CAPTURING MICROPARTICLES THROUGH THE MOTION O FLIQUID DROPLETS

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ABSTRACT

In this study, we aim to eliminate airborne microparticles through the motion of liquid droplets. In our experiments, microparticle-laden airflow is introduced from below, while liquid droplets are released from above. Direct collisions between droplets and particles result in microparticle removal. We identified that the initial relative positioning between droplets and microparticles significantly influences capture efficiency. When the relative distance is small, droplets capture microparticles effectively. Conversely, at a larger distance, microparticles deviate from their original paths, avoiding collision and remaining uncaptured. We analyze the trajectories of microparticles around droplets through a combination of high-speed imaging and theoretical modeling.

KEY WORDS

Airborne microparticles, Liquid droplet motion, High-speed visualization

1. INTRODUCTION

Coal-fired power plants release microparticles such as coal dust, which is a notable air pollutant. Conventional capture methods face challenges with coal dust due to its small size and fire hazards. Recent research (An, 2012 [1]; Lee et al., 2019 [2]; Oh et al., 2021 [3]) has investigated the use of microdroplets to capture these microparticles. Although experiments have demonstrated this method's effectiveness, there remains limited research on microparticle trajectories and the conditions that enhance capture. This study visualizes the interactions between microparticles and microdroplets, analyzes particle trajectories, and compares experimental results with theoretical models to better understand conditions that facilitate effective microparticle capture by microdroplets.

2. Experiments

Initially, we positioned a fan at the top of a square glass pipe to generate an upward particle-laden airflow. A syringe needle within the pipe released water droplets with diameters ranging from 2.5 mm to 2.8 mm. The particles used in the experiment included glass beads and lycopodium powder, with physical properties specified in Table 1. We systematically varied the initial relative position between droplets and particles and recorded their interactions using a high-speed camera. Measurements included droplet velocity, particle velocity, and particle trajectories.

Table 1: Particle’s physical properties \

	Glass bead	Lycopodium
Diameter (mm)	40~80	30~40
Density (kg/m^3)	1530	530

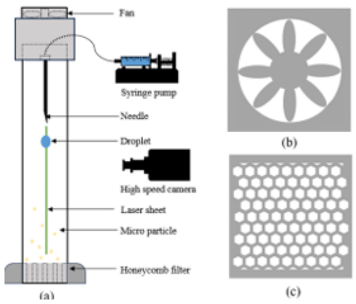

Fig.l: (a) Schematic of experimental setup. (b) Detailed illustration of fan used to induce a particle-laden flow. (c) Schematic of honeycomb-like filter used to generate a uniform particle concentration in the particle laden flow.

3. THEORETICAL MODELS

For particles moving through the air at a low Reynolds number ($Re_p<1$), the surrounding flow remains laminar. Given the small particle diameter, we used Stokes' drag to model the drag force. As particles reach their terminal velocity and approach a free-falling droplet, characterized by its diameter and velocity, their velocity changes due to the flow field created by the droplet. We formulated an expression for the particle’s acceleration based on this interaction, accounting for drag and gravitational forces.

Assuming a potential flow field around the droplet, we derived the flow velocity from a potential function that considers the distance from the droplet center and the angle between the particle and droplet center. By differentiating this function, we obtained the radial and angular components of the flow velocity, which describe how particles interact dynamically with the droplet's flow field.

Results

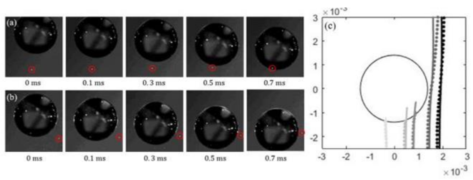

Fig.2: Two different particle trajectories depending on relative initial distance: (a) Captured motion droplet with particle (b) Non captured motion droplet with particle (c) Comparison of trajectories between experiments (dots) and theoretical models (solid line)

When a particle's initial position was closer to the central axis of the free-falling droplet, it was captured more effectively, as shown in Figure 2(a). Conversely, when the particle started farther from the droplet's axis, it tended to deviate away, leading to non-capture, as seen in Figure 2(b). Figure 2(c) presents a comparison between experimental observations (dots) and the predictions of the theoretical model (solid line).

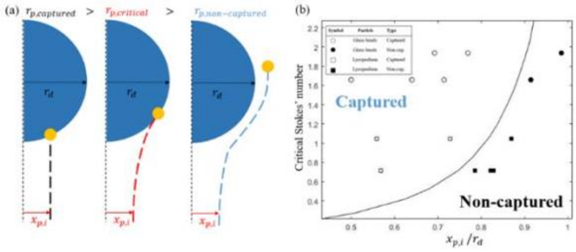

Figure 3. (a) Schematic of particle trajectories depending on radius of particle (b) Regime map showing captured and non-captured particles: Solid line represents critical stokes' number and dots represent stokes' number obtained through experiments

As shown in Figure 3(a), when the particle radius is small at a given initial position, the particle tends to follow the streamlines. However, with a larger radius, the particle is more likely to penetrate the streamlines, moving in a straighter trajectory, which increases the likelihood of capture by the droplet. We defined the critical particle radius as the radius at which a particle follows the boundary trajectory between capture and non-capture by the droplet. We also introduced the critical Stokes number, calculated based on the critical particle radius and the initial position relative to the droplet radius. Figure 3(b) displays a regime map that categorizes particle capture behavior in the droplet based on this critical Stokes number.

Conclusion

We conducted a fundamental study on the interactions between droplets and microparticles to enhance particle filtration methods without relying on physical structures. Using a high-speed camera, we visualized the interactions between droplets and microparticles and observed how particle trajectories deflected around an impacting droplet. The particles showed varying deflection distances based on their initial relative position to the droplet, which influenced their capture behavior. Additionally, theoretical models were developed to analyze and predict these behaviors.

APPENDIX

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