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Real-World Pipe-Out Emissions from Gasoline Direct Injection Passenger Cars

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Abstract: The analysis of real-world emissions is necessary to reduce the emissions of vehicles during on-road driving. In this paper, the matrix of gasoline direct injection passenger cars is applied to analyze the real-world emissions. The results show that high acceleration and high speed conditions are major conditions for the particulate number emissions, and the particulate number emissions are positively correlated with torque and throttle opening. The catalyst temperature and saturation are important factors that affect nitrogen oxide emission. The nitrogen oxide emissions of low speed and low torque conditions cannot be ignored in real-world driving. The carbon dioxide emissions are positively correlated with acceleration, torque and throttle opening. Once the vehicles are in the acceleration condition, the carbon dioxide emissions increase rapidly. The vehicles with higher average emission factors are more susceptible to driving behaviors, and the differences in the emission factors are more obvious, leading to an increase in the difficulty of emission control.

Keywords: GDI vehicles; real-world emissions; particulate number; nitrogen oxides; carbon dioxide; driving behavior

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1. Introduction

In recent years, there has been a growing focus on air pollution, including particulate matter (PM) and gaseous emissions [1]. PM is one of the main causes for smog, and gaseous pollutants such as carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NO_x) seriously endanger human health [2]. Additionally, carbon dioxide (CO_2) emissions contribute to global warming and rising sea levels, which threaten the human living environment [3]. Exhaust emissions from on-road vehicles are the main factor behind the mentioned types of air pollution [4,5]. Strict emission regulations and testing procedures are legislated to reduce exhaust emissions [6].

The gasoline direct injection (GDI) vehicles are favored by commuters because of their high thermal efficiency and power density [7]. GDI vehicles accounted for more than two thirds of new cars in the European market [8]. However, the NO_x and particulate number (PN) emissions are higher than in Port Fuel Injection (PFI) vehicles. Rich fuel-air mixtures in local regions and the wet wall phenomenon in the combustion chamber are conducive to PN formation; in addition, a high combustion temperature and high oxygen concentration lead to NO_x emissions [9]. It is demonstrated that [10] cold start and transient operations account for a large proportion of the PN emissions of GDI vehicles. It is reported that the PN emissions of GDI vehicles are one order of magnitude higher than in PFI vehicles and diesel vehicles equipped with a diesel particulate filter (DPF) [11]. Most of the particles emitted by GDI vehicles are smaller than 100 nm, which can easily penetrate into the human respiratory system [12]. Therefore, the PN emissions of GDI vehicles should be paid much more attention [13]. Regarding NO_x emissions, cold start and warm-up events are the main sources in on-road vehicles because of the low efficiency in NO_x removal of the after-treatment system.

The type approval emissions of regulated gaseous pollutants (CO, HC, NO_x) in Euro 6 regulations are at a lower level, and particle emissions in both mass and number are

also limited for GDI vehicles. Currently, the CO_2 emissions of on-road vehicles are also regulated [14]. On-road vehicles are tested under the type approval cycles, such as the NEDC (New European Driving Cycle) and WLTC (Worldwide Light-duty Test Cycle), to ensure their low exhaust emissions [15]. In order to meet the requirements of emission regulations, a three-way catalytic converter (TWC) and gasoline particulate filter (GPF) are used to reduce HC, CO, NO_x and PN emissions from GDI vehicles [16]. The percentage reduction in PN emissions from GDI vehicles is 60–90% by GPF [17], and the PN emissions of GDI vehicles with GPF are reported to be lower than 9.5×10^{11} #/km under specific conditions [18]. However, the complexity of real-world driving conditions, such as the driving behavior, road type, traffic conditions, etc., lead to real-world driving emissions being much higher than the type approval emissions [19].

