Overview

1. Purpose

The purpose of this study was to investigate the effects of fuel properties on the emissions of particulate matter (PM) and particle number (PN) emitted from vehicles equipped with direct injection engines using gasoline as fuel (GDI vehicle: gasoline direct injection vehicles) and to gather the knowledge needed for considering the introduction of PN regulations.

2. Introduction

In order to investigate the effects of fuel on PM and PN emissions, tests to measure PM and PN emissions were conducted using three types of regular gasoline having different specific gravity in terms of PM-Index and distillation properties for two GDI vehicles.

In 2019, we investigated the effect of the fuel properties of regular gasoline on PM and PN emissions. For this reason, vehicles and fuels are indicated by serial numbers.

3. Methods

3.1 Tested vehicles

Two gasoline direct injection passenger vehicles currently sold in Japan were used as test vehicles. One was a 1.3-liter passenger vehicle that complies with the 50% reduction in the 2018 regulations (Vehicle C). The other was a 1.5-liter passenger vehicle that meets the 2018 regulations (Vehicle D).

3.2 Test fuels

Three types of test fuels were used: ④ premium gasoline for domestic certification test (④ for WLTC P), ⑤ premium gasoline made heavier by adding 1-methylnaphthalene, etc. to the fuel for ④ certification test (⑤ for WLTC Heavier P), and ⑥ premium gasoline sold at retail stores (⑥ for Market P).

The specific gravity of the test fuel was confirmed from the following three properties: Particulate Matter Index (PM-Index), which is considered to be an index of PM emissions; the simplified PM-Index (SPMI), which is intended to easily obtain a value close to PM-Index; and the volume fraction of aromatics that have a carbon number (C: carbons) of 10 or more and therefore tend to generate PM easily. SPMI is calculated from the percentage of fuel distilled at 130°C and 170°C. As for the aromatic components, since the test fuels in this study contained aromatic components up to C13, the specific gravity was confirmed from the volume fraction of aromatic components from C10 to C13 (C10-13 Aroma).

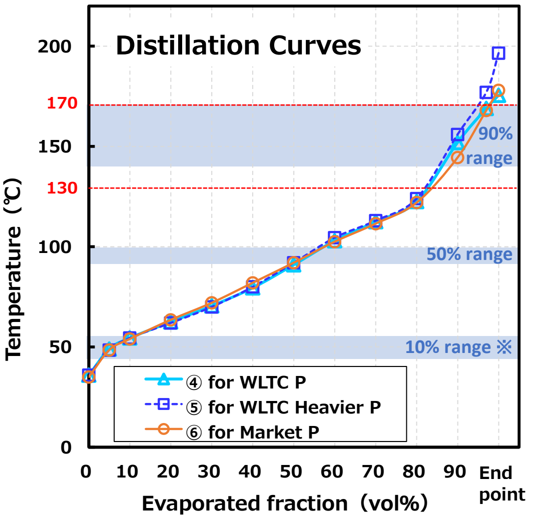


Fig. 1 Distillation curves of the test fuels

* Range of premium gasoline for authentication test by WLTC in Japan.

PM-Index : ⑤ for WLTC Heavier P (2.0) > ④ for WLTC P (1.3) > ⑥ for Market P (1.1)

SPMI : ⑤ for WLTC Heavier P (1.1) > ④ for WLTC P (0.88) > ⑥ for Market P (0.86)

C10-13 Aroma : ⑤ for WLTC Heavier P (3.3) > ④ for WLTC P (2.5) > ⑥ for Market P (1.3)

The specific gravity of the test fuel was confirmed from the distillation characteristics. It was found that ⑤ for WLTC Heavier P was the heaviest (Fig. 1).

3.3 Study items

The emissions that were studied were PM and PN, as well as regulated substances (CO, NMHC, NOx), total hydrocarbons (THC), carbon dioxide (CO_2), nitric oxide (NO), nitrogen dioxide (NO_2), and the carbon component in PM.

3.4 Test cycle

The test cycle consisted of four phases, namely three WLTC phases (Low, Medium, High: WLTC LMH) followed by Extra High (WLTC ExH). The test cycles were repeated three times or more.

