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SMALL SCALE EXPERIMENTS OF PM10 DISPERSION AROUND OBSTACLES

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Abstract: Particulate matter (PM) is the main determinant of air pollution caused by a variety of natural and human-caused sources. Because it can be suspended in the atmosphere for long periods of time and travel long distances, it can cause a major health crisis for humans and damage the environment as well. Studies are still required to understand how the PM moves around obstacles, especially in urban areas. In this study, small scale experiments were carried out to look into the effects of simple obstacles, heights and distance from the source on the PM10 concentration. Results show that when obstacle heights and distance from the source increase, the PM10 average concentration decrease. Also, turbulence created by the obstacles affects the PM10 concentration in both sensors before and after the obstacle, mainly in cases of high wind speed. In addition, the use of incense sticks as a source of PM pollution illustrated that moderate burning of incense sticks in indoor places could skyrocket the PM10 concentration to an unhealthy level.

Keywords: PM10 concentration; PM10 dispersion; Incense sticks; Obstacles; Wind speed

1. Introduction

Particulate matter (PM) is a broad term that encompasses a wide range of particle sizes. It includes particles with a diameter ranging from a few nanometers to 100 micrometers. Carbonaceous particles with adsorbed organic chemicals and reactive metals make up the PM component of air pollution. Nitrates, sulfates, polycyclic aromatic hydrocarbons, endotoxin, and metals such as iron, copper, nickel, zinc, and vanadium are all common components of PM [1]. These are usually divided into two basic particle metrics, PM10 (coarse particle with diameter <10μm) and PM2.5 (fine particles with diameter <2.5μm), in order to ensure adequate monitoring and regulation [2]. Coarse particles come from a variety of natural as well as anthropogenic sources, but they rarely make it past the upper bronchus of the lung. Fine particles are produced when fossil fuels are burned, and they pose a greater health risk than coarse particles because they penetrate into the small airways and alveoli (very small balloon air sacs, with the function of moving oxygen and carbon dioxide molecules into and out of the bloodstreams) [3]–[5]. Furthermore, High levels of PM have been linked to serious diseases such as silicosis, lung cancer, cardiovascular disease, and chronic obstructive pulmonary disease, so exposure to PM can have a serious impact on human health [6]–[8]. Besides that, PM exposure was associated with an increased risk of death [9]. According to the World Health Organization (WHO), exposure to high concentrations of PM10 and PM2.5 were linked to a high mortality rate [10].

The dispersion and the transport of PM plume in urban areas are still an open field due to its complexity. Many studies were conducted to understand more how the PM plumes are moving around different types of obstacles and how different parameters can influence it [12]–[14]. Building height variability and wind have effects on PM plume dispersion [15]–[17]. Simplified wind tunnel experiments and Computational Fluid Dynamics (CFD) simulations investigated the PM and air pollutants dispersion in simplified urban models [18]–[21].

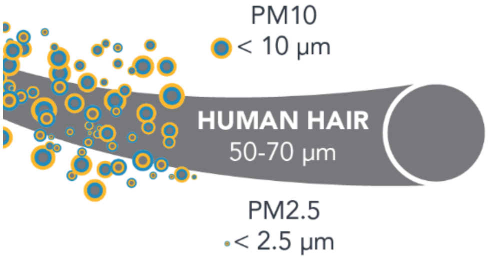

Figure 1. Particulate matter size comparison [11]

In this paper, small scale experiments were conducted in order to investigate the effects of obstacles, heights and distance from the source on the PM10 concentration. The goal was to understand the changing of the PM10 concentration around obstacles in a simple environment.

2. Materials and Methods

The experiments were done in an isolated laboratory room on the built table. The table had 3 PM10 sensors with a 50 cm distance between each sensor. The room temperature was stable during the experiments (25 ±1˚C); the same was for the Relative Humidity (RH) (50% ±3).