Driving behavior refers to the driving conditions induced by the driver habits, such as acceleration, vehicle speed, start-stop events, and gearshift strategies [20]. Driving behaviors in real-world conditions are complex [21], and aggressive driving behavior can lead to a sharp increase in NO_x, CO_2 and PN emissions. Gao et al. [22] reported that the NO_x emissions of GDI vehicles were more sensitive to acceleration than speed; meanwhile, more NO_x was emitted at low speed and high acceleration conditions. Huang et al. [23] found that aggressive driving behavior significantly increased the NO_x (from 22 mg/km to 27 mg/km), PN (from 1.2×10^{11} #/km to 2.7×10^{11} #/km) and CO_2 emissions (from 177.1 g/km to 215.2 g/km) of GDI vehicles on urban roads; in the meantime, the emission factors on urban roads were higher than on rural roads, which were followed by those of motorways. Yang et al. [24] concluded that the PN emissions of GDI vehicles were increased significantly by frequent acceleration events, and the peak PN concentration reached up to 4.0×10^7 #/cm^3. Kontes et al. [25] also pointed out that the PN emissions of GDI vehicles accounted for the largest proportion over urban roads. Momenimovahed [26] found that the increase in the traction power of GDI vehicles promoted an increase in PN emissions in real-world driving. The start-stop events are also important factors of the exhaust emissions [27]. Wang et al. [28] demonstrated that GDI vehicles emitted large amounts of NO_x during the warm-up period, which reached 85.39% of the total NO_x emission. Chen et al. [29] indicated that the particle emissions of GDI vehicles accounted for more than 50% of the total particle emissions in the NEDC driving cycle under cold start conditions. Myung et al. [30] revealed that driving modes lead to differences in the CO_2 and PN emissions of GDI vehicles in real-world driving.

In summary, the exhaust emissions of GDI vehicles in real-world driving have been widely investigated. However, there are few studies on the relationships between exhaust emissions and engine-vehicle related parameters being reported for GDI vehicles under real-world driving conditions, because the changes in engine-vehicle-related parameters are manifestations of the driving behavior. In addition, the effect of the differences between drivers is rarely explored. In this paper, the matrix of sixteen drivers and three different types of GDI vehicles is tested in real-world driving, and the influence of driver behavior on NO_x, CO_2 and PN emissions is analyzed. In addition, the emission factors of each vehicle are analyzed to discuss the difference between drivers. This paper provides evidence for the control of real-world exhaust emissions.

2. Experimental Section

In this work, three GDI vehicles were used to perform the real-world emission test in China. The specifications of the three GDI vehicles are shown in Table 1. The emission standards for the Golf, Peugeot-2008 and Focus are Euro-6a, Euro-6d and Euro-6c respectively. The type approval emissions of the Golf are authorized under the NEDC, and the Peugeot and Focus are under the WLTC. The Peugeot was equipped with a GPF in order to meet the PN requirements of regulations. Due to the protection of the experimental data, the vehicle specifications in tables are replaced by similar types, while the test results are unchanged. It does not have any impact on the analysis.

Table 1. Specifications of the three GDI vehicles.

Car Maker		Volks Wagenwerk	Peugeot	Ford
Model		Golf	Peugeot-2008	Focus
Manufacture year		2015	2019	2017
Fuel delivery		Direct injection	Direct injection	Direct injection
Aspiration		Turbocharged	Turbocharged	Turbocharged
Engine size/L		1.0	1.2	1.5
Max. power/kW		89.7	110	132.4
After-treatment	Gaseous	TWC	TWC	TWC
	Particles	N.A.	GPF	N.A.
Emission standards		Euro-6a	Euro-6d	Euro-6c
Gear number (type)		5 (M)	5 (A)	6 (M)
Type approval cycle		NEDC	WLTC	WLTC
Type approval NO_x (mg/km)		40	17.5	34.1
Type approval PN (10^{11} #/km)		N.A.	4.2	1.08
Type approval CO_2 (g/km)		99	153	115

In this study, three GDI vehicles were tested for emissions on real-world roads, and the test route included rural roads, urban roads, and motorways, corresponding to approximately 77%, 16%, and 7% of the total distance, which can reflect the differences between real roads. Sixteen drivers are included in the real-driving test. Each driver finished two tests along the given route with each vehicle. This means that each driver totally contributed six tests. In real-world driving, a state-of-the-art particle, PEMS (AVL M.O.V.E PEMS), and a gas PEMS were used to measure the instantaneous PN, NO_x, and CO_2 emissions from the three GDI vehicles recorded in the test, and the test scheme is shown in Figure 1. Finally, the relationships between driving behavior, vehicle operating parameters and real-world road emissions are analyzed. In order to avoid the impacts of high-volatility organic compounds and water vapor on particle monitoring, the petrol vehicles were fully warmed up and the system was calibrated before the test. For all the test events, no congestion was observed. The time of all test events was similar to ensure the similarity of the traffic conditions.

