ON-BOARD MEASUREMENT AND EMISSION PREDICTION FROM VEHICLE ENGINES USING ORDINARY FUEL AND FUEL ADDITIVES IN MONGOLIA

Batjargal BAYASGALAN\textsuperscript{1}, Toru MATSUMOTO\textsuperscript{2} and Ochirbat ALTANGEREL\textsuperscript{3}

\textsuperscript{1}Doctoral student, Graduate School of Environmental Eng., University of Kitakyushu
(1-1 Hibikino, Wakamatsu-ku, Kitakyushu, Fukuoka 808-0135, Japan) E-mail: w5dac401@eng.kitakyu-u.ac.jp

\textsuperscript{2}Professor, Faculty of Environmental Eng., University of Kitakyushu
(1-1 Hibikino, Wakamatsu-ku, Kitakyushu, Fukuoka 808-0135, Japan) E-mail: matsumoto-t@kitakyu-u.ac.jp

\textsuperscript{3}Officer of Air Pollution Reduce Department of the Capital city
(#501 Khangarid building, Chingeltei district, Ulaanbaatar, Mongolia) E-mail: ochir_allan@yahoo.com

Today, gasoline and diesel fuel with high sulfur content are widely used in Mongolia. According to the analysis results of fuel sample, the sulfur content in gasoline and diesel meet the Mongolian National Standard requirements, but the sulfur content in gasoline is two to eight times higher than that of the Euro 4 standard, and the sulfur content of diesel is also 22 to 23 times higher than that of the Euro 4 standard. We tested Lubricon A-112M, which is an enzyme-based additive used in bunker fuel. In this study, we conducted an emission factor measurement by using two vehicles with gasoline and diesel engines under three conditions; using ordinary fuel, using fuel additive once, and using fuel additive for six months. Then, vehicle emission was predicted by comparing EF measurement results.

The results show that for the vehicle with a gasoline engine, when using Lubricon A-112M, the emission level of NOx decreased by 1.69 to 1.87 times (26\%–37\%). For the vehicle with a diesel engine, when using Lubricon A-112M, the emission level of NOx decreased by 1.04 to 1.51 times (4\%–30\%), and the emission level of particulate matter (PM) decreased by 1.52 to 2.06 times (20\%–26\%). We compared the results obtained in real situation with those obtained in the scenario in which the fuel additive was used and the new gas exhaust standard was applied. In this scenario, the fuel additive was used in 30\% of all vehicles from 2016, and the Euro 4 standard was applied to all vehicles except those over 10 years old from 2020. The results of the scenario show that the emission level of NOx and PM reduced by approximately 8\% and 13\% in real situation until 2020. After that, NOx and PM reduced by 6–22\% and 16–30\%, respectively.

\textbf{Key Words :} emission factor measurement, vehicle emission, emission prediction

1. INTRODUCTION

In recent years, the level of air pollution in Ulaanbaatar city in Mongolia has increased greatly. The main sources of such air pollution consist of emissions from stationary sources and vehicles.

In the last decade, the number of vehicles in the capital city has increased more than 4.5 times. Sixty percent of motor vehicles in Mongolia can be found in Ulaanbaatar city. The increase in the number of vehicles has been high, and therefore, the load on roads and traffic congestion has become worse. As
per statistics in 2015, there are approximately 331.5 thousand vehicles, out of which 72% are over 10 years old. Most of the people in the city use second-hand vehicles because of the low standard of living; approximately 96% of vehicles are four years or older.

Currently, all petroleum products in Mongolia are imported. In 2015, 1,090 tons of fuel were imported, out of which 94% of the total was from Russia. With regard to fuel categories, diesel and gasoline constituted 59% and 39% of the total fuel, respectively, in 2015 (see Fig.1). The supply of fuel to Ulaanbaatar users was 44%. In recent years, the import of diesel fuel has decreased owing to mining activities.

Currently, the Mongolian National Standard (MNS) of vehicle fuel is similar to Euro 2 standard, but the sulfur content of diesel is four times higher than that of Euro 2 standard (see Table 1). Considering the analysis results of fuel sample, the sulfur content in gasoline and diesel meets the MNS requirements, but the sulfur content in gasoline is two to eight times and diesel is 22 to 23 times higher than those of the Euro 4 standard, respectively. Therefore, using fuel that contains a high quantity of sulfur, disrupts the normal operation of the system for filtering air pollutants in vehicles (see Table 2).

