrained in the fluid streams over the surface. Particle resuspension from common flooring is an important source of particulate matter (PM) concentration in the indoor environment,[1]. Robinson et al. [2] reported that people spent approximately 90% of their time indoors. Long et al. [3] reported that indoor activities could lead to increase of PM concentration by several orders of magnitude when compared with the background level. Ferro et al. [4] and other researchers showed that indoor activities such as walking, vacuum cleaning and sitting on upholstered furniture, cause resuspension of particles. Roberts et al. [5] suggested that the deep dust on carpets is the main source of floor particle emission.

Several models on particle attachment and removal have been developed. Johnson, Kendall and Roberts [6] developed a model that is now referred to as the JKR model. The JKR model includes the effects of surface energy and surface deformation on particle adhesion and detachment. Derjaguin, Muller and Toporov [7] developed a comparable particle adhesion theory which is referred to as the DMT model.

Studies indicate that particle detachment and resuspension depend on many factors including the airflow velocity, relative humidity and capillary forces, particle diameter, the airflow turbulence intensity, substrate acceleration, electrostatic charge, and etc. However, despite a large body of literature examining particle resuspensions, relatively little work has been done on the fundamentals of dust particle resuspension from common flooring in the indoor environment, and particularly on the role of human walking on resuspension.

Recently, particle detachment, resuspension and transport due to human walking in indoor environment were studied by Zhang et al. [8]. Earlier efforts hypothesized that during the gait cycle, high speed airflow is generated at the floor level and leads to particle resuspension. The details of this mechanism for real irregular particles on real rough surfaces are not well understood.

Earlier models were developed for spherical particle detachment from smooth surfaces but in reality, dust particles are irregular in shape and they have a wide size distribution. Dust particle resuspension is closely dependant on the shape and size of the particle and the nature of the contact of the particle with the flooring.

In this work we measured the resuspension of 1-30 microns dust particles from two kinds of common floorings, under different airflow velocities in an experimental laminar flow wind tunnel. The wind tunnel allows the airflow velocity to reach up to about 21(m/s) under the laminar flow conditions. We measured the ratio of dust particles removed from flooring at each time step. The information is compiled and analyzed. The results show the effects of various parameters that affects the resuspension of dust particles from common flooring.

PROCEDURES OF EXPERIMENTAL STUDY

To measure the effect of airflow on dust particle resuspension, we measured dust resuspension from two common flooring substrates for velocities ranging from 3(m/s) to 21 (m/s) in a laminar wind tunnel.

The substrates studied were linoleum and hardwood flooring samples. The substrates were seeded with house dust particles in a mixing chamber and placed in the laminar flow wind tunnel. The laminar flow wind tunnel is equipped with a microscope which captures images the particles on the substrate. Figure 1 shows the schematic of the wind tunnel. A picture of the wind tunnel is shown in Figure 2. The thickness of the channel in the tunnel is 3 mm and flow is in laminar regime for velocities up to about 20 m/s.

The images were used to determine the percent of particles that are resuspended. Particles are initially deposited on a sample flooring piece that is shaped in the form of a cylinder that fits flash mount in the tunnel. After the flooring sample with deposited dust is placed in the wind tunnel, an image was captured as an initial condition. Then, the airflow velocity was increased in steps and images were captured at the following intervals: 4.5(m/s), 7(m/s), 9(m/s), 11(m/s), 12.5(m/s), 14(m/s), 15.5(m/s), 17(m/s), 18(m/s), 19(m/s), 20(m/s) and 21(m/s). The images are compared with the original image using an image processing scheme. The image analysis for each flow velocity was performed with the Imagej software (Ver.1.42q, National Institute of Health, USA) to determine the size and number of particles that are on each image. The comparisons of the images determine the percentage of particles that removed. Five repeated experiments were conducted for each substrate. Figures 3 shows a sample image of particle on the flooring. The image is analyzed with the Imagej software. Figure 4 shows a sample black and while image of the particles that were recorded in Figure 3.

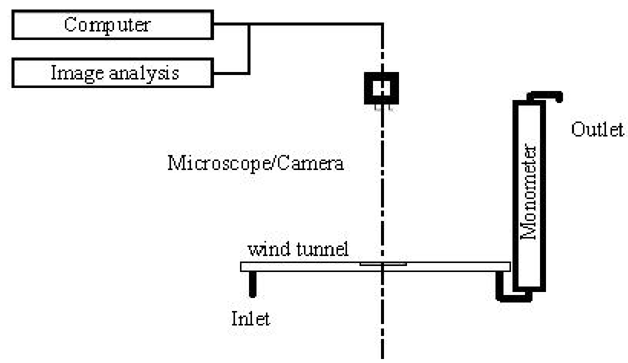

Figure 1. Schematics of the experimental setup for dust resuspension study.

Figure 2. Schematic of the laminar flow wind tunnel.

RESULTS AND DISCUSIONS

The experimental results are provided as the percentage of detached particles versus airflow velocity for each type of flooring. As was noted before, dust particles have a wide size distribution;

therefore, in order to present the results, the particles are divided into in three size ranges: 1-10µm, 10-20µm, and 20-30 µm.