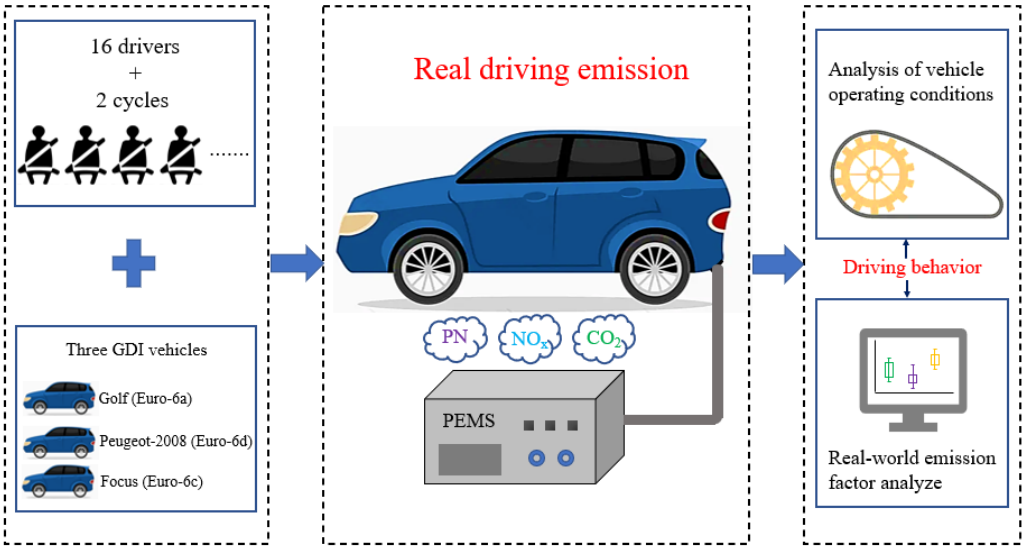


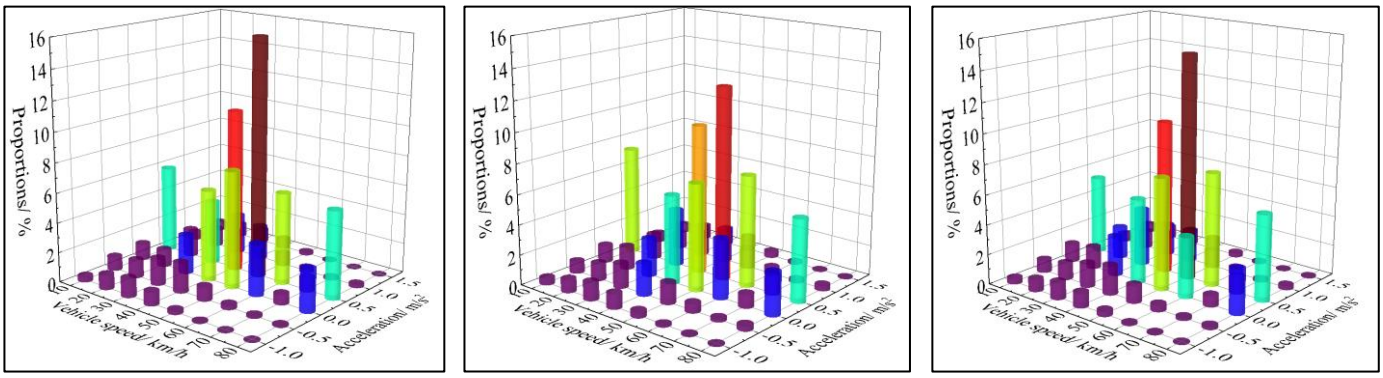
Figure 1. Test scheme.