We did not find any research article similar to our study, but we found some related research papers; for example, the emission measurements conducted on board two ships with a focus on comparing number concentrations of ultrafine particles in diluted exhaust for three different fuel qualities. The fuels are chosen based on their relevance to existing and coming into force regulations on sulfur in fuel. The research on particulate emissions from direct-injection common-rail (DI CR) diesel vehicle fuelled with research fuels of differing sulfur content. The experiments confirmed the distinct influence of sulfur content in diesel fuel on particulate emissions. Set of laboratory tests were carried out to investigate the engine performance using four-stroke petrol engine under different operating conditions.

It is impossible to clean the air, or in particular to reduce air pollution from the transportation sector, without getting sulfur out of fuels. No significant air pollution reduction strategy can work without reducing sulfur to near-zero levels. Sulfur fouls conventional and advanced technologies to control vehicle emissions, including carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NOx) and hydrocarbons (HC). Low-sulfur fuels are the key to reducing emissions from existing vehicles and enabling advanced control technologies and fuel-efficient designs for new vehicles.

There are 11 ambient air-quality monitoring stations in Ulaanbaatar city. The MNS of the average air quality for SO2, considering a year, is 0.01 μg/m3, and for NO2, it is 0.03 μg/m3. The annual concentration levels of SO2 and NO2 have exceeded MNS since 2010. The annual average concentrations of SO2 have increased from 0.007 μg/m3 in 1999 to 0.085 μg/m3 in 2015, which is 12 times higher. The annual average concentrations of NO2 have increased from 0.007 μg/m3 in 1999 to 0.054 μg/m3 in 2015, which is eight times higher (see Fig.2).

One of the main reasons for vehicle emission is fuel quality. Thus, we tested a fuel additive (Lubricon A-112M), which is an enzyme-based additive used in...
bunker fuel vehicles. It keeps the inside of the engine clean, thereby reducing the emissions of nitrogen oxides (NOx), suspended particulate matter (SPM), and hydrocarbons (HC)\(^{10}\). Moreover, it has 20% less sulfur content than diesel following the result of Laboratory of Petroleum Product Analysis Mongolia\(^{11}\). Thus, vehicle emission predictions were conducted in cases using fuel additives and applying Euro 4 standard.

The use of fuel additive in emission factor measurement was conducted for the first time in Mongolia. In an effort to assess the effectiveness of the Euro 4 standard and vehicle fuel additive, and also to support the update of current EF databases, emission data from two passenger cars (both diesel and gasoline) were collected and analyzed. This emission prediction model is worth supporting in national emission inventories and assessing the performance of air quality policies.

2. METHODS

Lubricon A-112M (fuel additive) is a new product that was first introduced in late 2016 in Mongolia. In the past, EF measurement was not tested on this type of product in Mongolia. In this study, two vehicles with gasoline and diesel engines were selected. We conducted emission factor (EF) measurement under three conditions: (1) using ordinary fuel, (2) using fuel additive once, and (3) using fuel additive for six months. Then, vehicle emissions were predicted by comparing the EF measurement results.

(1) Emission factor measurement

Two types of vehicles were used in this study. The first one was a 1300-cc gasoline-engine-powered Hyundai, an Accent passenger car, which was manufactured in 2005. The Gross Vehicle Weight rating (GVWR) was 1580 kg. The second one was a 2600-cc diesel-engine-powered Hyundai Grace micro-bus, which was manufactured in 2003; GVWR was 3045 kg. Accent and Grace are typically used for taxi and public transport in suburbs of Ulaanbaatar, Mongolia. It is also suitable for age classification and engine category (gasoline and diesel). By age classification, 3.7% of the total vehicles are 0-3 years old, 23.7% are 4-9 years old, and 72.6% are over 10 years old.

This study was conducted under three conditions: Accent1 and Grace1 used ordinary fuel, Accent2 and Grace2 used fuel additive once, and Accent3 and Grace3 used fuel additive for six months. We assumed that which product needed time to adapt to the engine, and also, it would reduce emission when used for a long time. For this reason, the fuel additive was for six months by these vehicles (see Table 3).