4. Results

4.1 PM emissions

The emissions obtained were generally higher in order of heavier fuel. The average emission of WLTC LMH of vehicle C was 2.6 times higher in the case of ⑤ for WLTC Heavier, compared to ④ for WLTC when used as the reference, and 2.7 times higher in the case of WLTC LMH + ExH. As for vehicle D, the average emission of WLTC LMH was 1.8 times higher in the case of ⑤ for WLTC Heavier, compared to ④ for WLTC when used as the reference, and 2.0 times higher in the case of WLTC LMH + ExH. WLTC ExH was not controversial due to its low emissions. In addition, it was found that the effect of fuel properties on the PM emissions was larger than that of the PN emissions as described below.

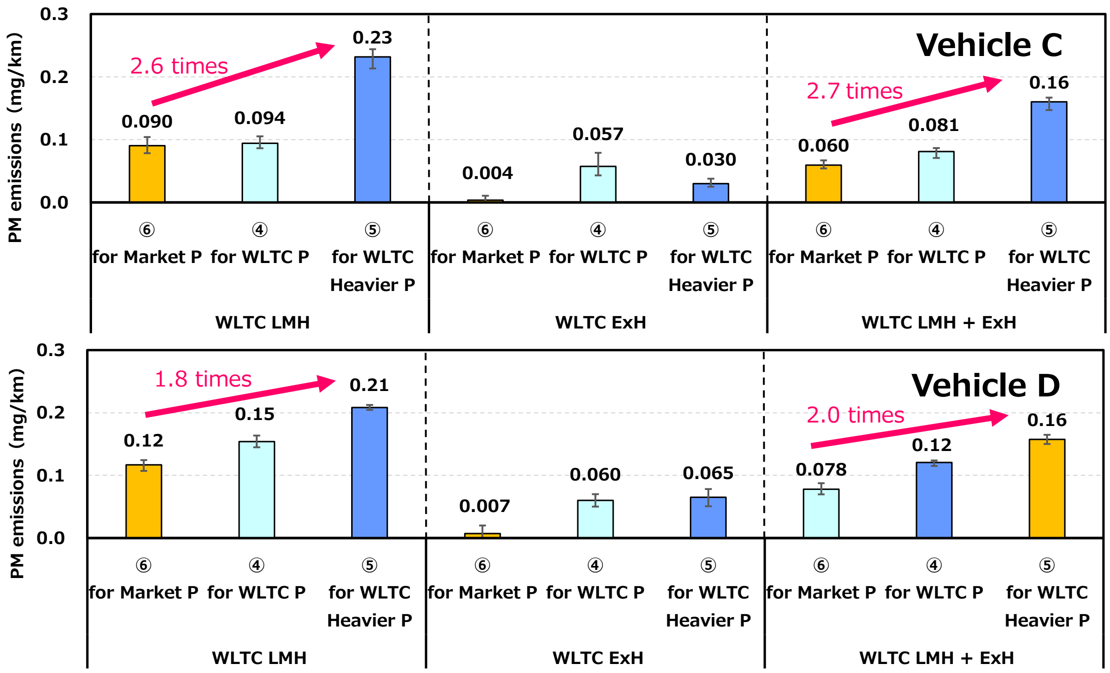


Fig. 2 Comparison of PM emissions from fuels having different properties (error bars indicate maximum and minimum)

4.2 PN emission amounts and emission behavior

As with the PM emissions, the PN emissions increased in the same order as fuel heaviness (Fig. 3). The average emission of WLTC LMH and WLTC LMH + ExH of vehicle C became 1.4 times higher in the case of ⑤ for WLTC Heavier, compared to ④ for WLTC when used as the reference. As for vehicle D, the average emission of WLTC LMH and WLTC LMH + ExH became 1.5 times higher in the case of ⑤ for WLTC Heavier, compared to ④ for WLTC when used as the reference. WLTC ExH was not controversial due to its low emissions.