3. Results and Discussions

3.1. Real-World Operations of Three GDI Vehicles

In order to investigate the driving behaviors in different GDI vehicles, the operating parameter distributions of real driving conditions are presented in this part. Figure 2 shows

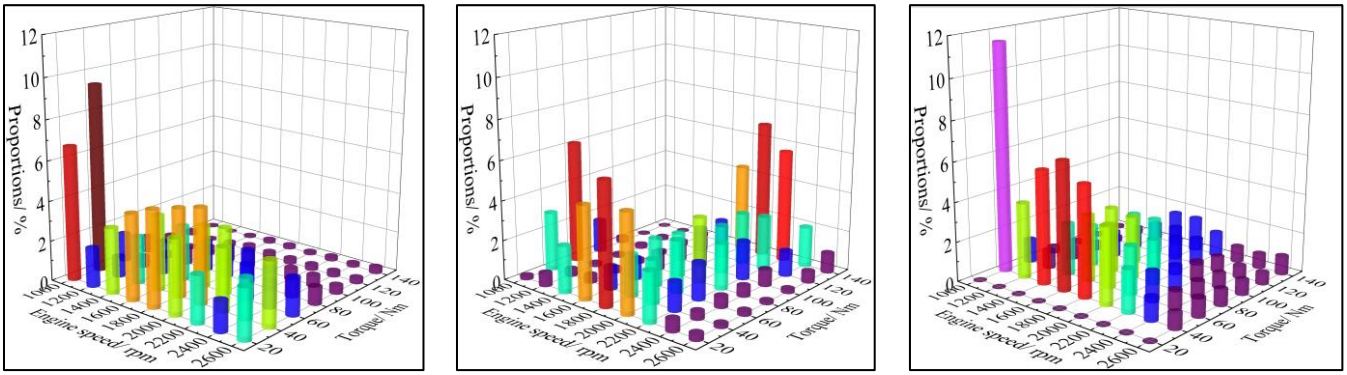
the operation distribution vs. vehicle speed and acceleration of the three vehicles. The results show that all the vehicles have similar distributions in velocity and acceleration. Because rural roads accounted for 77% of the total test distance, most of the operating points of the three vehicles range from 30–80 km/h, with an acceleration distribution of 0–0.5 m/s^2. The operating conditions of 50 km/h and 0.5 m/s^2 account for the largest proportion. The speed of 10 km/h and acceleration of 0.5 m/s^2 account for approximately 6% of the whole journey.



(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 2. Operation distribution vs. vehicle speed and acceleration.

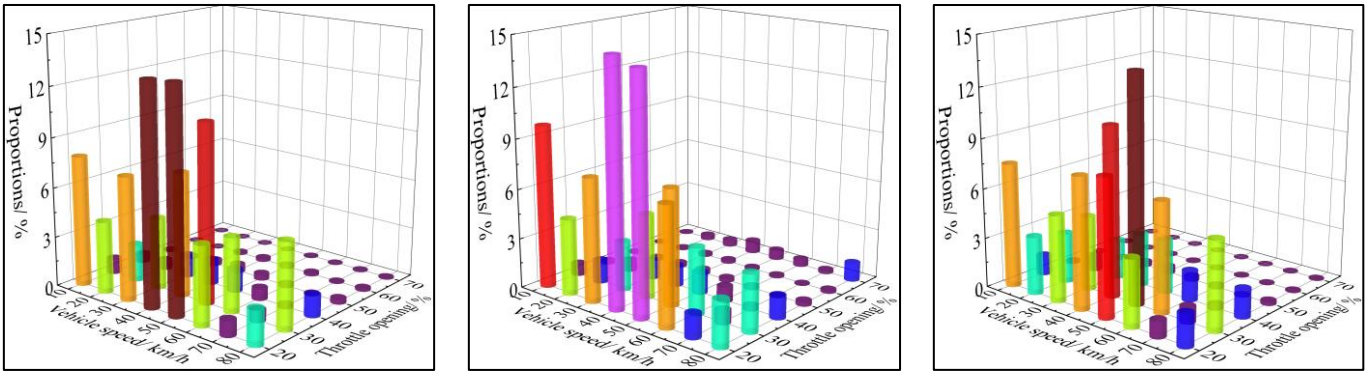
The distributions of the operating conditions as the effects of the engine speed and torque are significantly different among the three vehicles, as shown in Figure 3. Shahariar et al. [31] pointed out that the speed and torque distributions are also different for various driving styles, and aggressive driving styles led to high proportions of low speed and large torque. The figure indicates that the engine speed and torque distributions change significantly due to gear-shifted strategies and vehicle specifications. The engine speed and torque of the Golf are approximately evenly distributed among 1000–2600 rpm and 20–80 Nm; however, the engine speeds of the Peugeot are in the range of 1600–2200 rpm and 20–140 Nm. The Focus's speed and torque are distributed between 1000–2600 rpm and 40–140 Nm, and the small torque condition (40 Nm) accounts for a large proportion.