We aimed to study the amount of emitted PM and NOx from engines while vehicles were running, and thus, made a comparative assessment using ordinary fuel and fuel additive (Lubricon A-112M). The addition rate was 1,000:1 (1000 ppm = 1 g/L).

An on-board emission measurement system, which could only measure NOx for the vehicle with a gasoline engine, but could measure both NOx and PM for the vehicle with a diesel engine was used in this study. This measurement system measures the exhaust gas concentration (ppm) and exhaust flow from the exhaust pipe simultaneously.

Each test vehicle was conducted on two different
days to allow measurements. Further, two days were required to install and remove the emission measurement system from the vehicle. It took four days to complete a single measurement.

Two different routes were used for measurements (see Figs.3–4). These two routes passed through main roads with high traffic volume. Traffic census taken on the main road showed 470 million vehicles a year in Ulaanbaatar. By vehicle type, 92% of all vehicles was a passenger car. Buses and trucks made up 8% of all traffic census. People usually prefer their own private car to public transport because the public transport is not well developed in Mongolia\(^\text{12}\).

Using the measurement results, emission (g) was calculated. Moreover, with the system installed in the target vehicle, the emission under all conditions (acceleration, deceleration, constant speed, and stop) was measured. The on-board emission measurement system was different and more advanced than the general portable exhaust gas analyzer. The concentration of NOx and PM, fuel consumption, and GPS location were measured at intervals of 0.5 s. Because sensors that could be installed in an engine exhaust pipe to take measurements were available, using a separate instrument was not required for taking samples. Therefore, samples were not kept in static volume as it was possible to take quick measurements (see Figs.5–7\(^\text{5}\)).

(2) Emission prediction

A dynamic model of mobile sources of air pollution was used to predict the emission levels from vehicles with a monitoring system over time. Stella Professional is a dynamic modeling software that helps researchers understand how the environment modifies and make predictions on how it will evolve in the future\(^\text{13}\).

Fig.5 On-board emission measurement system scheme.

Fig.6 MEXA-720 NOx analyzer.

Fig.7 MEXA-130S PM analyzer.

Fig.8 Passenger car cohort model with leakage.
Here, we aimed to assess the effectiveness of using fuel additives and applying the new gas exhaust standard. We compared the results obtained in real situations with those in the scenario in which fuel additive was used and the new gas exhaust standard was applied.

In this scenario, the Lubricon A-112M fuel additive was used in 30% of all vehicles from 2016, and the Euro 4 standard was used for all vehicles except those over 10 years old from 2020.

We used the average reduction rate of fuel additive EF measurement results for emission component in the scenario.

The Stella model included seven vehicle submodels, based on the seven vehicle classifications used for Ulaanbaatar. The submodels included dividing the vehicle population into four different subpopulations (cohorts) based on their period of operation. Further, leakages were added for each cohort. These leakages represent untimely vehicle scrappage, either due to accidents or breakdowns. Finally, an emissions component was added (see Fig.8). The time in service of a light duty vehicle (LDV) was considered to be 20 years, and 25 years for a heavy duty vehicle (HDV). The number of new vehicles purchased every year was defined by the composition of the average exponential growth rate from 2007 to 2015, and the total number of vehicles in each vehicle classification\(^1\)^.

To calculate emission from a given population of vehicles, the following equation was used\(^1\): \(E_i = \sum_j V_j \times VKT_j \times EF_{ij}\)

Where

This formula is the same as the algorithm of the European Environmental Agency air pollutant emission inventory guidebook 2016 and used for calculating vehicle emission\(^1\). Thus, emission prediction is dependent on vehicle population prediction.

According to the emission inventory, vehicles are classified into two main groups: LDVs and HDVs.

These two groups are classified into smaller groups according to their period of operation as per the statistical data. Comparing the statistical data of 2015 with that of 2007, the total vehicle population increased by 3.6 times, the number of buses increased by 1.8 times, and the number of trucks increased by 4.3 times. The average increase in the number of vehicles was 17%. With regard to vehicle categories, in 2015, data show that 77.5% were passenger cars, 19% were trucks, and 3.5% were buses. We used the total distance traveled by the vehicles annually by vehicle kilometer traveled (VKT) data of capacity development project for air pollution control in Ulaanbaatar city report (see Tables 4–5, Figs.9–10\(^1\)).

