Road Dust Reduction by Filter Installed on Public Bus

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Abstract. In this research, to minimize road dust in the air which has a harmful effect on public health a new filtering device prototype was proposed. The proposed device was designed to be mounted on public buses. The best location of the device on the public bus was found from the airflow dynamic analysis around a public bus which runs in Ulaanbaatar city. It was found from the numerical simulation, the air flow around the bus is perturbed at the rear side of the bus. It produces vortices at the rear side of the bus. Considering the power supply to the filtering device, the engine room at the rear side of the bus was chosen as an optimal location for the device. The device was mounted on a public bus and had collected road dust for two weeks. From the test results, it is concluded that the proposed device has a very high performance in collecting road dust with minimum efforts.

Keywords: Road dust, Aerodynamic analysis, Air pollution.

1 Introduction

Air pollution has become one of the big challenging issues in Mongolia. In the winter time, air pollution in Ulaanbaatar reaches the highest in the world. There are three main sources of the air polluting factor in Ulaanbaatar: (1) Ger district area for heating and cooking, (2) transportation with the traditional combustion engine cars, (3) Power plants heating systems. All those dust sources emit gases: carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter (PM). National Agency for Meteorology and Environment Monitoring in Mongolia considers the PM particle as more serious issue than any other factors due to the excess of PM number during the winter season. In January 2019, average concentration of the PM 2.5 was reported as 195μg/m^3, that is three times higher than the air quality standard (MNS 4585:2016) of 50μg/ m^3. PM10 and PM2.5 could harm human health and be one of the critical causes of airborne diseases.

Since the year 2000, the number of vehicles in Ulaanbaatar significantly increased and led to much higher emission of gases like NOx and made particulate matters fly into the air. Especially the large public buses operating in Ulaanbaatar are perturbing

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road dust on streets. Currently, there are 82 bus companies in Ulaanbaatar with 1,662 bus routes running a total length of nearly 3,900km per day [1]. Most of the public buses and private cars have been run over 10 years, which definitely produce air pollutants. About 80% of peoples who use public buses in Ulaanbaatar are exposed to harmful air pollutants on streets. More people are moving from countrysides to Ulaanbaatar city to have better life. Ger districts where the immigrated families stay are being expanded year by year. Almost all the householders in Ger districts burn conventional raw coal, which results in air pollutant, too.

In this research a prototype of road dust filter device which can be mounted on public bus was designed to collect road dust. Because the public buses run all the area of Ulaanbaatar city nearly twenty hours and generate flying dust, the buses can be mounted with dust collectors. Before installing a dust filter device on a bus, airflow around the bus when it runs was investigated to determine the optimal location of the filter device.

2 Road Dust and Human Health Effect

In Ulaanbaatar city, most of the roads in Ger areas are not paved and very dry from Spring to Fall. The very dry unpaved roads are the main source of airborne dust in Ulaanbaatar city. Not only the unpaved road but also the paved road serve as the source of road dust problem in Ulaanbaatar city. Other sources of road dust are factories and construction work sites, such as, land cleaning, drilling, blasting, and ground excavation. Especially in Ulaanbaatar city lots of new apartments are being under construction. The various construction works and the heavy vehicles operation can create approximately 0.011-0.11 tons of PM10 per month.

Airborne dusts can cause health problems alone or combined with other air pollutants [2-4]. Most harmful air pollutants is PM2.5, for the particle diameters is less than 2.5 microns meters, it can penetrate into human lung without being filtered. It is a major cause of diseases such as stroke, heart disease, lung cancer, and acute and chronic respiratory diseases. In 2012, it was reported that one out of nine deaths in Mongolia was from air pollution-related diseases. The data from Mongolian National Agency for Meteorology and Environments Monitoring (in Fig. 1) showed that the average concentration of PM2.5 from 2016 to 2018 was 106$\mu g/m^3$, which is so many times higher than the WHO standard, i.e. 5-10$\mu g/m^3$ [5].