(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 3. Operation distribution vs. engine speed and torque.

Figure 4 shows the operation distribution vs. vehicle speed and throttle opening of the three vehicles during the test. For the three vehicles, the distributions of speed and throttle opening are similar. The operations of the three vehicles are mainly concentrated in the speed range of 10–80 km/h and throttle opening range of 20–40%, with the largest proportions occurring at the speed range of 40–50 km/h. In addition, three vehicles also account for a large proportion of low speed and small throttle opening conditions, such as 10 km/h speed and 20% throttle opening.

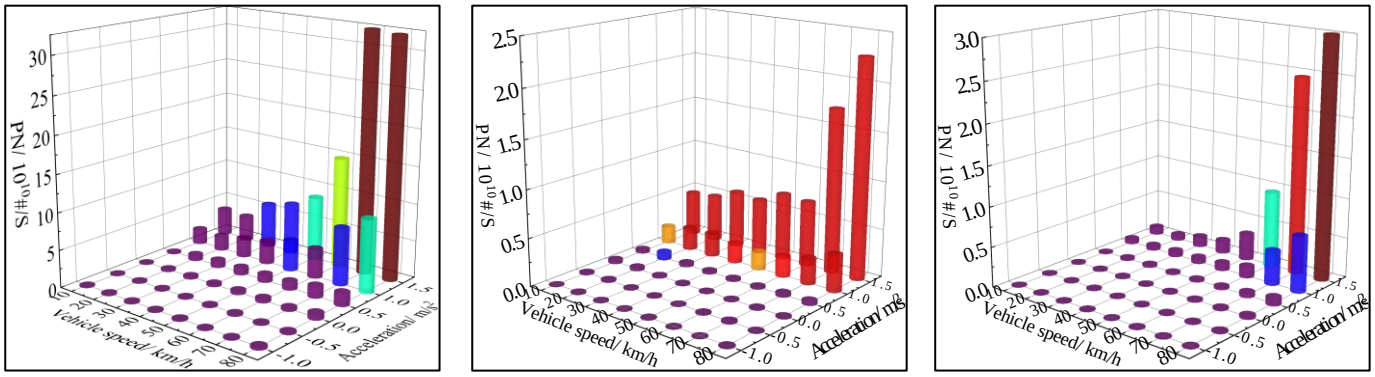


(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 4. Operation distribution vs. vehicle speed and throttle opening.

3.2. Real-World PN Emission Rate Distributions

In order to study the effect of driving behavior on real-world PN, NO_x and CO_2 emissions, and analyze the differences between different GDI vehicles, the changes in average instantaneous emission rates with the driving conditions were calculated. Figure 5 shows the PN emission rate vs. vehicle speed and acceleration of three vehicles during the real-world test. The results from Kontse et al. [32] showed that the PN emissions of non-GPF GDI vehicles (Euro 6b) exceeded 1.6 times of the emission limit under the cold-start RDE-compliant route. In this research, the vehicles were fully warmed up before the emission test. The average peak PN emission rate of the Golf is 10 times higher than the Peugeot, and the peak PN emission rate exceeds 30×10^{10} #/s. This is mainly caused by the fact that the Golf lacks a GPF. In addition, the type approval emissions of the Golf are Euro-6a compliant, and the type approval test cycle is NEDC, where the driving behaviors are more gentle than in the WLTC cycle [33], resulting in higher PN emissions for the Golf under real-world driving. The peak PN emission rates for the Focus do not present much difference from the Peugeot, as both passenger cars meet the Euro 6c standard's PN emission limits.