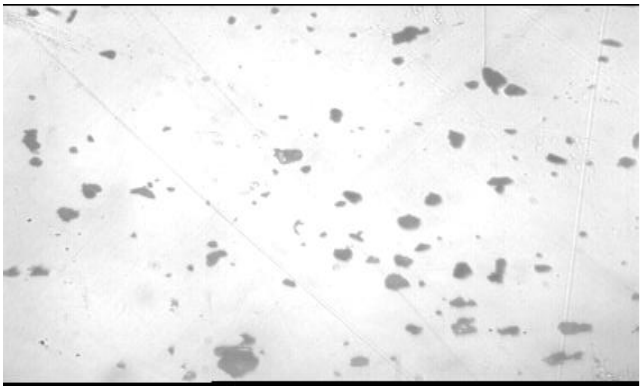

Figure 3. Sample picture of dust particles distribution on flooring.

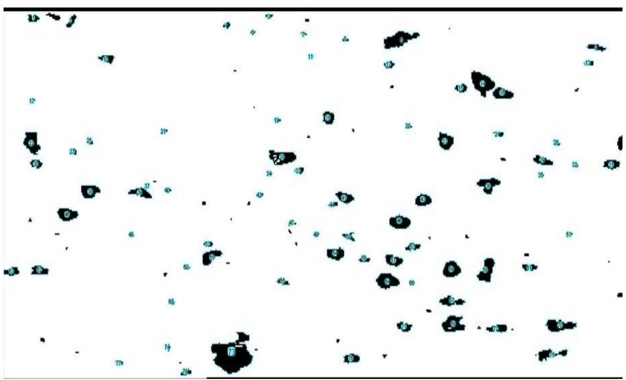

Figure 4. Sample picture of dust particles analyzed with Imagej.

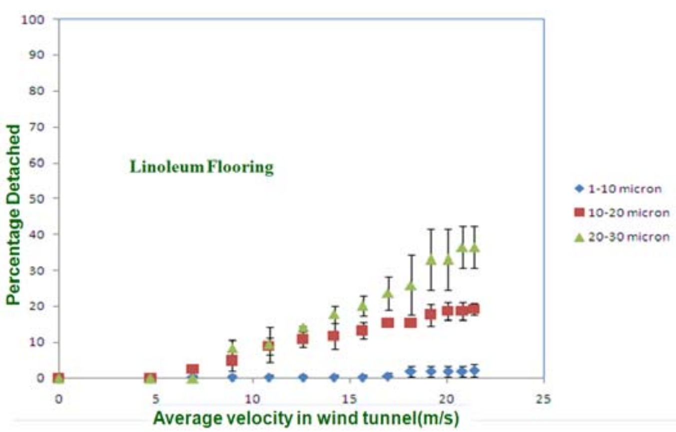

Figure 5. Percentage of detached particles for linoleum flooring.

The corresponding mean percentage of removed particles for each linoleum and hard wood substrates are shown in Figures 5 and 6. In these figures, error bars are the standard deviations of the sample

Consistent with the previous particle detachment studies, Figures 5 and 6 show that the larger particles are more easily removed. Also, for all size distributions, resuspension of dust particles from hardwood flooring was more easily achieved compared with the linoleum flooring. Dust particles in the range of 10-20 µm and 20-30 µm had a relatively high rate of resuspension. For smaller particles, less than 10 µm, the percentage of removal is quite low for the range of velocities studied. The low rate of removal of small particle is mainly due to the high value of the ratio of the adhesion force to the hydrodynamic forces acting on the particle. For laminar flows the air velocities near the wall is very low at short distance from wall due to the no-slip condition at the floor level. Thus, small particles see very little drag.

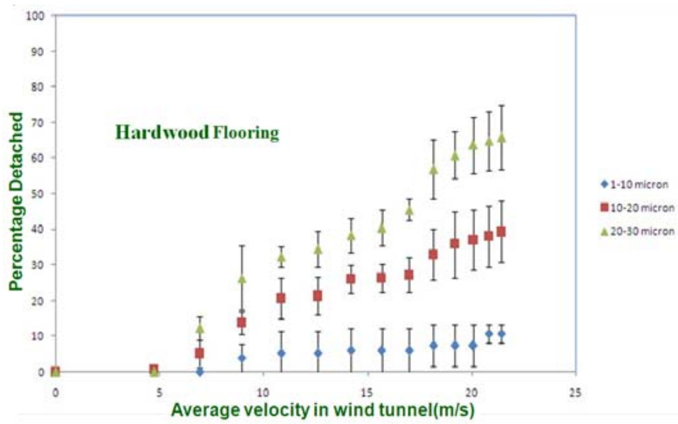

Figure 6. Percentage of detached particles for hardwood flooring

Soltani and Ahmadi [9,10] have hypothesized that the micro-roughness of the particles and the flooring leads to higher resuspension rate due to less physical contact areas between the dust particles and flooring.

CONCLUSIONS

As expected, the resuspension of dust particles was closely related to the size of dust particles. Dust particles in the range of 1 to 10 micron in diameter rarely resuspended in the laminar wind tunnel at the range of velocities tested, while the larger particles resuspended proportional to their size.

Resuspension of dust particles from wooden flooring was easier than linoleum flooring. It is conjectured that this is because of the differences in the adhesion force (surface energy) and the nature of the micro roughness that are present. There is also the possibility of the presence of downward electrostatic force that could significantly alter the nature of adhesion and resuspension of particles from flooring.

The plan for future is to analyze the nature of adhesion and provide quantitative model for dust particle resuspension as well as perform experimental and modeling study on the effect of charge on particle resuspension.

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