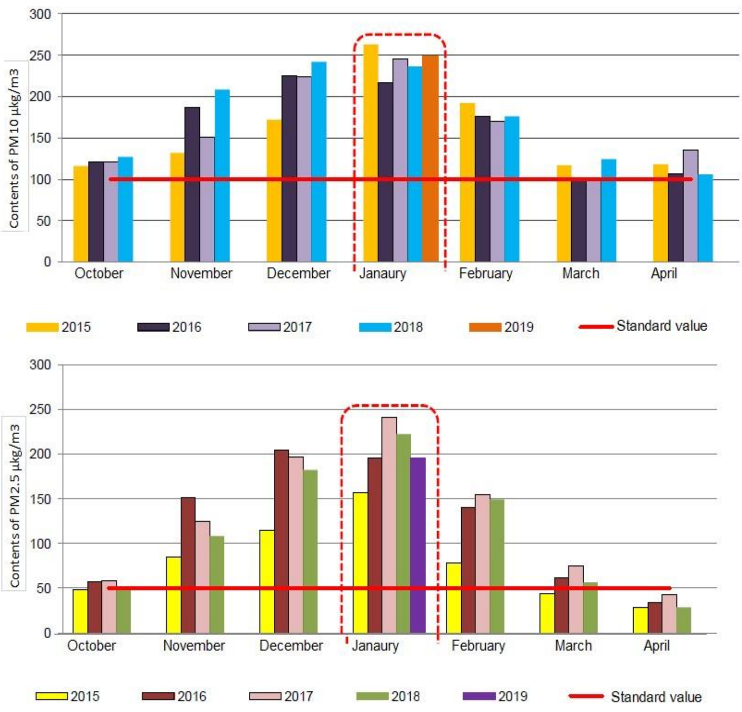


Fig.1. Average cotents of PM10 and PM2.5

3 Airflow Simulation for Filter Location

3.1 Bus for Simulation

The bus model of Daewoo BS 106 (Fig. 2) was selected for airflow numerical simulation. It was produced in Korea and is a popular bus model in Ulaanbaatar city for public transportation. An airflow simulation was performed to determine the opmtimum location of the filter device so that it could collect road dust effectively. The airflow simulation was conducted by utilizing ANSYS software, especially the CFD analysis function. Using the software, aerodynamic parameters such as airflow, pressure and velocity distribution around the bus were investigated thouroughly.

To build the finite element model of the bus for simulation, a three dimensional model of it was built using AutoCAD drawing program. The real dimension of the bus was used to build the numerical model close to the real phenomena. Table 1 shows the dimension of the bus. The detail parts of the bus were not included in the finite element model, such as mirror, ventilation system case on the roof-top, and down-parts. This omission of the detail parts is reasonable because the airflow around the bus will not be influenced by itself.

Fig. 2. Daewoo BS 106 for aerodynamic simulation.

Table 1. Bus external dimensions

Description	Dimension (mm)
Overall length	10,410
Overall width	2,490
Overall height	3,225
Wheel base	5,200
Body overhang (Front)	2,100
Body overhang (Rear)	3,110
Tread (Front)	2,050
Tread (Rear)	1,853

3.2 Numerical Simulation Model

The bus figure for the simulation was drwan by using AutoCAD software. The drawing was imported to ANSYS software for the discretization and simulation. The fluid domain of 1 m around the outer surface of the bus was created in three direction. The mesh was created on the surface of domain and the bus (Fig. 2). The surface bodies had as base format for triangular mesh (Fig. 3).

For the modeling the maximum mesh size was chosen as 1.43 m. Coarse mesh was used for meshing due to the limitation of elements mesh. The bounding box diagonal dimesion was 14.3 m. Totally, 99,867 nodes and 540,392 elements were used for the finite element analysis.

In this research, the wind was assumed to blow to the front side of the bus and only straight wind to the front of the bus was considered with the wind velocity of 11.5 m/s. So the inlet speed was set as constant wind speed of 11.5 m/s. No gauge pressure is assumed at the outlet condition (Fig. 4).

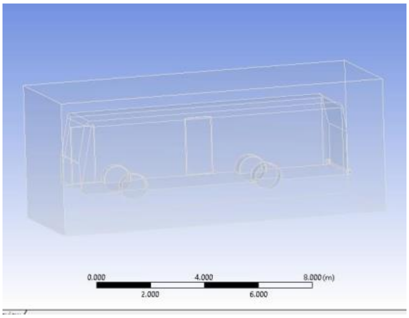


Fig. 2. Inside enclosure.

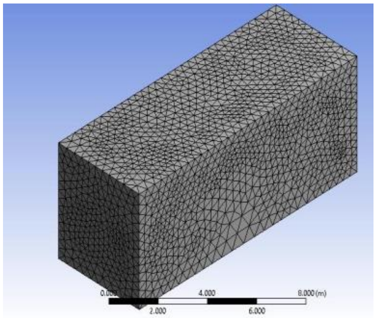


Fig. 3. Mesh model. enclosure.