As regards the behavior of PN emissions, PN was emitted mainly after a cold start and during acceleration (Fig. 4). Also, a difference in PN emissions due to fuel heaviness was confirmed after a cold start and during acceleration. In WLTC ExH, where the engine was warmed up at a high temperature, there was no obvious effect of fuel difference even if PN was emitted during acceleration. In addition, the cumulative emission rate of PN was confirmed in chronological order, and the contribution rate of each test phase to the total PN emission amount differed greatly depending on the vehicle model (Fig. 5). Therefore, it was expected that there would be various emission patterns in other vehicle models traveling in a general environment.

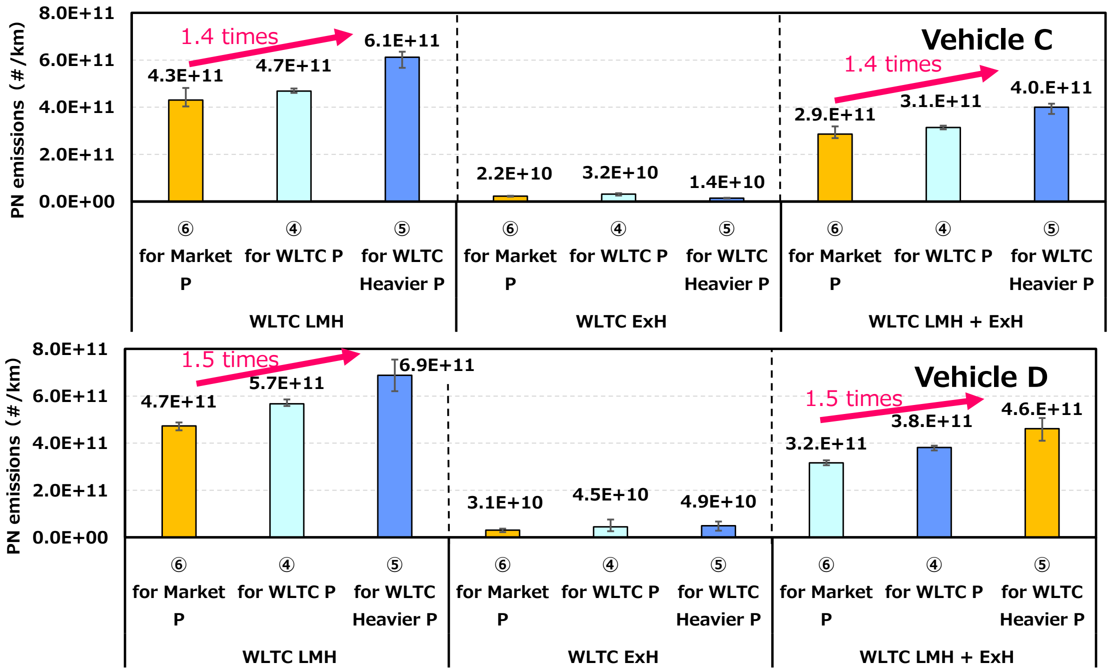


Fig. 3 Comparison of PN emissions from fuels having different properties

(error bars indicate maximum and minimum)