2.1 Experiment set up

The experiments were done with two different wind speeds (2.9 and 1 m/s) provided by two different small ventilators. The use of the ventilators is to make sure that the PM plume will follow the wind direction toward the sensors and to avoid the spreading of the plume around the room. As mentioned, three sensors were used, sensors A, B and C, as shown in Figure 2, sensor C is placed near the source, sensor B is in the middle and sensor A is 1 meter away from the source. The obstacle was placed at three different distances between sensors A and B, with changing of the obstacle height (120, 240 and 360 millimetres).

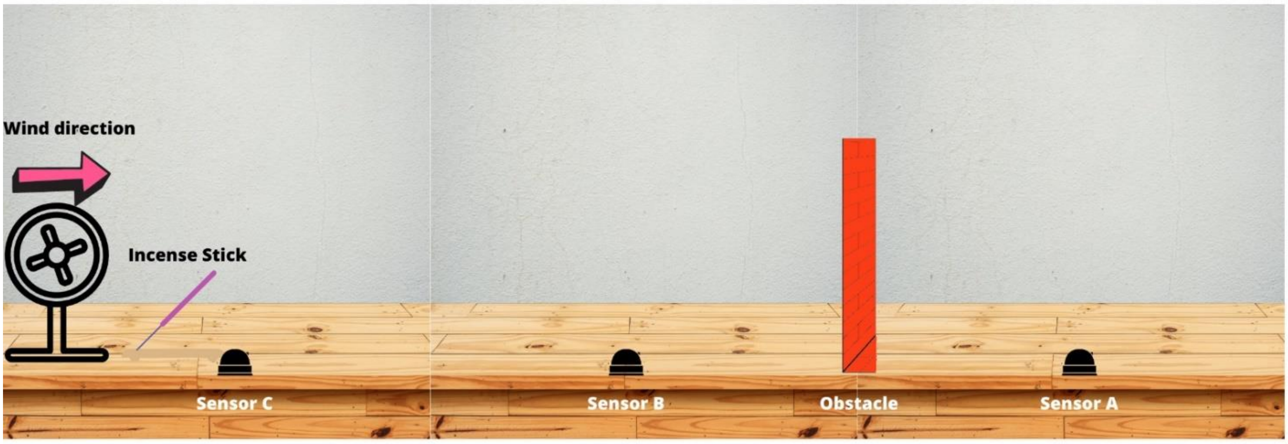

Figure 2. Experimental set-up

The incense sticks were used as a source of PM10 plumes due to the number of particles emitted from incense smoke in a short time. There were many research studies that investigated the effect of the use of incense sticks on PM10 concentrations. Numerous studies point out that during the burning of the incense sticks, the particle concentration increase dramatically, and so is the concentration of PM2.5 and PM10 to extreme levels; not only the PM concentration that increases during the incense stick burning but also the level of Carbone Oxide (CO), Nitrogen Oxides (NOx) and Sulfur dioxide (SO_2) concentrations go up [22]–[27].

Each experiment took 15-20 minutes by burning one incense stick with fixed wind speed, obstacle distance from the source and obstacle height. The total number of variations (experiments) was 18.

2.2 Data analysis

Measurements were registered continuously in a programmed excel sheet during each experiment for every 30 seconds. The results present the average PM10 concentration in each test and are presented in graphs depending on the obstacle height and distance from the source for the three sensors.

3. Results

The results of the experiments showed some interesting aspects for the understanding of the PM10 dispersion around the simple obstacle (Walls).

3.1. Sensor A

Sensor A is the sensor behind the obstacle. Figure 3 shows the average concentration of PM10 during each experiment in the function of Obstacle heights and distance from the source. The average PM10 concentration increase with increasing the obstacle distance from the source at higher wind speed, while at low wind speed, it is almost stable. At a wind speed of 2.9m/s, the average PM10 concentration was the same for obstacle heights of 240 and 360mm, while it was at its peak when obstacle height was 120mm. While for the wind speed of 1m/s, the peak average PM10 concentration was at the obstacle height of 360mm and almost the same at the other two heights.