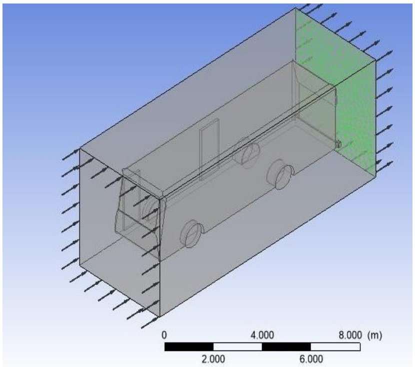


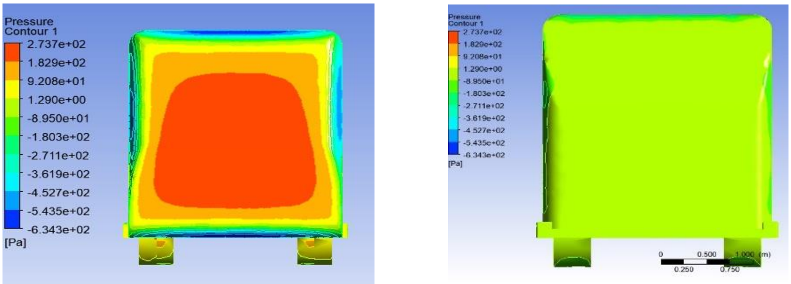
Fig. 4. Wind flow simulation on analysis domain.

3.3 Simulation Results

From the aerodynamics simulation the velocity vectors, airflow path lines, and pressure distribution were found around the bus. Fig. 5 shows the pressure distribution on the bus surface. The windshield, front of the bus, and cowl are under very high pressure as predicted. Corn of the windshield is less pressured. The rear side surface is under negative pressure, which means sucking air to the rear surface of the bus.

The pressure distribution generated by velocity differences at the frontal and rear sides is shown in Fig. 5. As expected, the velocity streamline creates the low pressure on the rear side of the bus, where the turbulent flow speed is lower than the air speed around the bus and the vortices are formed at upper and lower parts. The two vortices are nearly the equal size (Fig. 6).

The proper mounting location of the proposed filter device was chosen as in the engine room, which is located in the rear side of the bus. The road dust which are disturbed and flown into air by the bus movement will flow into the filter device located at the back side of the bus. The turbulent vortex flows formed into opposite direction will be helpful for the filter device to suck flown air with less power.



(a) Front side (b) Rear side

Fig. 5. Pressure distribution.

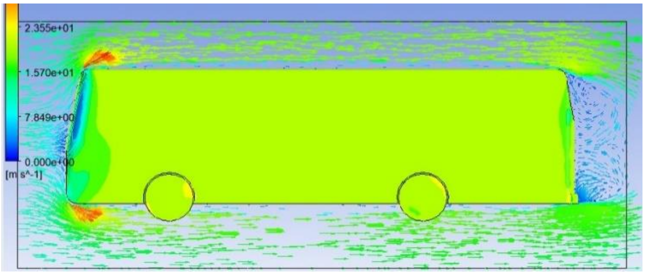


Fig. 6. Airflow velocity vector.

4 Prototype Design and Test Results

4.1 Motor Selection

The power of a motor for sucking air flow to filter road dust was calculated as equation (1). Because the electric power from the bus engine room is used to run the motor, the motor input voltage was set as 24 V. With the voltage limitation, the motor power was calculated using a simple formula. The electrical power of the motor is defined by the following formula.

$$P_{in} = I \times V \tag{1}$$

where, P_{in} is the input power, measured in watts (W), I is the current, measured in amperes (A), V is the applied voltage, measured in volts (V).

The output power of the motor depends on the angular speed and the torque and it can be calculated by using the following formula.

$$P_{out} = \tau \times \omega \tag{2}$$

where, P_{out}- is the output power, measured in watts (W), τ is the torque, measured in newton meters (N·m), and ω is the angular speed, measured in radians per second (rad/s).

A motor was chosen from product catalogues which fitted with 24 voltage. The motor specification is shown in Table 2.

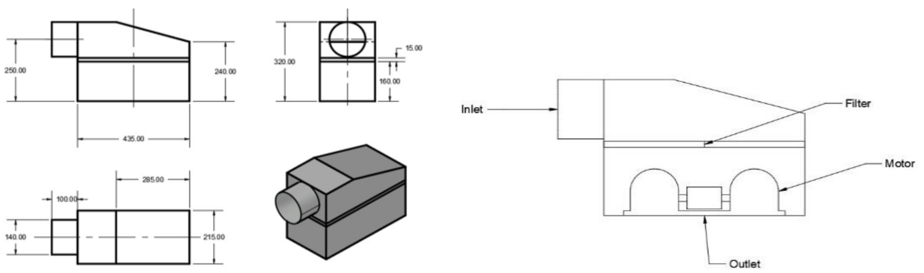
Table 2. Motor specification

Description	Value
Size	350 mm
Current	12.5 A
Voltage	24 V
Angular speed	3900 rpm
Air volume	1000m^3/ hr

