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Investigation of the Potential and Mechanism of Clove for Mitigating Airborne Particulate Matter Emission from Stationary Sources

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Abstract

Vegetative Barriers (VB) have the potential to mitigate air pollutants emitted from area sources, including concentrated Animal Feeding Operations (AFOs). However, the mechanism has not been fully investigated, thereby limiting the application of vegetation systems in practice. An experimental method with repeatable and controllable conditions was developed to measure the change of Particulate Matter (PM) concentrations at upwind and downwind of VB in the wind tunnel and observe accumulated PM on leaves with Scanning Electron Microscope (SEM), thus evaluating the ability of VB in mitigating PM emitted from AFOs. Branch-scale vegetation, clove (*syzygium aromaticum*) was selected because its leaves are one of the major factors affecting PM dispersion. The results show that the branch-scale barriers, as porous medium have the ability to interfere with airflow and reduce PM, which could be influenced by wind speed, particle size fraction and surface area density of clove. Moreover, clove elements could adjust to the wind and the micro structure of clove (such as the hierarchical structures of leaves) affected on the PM deposition. These results indicate that the methods developed in this study may be used to evaluate the potential of vegetation in mitigating PM from stationary sources, and some characteristics of vegetation can be further studied as bionic prototype for exploring engineering application of reducing particulates.

Keywords: vegetative barrier, particulate matter, wind tunnel, clove, animal feeding operation

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1 Introduction

Particulate Matter (PM) consisting of the mixture of solid and liquid particles suspended in the air is among the first air pollutants that drew attention of researchers worldwide[1,2], especially in China, which recently has been experiencing extremely severe and persistent haze pollution in several regions[3]. Emissions of PM from intensive Animal Feeding Operations (AFOs) are considered harmful to human health (such as respiratory, heart and lung diseases) and affect the local and regional air quality[4–7]. Among existing mitigation strategies, animal producers show great interests in using vegetation systems to prevent and reduce the spread of pollutants to neighboring residents[2,8,9].

Vegetative Barriers (VB) are also known as vegetative system, buffer, shelterbelt and windbreak, which typically include trees and shrubs arranged in row or group configurations[8]. Some special branch-scale structures and micro-structures of vegetation have formed in the evolution and contribute to their adapting to environment[10]. Based on limited number of research in urban PM reduction by vegetation, VB can collect PM primarily by physical mechanisms, such as impaction[11,12]. Leaves, porosity, canopy morphology and elements, micro-structure of trees and shrubs play major roles in trapping PM[13–16], since some unique structures of plant leaves have been formed in the evolutionary process[10,17]. Even the same species of vegetation might significantly present different capability of capturing

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PM in different polluted regions due to variation in particle size, PM components, and meteorological conditions. Therefore the research on the removal of airborne particles emitted from specific or stationary source area by VB is important and urgent for barrier design and management to get maximum effectiveness[12,18,19].

A few studies have been conducted to evaluate the potential of vegetation in trapping PM and other air pollutants from AFOs. Adrizal *et al*.[9] indicated that plant foliage has the capacity to capture all size categories of PM from poultry exhaust fans and showed unique species differences in their capacity to hold PM. Laird[20] reported that downwind particles transmission could be reduced by 35% – 56% using VB. Current studies on the efficiency of vegetation in reducing PM emissions from stationary source of AFOs are very limited and more researches are needed to evaluate their effectiveness and to establish abatement strategies for engineering application.

This study aimed at exploring reliable methods for evaluating the effectiveness of VB (clove) from two aspects, branch-scale structure of VB and micro-structure of the vegetation elements under comparable conditions. Considering that wind tunnel studies can provide many insights into pollutant dispersion with controllable experimental conditions and can be further linked to on-site measurements[2,12], a wind tunnel was developed for providing reproducible and consistent experimental conditions. The objectives of this study were to develop a laboratory experimental method for rapidly ascertaining the ability of vegetation barriers in controlling PM emissions with controllable wind speed, stationary PM sources from AFOs, and comparable configuration of vegetation barriers; and to quantitively and qualitatively evaluate the effectiveness of branch-scale barriers of clove and the micro-structure of clove leaves in mitigating the dispersion of small particles, which may provide bionic investigation to inspire the improvement of current PM reduction strategies.

2 Materials and methods

In this study, a low-speed wind tunnel was designed based on the wind-speed statistics of Jilin Province in China with annual average of 2.6 m·s^{-1} from 1975 to 2012[21]. For the experimental tests, different treatments were considered which included three levels of wind speed (v_1, v_2, v_3), two levels of size fraction (P_I and P_{II}) of particles generated for particle dispersion, four levels of VB (without barrier and three levels of Surface Area Density (SAD) with barriers, *i.e.*, control, S_1, S_2, S_3). A total of 24 sets of tests were replicated 3 times as described in the following sections.

2.1 Experimental setup

The wind tunnel (Fig. 1) was designed according to the principles given in Refs. [22, 23], with the test section of 2.0 m in length and highest wind speed of 6 m·s^{-1}. To simulate the emissions of PM from feedlot facilities, powder particles were continuously dispersed at the airflow inlet of the contraction section using customized aerosol diffuser and injection system (BT-901, Bettersize Instruments Ltd., China) with flow rate of 1 L·min^{-1}. The VB were set up 0.6 m away from the inlet of the test section and perpendicular to the incoming flow direction. The bottom surface of the test section was assumed as plane of z = 0; the lateral side of barriers facing airflow was assumed as x = 0; and the vertical plane at the center of plane x = 0 was assumed as y = 0. Monitoring points 1–7 were velocity monitoring points, meanwhile monitoring points 1 and 4 were also PM concentration monitoring points, as shown in Fig. 1. During all tests, average temperature and relative humidity in the laboratory were 23 ˚C and 18%, respectively.

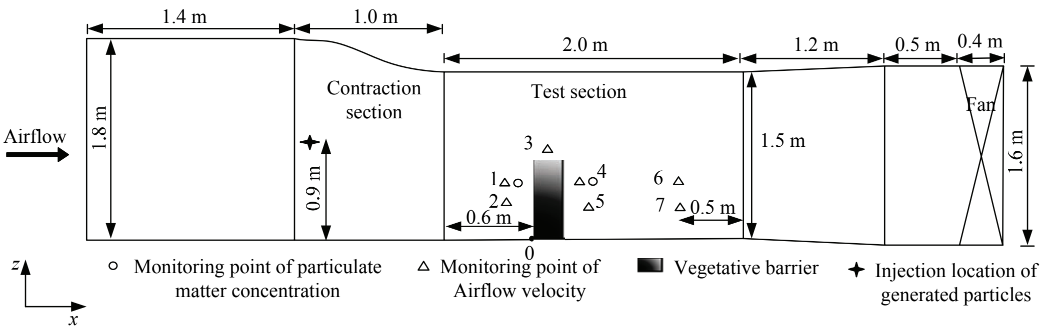

Fig. 1 Diagram showing the wind tunnel experimental setup (not drawn to scale).