The emission factors are closely related to vehicle traffic speed. The level of emission factor depends on...
vehicle speed. The daily average speed on the road was 30 km/h.

The emission factor was selected with regard to the classification and age of the vehicles (see Fig.11)\(^{13}\). For vehicles with diesel engines, the emission factor unit is gram/kilometer/ton (g/km/t); therefore, it is necessary to multiply it by the gross vehicle weight (GVW). The GVW of a LDV is 2.3 tons and that of an HDV is 15.7 tons\(^{13}\).

3. RESULTS AND DISCUSSION

(1) Emission factor measurement

The results show that there is no big difference when using fuel additive for the vehicle with gasoline engine once or for a long time. However, it is more effective to use fuel additive for a long time to reduce NOx emission for the vehicle with a diesel engine.

When using fuel additive for vehicle with diesel engine once, the emission level of NOx decreased by an average of 4% and when using it for six months, the emission level of NOx decreased by an average of 30% (see Table 6 and Figs.12–14). For the vehicle with a gasoline engine, when using fuel additive, the emission level of NOx decreased by an average of 1.69 to 1.87 times (26%–37%). For the vehicle with a diesel engine, when using fuel additive, the emission level of NOx decreased by an average of 1.04 to 1.51 times (4%–30%), and the emission level of PM decreased by 1.52 to 2.06 times (20%–26%) (see Table 7). The emission level of NOx tended to decrease as the vehicle speed increased (20–60 km/h), but for the PM, it tended to decrease with the increase in speed, only when using the fuel additive (until 40 km/h), (see Table 7).

Table 4 Vehicle population (2015).

| Vehicle classification | Proportion |
|------------------------|------------|
| Gasoline               | 77.50%     |
| Diesel                 |            |

| Vehicle classification | (No. of vehicles) |
|------------------------|-------------------|
| Petrol car             | 234028            |
| Taxi                   | 593               |
| Bus                    |                   |
| Public                 | 1665              |
| 10-16 seats            | 291               |
| 17-25 seats            | 61                |
| 26-45 seats            | 1313              |
| Private                | 9795              |
| 17-25 seats            | 4064              |
| 26-45 seats            | 491               |

Table 5 VKT for vehicle classification.

| Vehicle classification | VKT (km/year) |
|------------------------|---------------|
| Petrol car             | 12000         |
| Taxi                   | 73000         |
| Truck                  |               |
| GVW<3 ton              | 12000         |
| GVW>3 ton              | 6000          |

| Bus                     | Public | Private |
|-------------------------|--------|---------|
| 10-16 seats             | 7200   | 12000   |
| 17-25 seats             | 7200   | 6000    |
| 26-45 seats             | 15900  | 6000    |

Table 6 Regression coefficient of EF measurement.

| Regression coefficient | EF measurement of vehicle type | Ac- cent_1 | Ac- cent_2 | Ac- cent_3 |
|------------------------|--------------------------------|------------|------------|------------|
| Nox_Accent             | a                              | -0.005     | -0.015     | -0.013     |
|                        | b                              | 0.000      | 0.000      | 0.000      |
|                        | c                              | 1.925      | 0.313      | 0.919      |
|                        | d                              | 0.835      | 0.731      | 0.714      |
| Grace_Accent           | a                              | 0.008      | -0.011     | -0.004     |
|                        | b                              | 0.000      | 0.000      | 0.000      |
|                        | c                              | 10.691     | 6.509      | 4.890      |
|                        | d                              | -0.175     | 0.340      | 0.198      |
| Nox_Grace              | a                              | 0.002      | -0.001     | -0.003     |
|                        | b                              | 0.000      | 0.000      | 0.000      |
|                        | c                              | 0.363      | 0.045      | -0.100     |
|                        | d                              | -0.015     | 0.040      | 0.070      |

Fig.11 Passenger car (gasoline), EF of NOx.
We predicted vehicle emission in two types of situation: the real situation and a scenario. The real situation means the current situation. The scenario means a situation where actions should be taken to reduce vehicle emission.