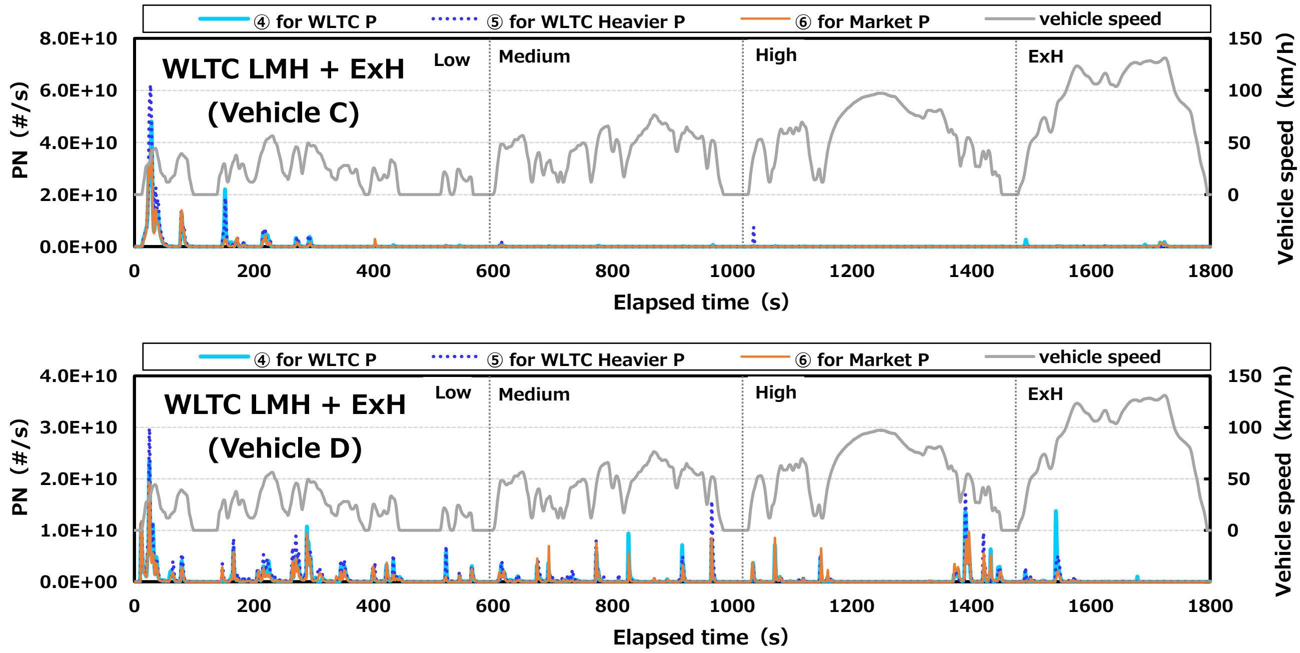


Fig. 4 PN emission behaviors in WLTC LMH + ExH

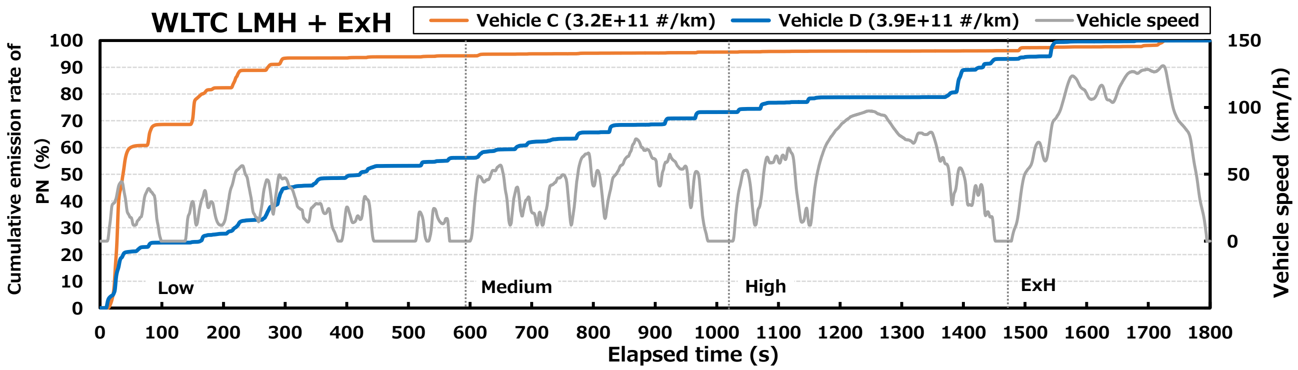
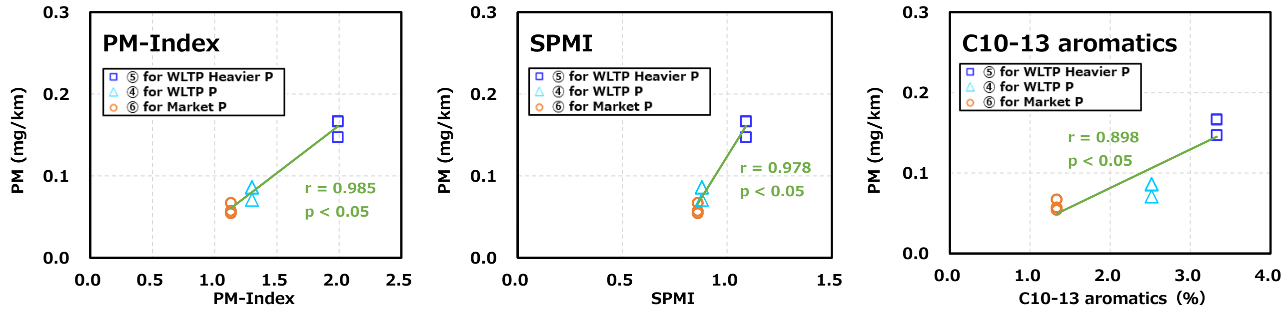