4.2 Filter and Device Prototype

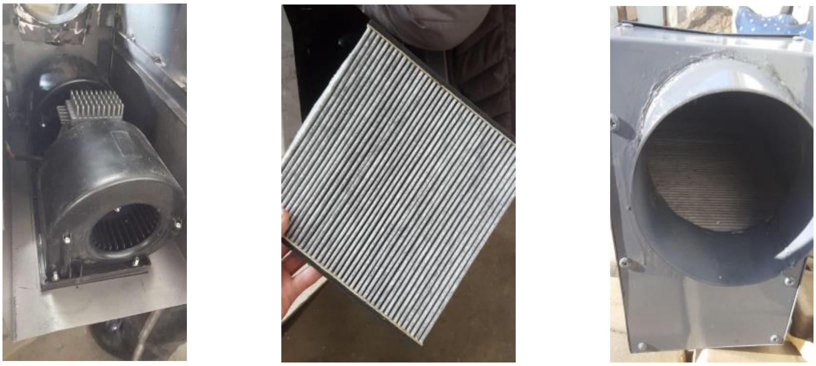
The activated carbon air filter was used for filtering the air sucked in to the filtering device which was installed in the engine room of the bus. The carbon air filter is activated by additional process to enhance gas molecule trapping capability. First, it is implanted with hot air, carbon dioxide, or steam, which creates a lattice of tiny pores in the carbon and increasing its surface area. This process produces more places for molecules to be trapped, which enables the carbon filter far more effective. A single gram of simulated carbon can have hundreds of square meters of internal surface area. The activated carbon air filter uses adsorptions process for removing pollutants from the air. The size of the filter for this research was 21.59 cm × 21.59 cm.

The filtering device prototype which hosted in the motor and filter was designed as shown in Fig. 7. Fig. 8 shows the motor and filter installed inside of the device case. As shown in Fig. 7 (b), due to the small size of the filter, two filters were put together in series horizontally above the motor. The assembled unit of motor and filters was mounted inside of the engine room of the bus, as shown in Fig. 9.



(a) Dimension of the filtering device case. (b) Scheme of filter device case.

Fig. 7. Designed filtering device prototype.



(a) Motor (b) Filter (c) Device
case

Fig. 8. Installation of motor and filters.

Fig. 9. Mounted device inside of the engine room.

4.3 Test Results

The bus mounted with the device had traveled 12 days (two weeks) along the original bus route around Ulaanbaatar city. Road dust had been collected by the device during the bus operation time, nearly 15 hours per day. Collecting road dust was performed in two different ways. During the first 6 days of test, the inlet of the device prototype was not extended to the outside of the bus. Thus, the air inside of the engine room was sucked and filtered by the device. After this, the inlet was extended to the outside of the bus so that the device could suck the air from the rear outside of the bus. The second test also was done for the same duration as of the first test in order to compare the performance of the device depending on the inlet types.

Table 3 shows the total dust amount collected from the two tests. The same filters from the first test were also used for the second test. From the first test, the road dust amount collected by the device was measured as 30.16 g, while it was 125.52 g from the second test. The difference in the collected road dust between two tests was attributed to the vortex at the rear side of the bus. When the bus runs, the vortices produced by the negative pressure at the rear surface of the bus blows the dusty air to the bus as shown in Fig. 6. The flying dusty air could not flow into the engine room because the rear body plate of the bus blocks this flow. So the inlet of the device could not suck this dusty air. That is why the collected road dust from the first test was smaller than that of the second test, in which the dusty air flew into the device through the inlet extended to the outside of the bus.

Table 3. Test results: collected road dust weight.

Description	Original filter weight (g)	Filter with dust (g)	
		First test	Second test
Filter one	135.96	153.22	216.88
Filter two	138.09	150.99	182.69
Total dust amount	-	30.16	125.52*

* The net road dust amount collected from the second test is 95.36 g (=125.52 – 30.16).

The performance of the device was measured by the ratio of the total weight of the dust collected to the air volume sucked into the device by the motor. The air volume the motor sucked was computed as: 1,000 m^3/hr × 6 days × 15 hr = 90,000 m^3/hr. The road dust amount collected by the device is 30.16 g and 95.36 g from the first and second test, respectively. Thus, the performance of the device in the two tests is 300 μg/ m^3 and 1,100 μg/ m^3, respectively.

5 Conclusion

In this study, the new road dust filtering device prototype was proposed. The device was designed and mounted on a public bus. The bus movement distrubed the road dust on the street and the dusty air was sucked by the device effectively. The test results showed the device's high performance in collecting road dust. The proposed device could be mounted on many public buses to collect more road dust with minimum effort in the future.

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