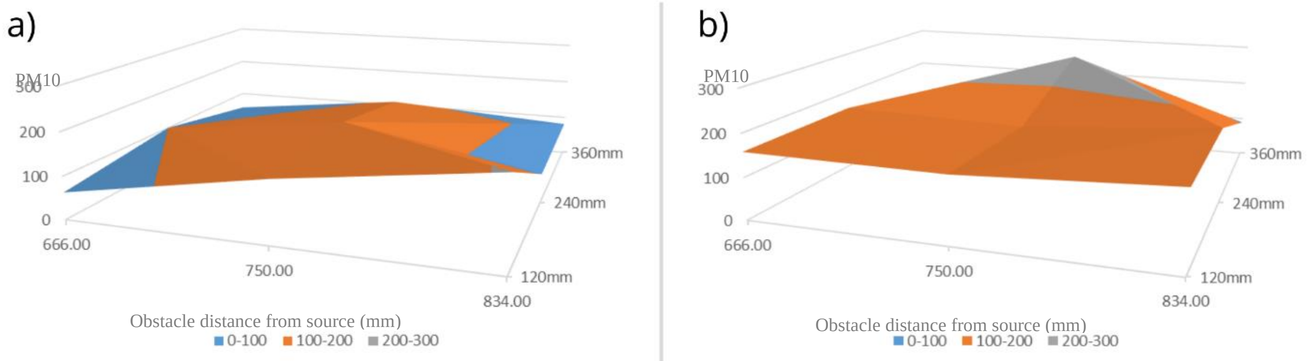

Figure 3. graphs of Average PM10 concentration registered by Sensor A in the function of Obstacle heights and distance from the source in case of a) wind speed 2.9 m/s and b) wind speed 1 m/s

3.2. Sensor B

For sensor B, which is the sensor placed before the wall, the PM10 average concentration was higher in the case of wall height of 240 and 360mm, and wall distance of 750mm at a wind speed of 1m/s (Figure 4).

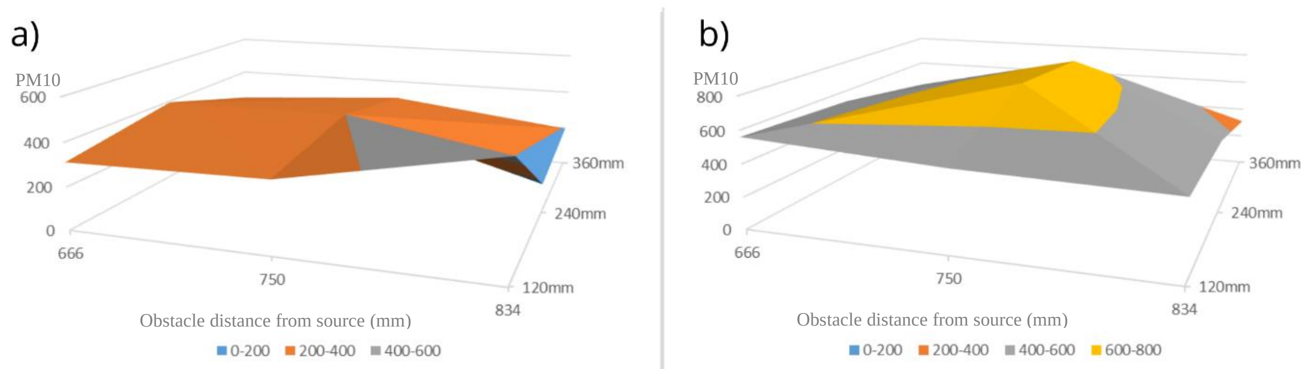

Figure 4. Graphs of Average PM10 concentration registered by Sensor B in the function of Obstacle heights and distance from the source in case of a) wind speed 2.9 m/s and b) wind speed 1 m/s

While it reaches the maximum when the obstacle distance from the source is 834mm, obstacle height is 120mm and wind speed of 2.9m/s.

3.3. Sensor C

The sensor C placed near the source registered almost the same average concentration of PM10 at a wind speed of 1m/s with a decrease in concentration in case of obstacle height of 360mm and distance from the source of 834mm (Figure 5). On the other hand, it was changing at a wind speed of 2.9m/s. The peak average PM10 concentration was the same as sensor B when the obstacle distance from the source was 834mm, and the obstacle height was 120mm.