Fig. 5 Cumulative emission rate of PN in WLTC LMH + ExH (fuel is ④ for WLTC P)

4.3 Correlation between fuel properties and PM and PN emissions

Among the fuel properties, PM-Index, SPMI and C10-13, which are considered to be indicators of PM emissions, were confirmed to show a correlation between PM emissions and PN emissions for the three fuel properties. Taking WLTC LMH + ExH as an example, the correlation with PM emissions is shown in Fig. 6, and the correlation with PN emissions is shown in Fig. 7. In some cases, it was difficult to confirm the correlation because the PM-Index and SPMI of ④ for WLTC P and ⑥ for Market P were similar, and the emission of WLTC ExH was low. However, in WLTC LMH and WLTC LMH + ExH, the correlation coefficient of PM emissions and PN emissions was 0.8 or more under all conditions, and there was a significant correlation of $p < 0.05$. Therefore, the three properties used as indicators of severity were effective in predicting and evaluating the effects on PM and PN emissions.

➢ Vehicle C



➢ Vehicle D

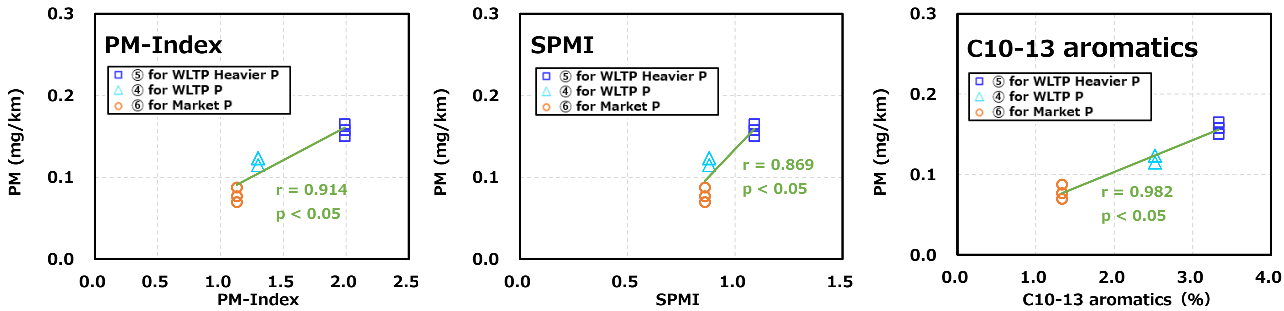
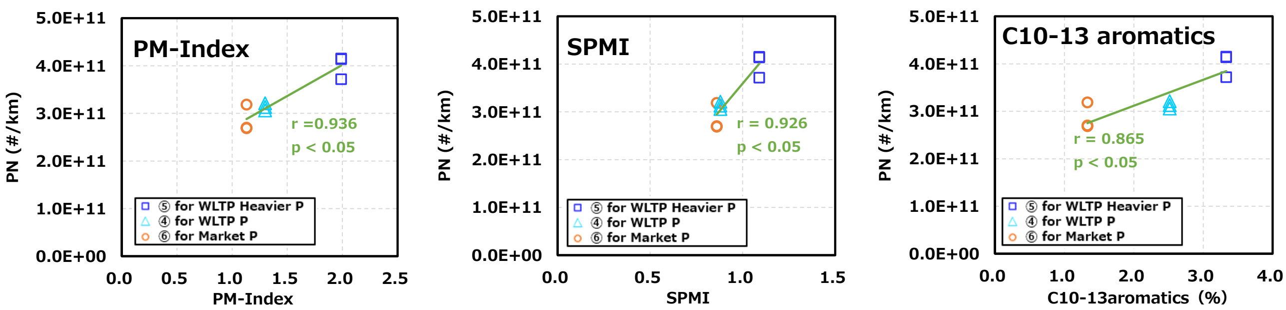


