Study on the Influence of Filtration Velocity on the Design of Optimal Filter Thickness for Air Purifiers

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Abstract

Problem Statement:

Although indoor air purifiers are increasingly employed to reduce particulate exposure, current design practices often lack a theoretical foundation for optimizing filter thickness in terms of both filtration efficiency and energy consumption.

Objective:

This study aims to develop a predictive framework for determining the optimal filter thickness (T_{opt}), integrating key filter parameters and fan performance characteristics.

Methodology:

A simulation model was developed, integrating single-fiber theory, fan performance curves (P–Q), and pressure drop data. Under fixed filter and fan specifications, the model computes system airflow, particle-size-specific filtration efficiency, and the resulting Clean Air Delivery Rate (CADR). Filter thickness was systematically varied, and regression analysis was applied to determine T_{opt} under a range of operational conditions.

Main Finding:

T_{opt} is shown to vary with face velocity, fiber diameter, packing density, and fan curve slope. Face velocity emerged as the primary factor influencing filtration efficiency at T_{opt}, with lower velocities consistently resulting in higher efficiencies. For filters with efficiency >99%, maintaining face velocity below 0.1 cm/s is essential to prevent energy waste. Fan curve slope alters the system operating point, affecting both airflow and optimal filter configuration. These results emphasize the importance of incorporating fan dynamics—particularly the slope of the performance curve—into filter design to achieve maximum CADR. Conclusion: Optimizing air purifier performance requires an integrated approach that accounts for filter geometry and fan dynamics. The proposed framework provides design insights for achieving high CADR while minimizing energy use in compact purification systems.

Keywords: CADR; optimal filter thickness; fan performance curves.