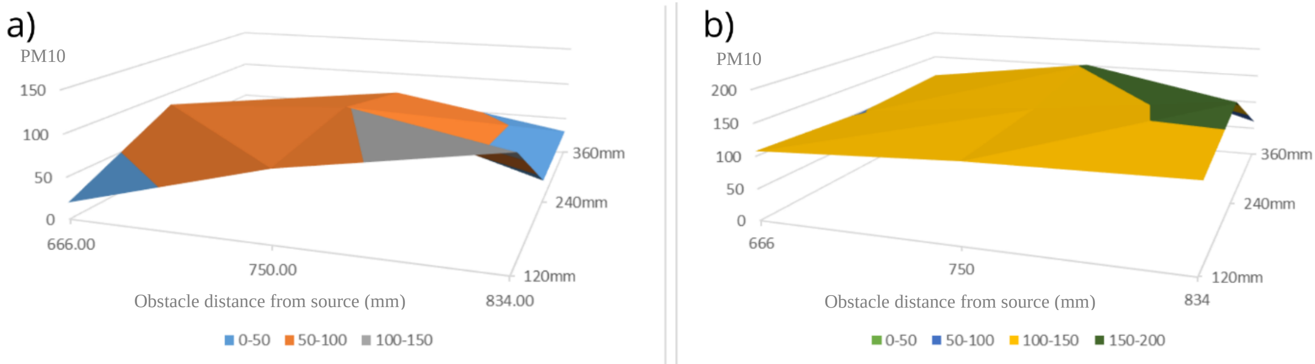

Figure 5. Graphs of Average PM10 concentration registered by Sensor C in the function of Obstacle heights and distance from the source in case of a) wind speed 2.9 m/s and b) wind speed 1 m/s

4. Discussion

The results of this research concluded that there is a significant positive effect on Obstacle heights, the distance of the obstacle from the source, and the wind speed. The PM10 average concentration decrease significantly in sensor A (behind the wall) when the obstacle height increases and also when the obstacle distances from the source increase also in case of the two-wind speed (1m/s and 2.9m/s) with higher concentrations registered in case of wind speed is 1m/s. While, changes in the PM10 average concentration ware also seen in the case of Sensor B (in the middle) and sensor C (near the source), especially in the case of high wind speed (2.9m/s) and, that is due to the turbulence created before and after the walls when the wind hits it, in addition to the reflection of PM plumes by the obstacle.

Generally, the PM10 average concentration tends to decrease when obstacle heights increase but are also combined with the position of the obstacle far from the source.

Moreover, using Incense sticks as a source of PM pollution showed that while the stick is burning, it continues to spike the PM10 concentration, as before the experiments, the background concentration of PM10 was 7±3 $\mu g/m^3$, and during the experiments, it can reach 700 $\mu g/m^3$, which manifest the short-term effect of burning the incense stick and its risk of affecting the indoor air quality if used in excess.

5. Conclusions

This paper investigated the PM10 dispersion around the wall of different heights and distances from the source in a simple environment. Two wind speeds were used in the experiments (1m/s and 2.9m/s) and variations of three wall heights (120, 240 and 360mm) constructed by simple breaks and three different distances from the source (666, 750 and 834mm).

The results showed higher average PM10 concentrations were registered in case of low wind speed (1m/s); increasing the wind speed results in decreasing the PM10 concentration. As the Obstacle height goes up, the PM10 concentration goes down, especially in position after the obstacle. Moreover, the PM10 concentration decrease by going far from the source and decreases, even more when an obstacle is placed between source and sensor. The turbulence created by the effects of the walls also the before and after wall sensors measurements.

Even so, more research is needed, and more parameters should be considered for a deep understanding of the PM plume dispersions around different types of obstacles.

Additionally, burning of the incense stick increases the PM10 concentration dramatically in the experiment room, and excessive use of it deteriorates the indoor air quality.

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