Fig. 6 Correlation between fuel properties and PM emissions in WLTC LMH + ExH

➢ Vehicle C



➢ Vehicle D

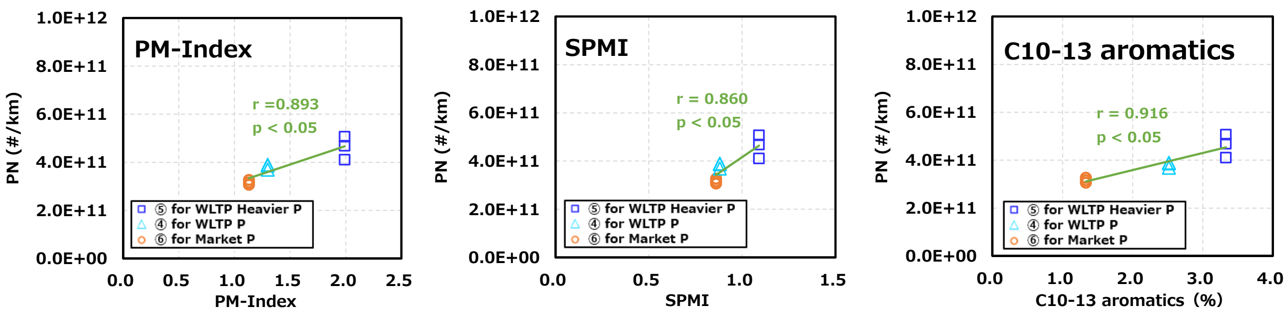


Fig. 7 Correlation between fuel properties and PN emissions in WLTC LMH + ExH

5. Conclusions

The following results were obtained in this study.

- The PM-Index, SPMI, and C10-13 aromatics, which are indicators of fuel specific gravity, were significantly correlated with PM and PN emissions. The emissions increased as the fuel became heavier.
- The effect of fuel properties on emissions was greater for PM than for PN.
- The effects of fuel properties on PN emissions were mainly observed during a cold start and acceleration.
- However, there was no obvious effect of differences in fuel properties on PN emissions when the engines were fully warmed up.
- the cumulative emission rate of PN was confirmed in chronological order, and the contribution rate of each test phase to the total PN emission amount differed greatly depending on the vehicle model.
- No effect of fuel heaviness was observed for the survey substances other than PN and PM.

6. Future issues

This study revealed that the emissions of PM, PN, and PM-related substances greatly changed depending on the fuel properties. However, further studies are needed to determine which fuel properties will affect emissions and to what extent. In addition, the cumulative emission rate of PN was confirmed in chronological order, and the contribution rate of each test phase to the total PN emission amount differed greatly depending on the vehicle model. Therefore, it is considered that the contribution rate of each test phase differs greatly depending on the vehicle type in the PM emissions as well as the PN emissions. These results suggest that the effects of fuel also differ depending on the vehicle type, so it is necessary to collect data for different vehicle types.

The United Nations requires emission regulations under temperature conditions that match the actual driving environment, and UN-ECE / WP29 is considering adding low-temperature tests and high-temperature tests to the emission regulation test method. Furthermore, in the thirteenth report released in May 2017, Japan states that “Japan should actively participate in and contribute to the review of international standards.” Therefore, in order to respond to future regulations, further study is needed to understand the status of emissions at low temperatures where emissions increase, and the effects of fuel properties on PM and PN emissions in low-temperature environments.