In comparing the real situation with the scenario, the emission levels of NOx and PM reduced by approximately 8% and 13% until 2020. After that, the emission levels of NOx and PM reduced by 6%–22% and 16%–30%. Thus, it means that the emission levels of NOx and PM reduced by 8% and 13%, respectively, when using fuel additive, and 6%–22% and 16%–30% when applying the Euro 4 standard (see Table 8, Figs. 15, 16).

For HDV, in comparing the real situation with the scenario, the emission levels of NOx and PM reduced by 7%-38% and 13%-42%. However, the emission level of LDV was similar in the real situation and in the scenario. This scenario was more effective to HDV, but for LDV, it was not. The emission levels of NOx and PM in LDV reduced by approximately 10% and 13% when using the fuel additive. Because the EF level in the real situation was similar to that of the Euro 4 standard, there was no big difference when applying the Euro 4 standard to vehicles 0-9 years old. If we apply this standard to vehicles over 10 years old, there will be a big difference in LDV emission. In other words, for HDV, the emission levels of NOx and PM reduced by approximately 7% and 13% when using fuel additive, also 17%–38%, 21–42% when applying the Euro 4 standard (see Figs. 17, 18).

This scenario is more efficient for the vehicle with a diesel engine and HDV.

### Table 7 Average reduction rate.

|                      | NOx  | PM  | NOx  | PM  |
|----------------------|------|-----|------|-----|
| Average reduction rate of Accent1 and Grace1 |      |     |      |     |
| **(times)**          |      |     |      |     |
| Accent1/Accent2      | 1.87 | -   | 37%  | -   |
| Accent1/Accent3      | 1.69 | -   | 26%  | -   |
| Average              | 1.77 | -   | 31%  | -   |
| **(percent)**        |      |     |      |     |

### Table 8 Emission prediction.

| Years | NOx Real situation | Scenario | PM Real situation | Scenario |
|-------|--------------------|----------|-------------------|----------|
| 2016  | 4743.0             | 4333.6   | 330.8             | 286.9    |
| 2017  | 4550.0             | 4157.3   | 316.1             | 274.2    |
| 2020  | 4650.3             | 4465.9   | 308.5             | 268.1    |
| 2022  | 4865.5             | 4347.7   | 319.9             | 254.0    |
| 2024  | 5088.7             | 4142.7   | 332.5             | 233.9    |
| 2025  | 5384.4             | 4375.5   | 353.4             | 249.8    |
| 2026  | 5709.3             | 4617.7   | 376.8             | 267.7    |
| 2028  | 5552.2             | 5267.3   | 432.3             | 310.1    |
| 2030  | 7564.2             | 6043.0   | 500.3             | 362.0    |
| 2032  | 8922.2             | 7088.7   | 591.6             | 433.6    |
| 2034  | 10682.9            | 8491.6   | 705.5             | 522.9    |
| 2035  | 11512.1            | 9110.7   | 768.7             | 571.5    |
| 2036  | 12436.1            | 9711.5   | 839.9             | 626.2    |
| 2038  | 14718.4            | 11424.0  | 1010.0            | 756.7    |
| 2040  | 17272.4            | 13389.1  | 1190.1            | 886.9    |
4. CONCLUSION

It is more effective to use Lubricon A-112M for the vehicle with a gasoline engine for NOx reduction and for the vehicle with a diesel engine for PM reduction. The fuel additive is more efficient for NOx reduction in the vehicle with a diesel engine when used for a long time. According to the study, the Euro 4 standard is more effective for HDV.

We did not apply our scenario to vehicles over 10 years old, thus this study covered about 30% of the total vehicles. As to the measurement results, usually the EF level of vehicles over 10 years old exceeded Euro 4 standard. For example, in the passenger car, NOx EF in the real situation was 10-70 times higher than Euro 4 standard (see Fig.19). Also, there was no vehicle EF standard, as it is new in Mongolia; therefore, we did not apply Euro 4 standard to all vehicles.

Currently, vehicles over 10 years old account for 70% of total vehicles. If this study covered 50%-60% of total vehicles, the result would be quite different and more efficient. To do this, we need a proper legal arrangement to control and reduce the population of old vehicles. In addition, legislation or technology alone cannot bring down emission levels significantly if the fuel quality does not improve. Currently, high-sulfur-content gasoline and diesel fuels are used in Mongolia. Therefore, the standard of vehicle fuel needs to be updated according to more suitable terms.

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