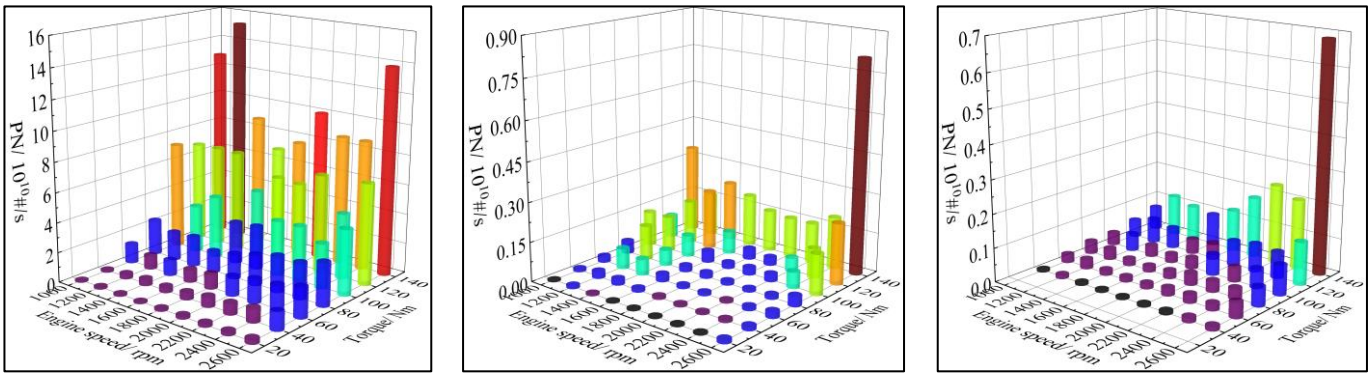
(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 5. PN emission rates vs. vehicle speed and acceleration.

The average instantaneous PN emission rates of three vehicles increase with the speed and acceleration. The PN emission rates reach peak values when the vehicles operate in the range of 70–80 km/h and with an acceleration of 1.5 m/s^2. This means that high acceleration and speed conditions are acute events of the PN emissions of GDI vehicles. Under such operating conditions, excessive fuel injection leads to a less even mixture in the combustion chambers, resulting in large amounts of PN emissions [34]. Pirjola et al. [35] investigated the PN emissions of turbocharged GDI passenger cars and concluded that the PN emissions were higher under the acceleration and steady-state driving conditions

than during deceleration. From Figure 2, although the proportions of the acceleration of 1.0–1.5 m/s^2 of the three GDI vehicles are low, the PN emissions are higher. This means that acceleration significantly affects PN emissions. The driver should avoid using excessive acceleration in real-world driving, especially at high speeds.

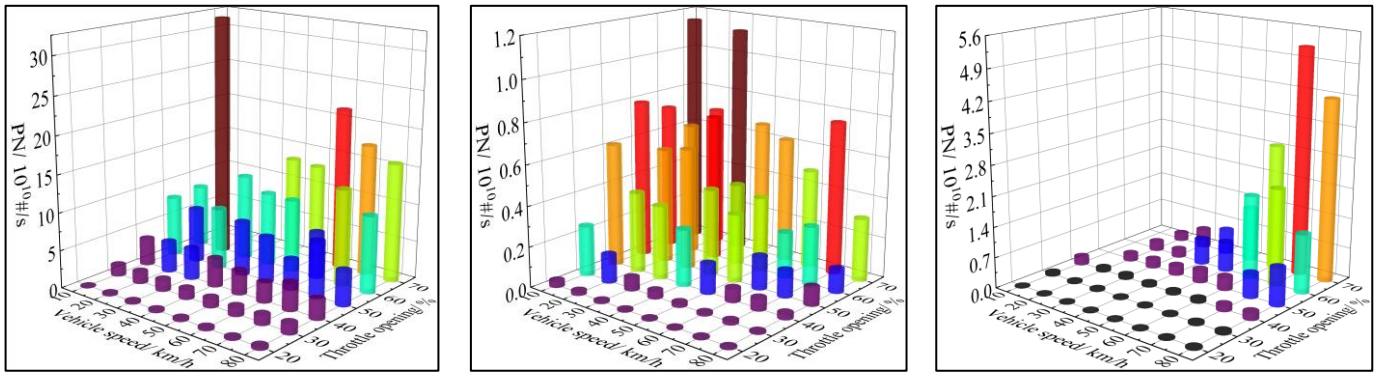
The influence of engine speed and torque on PN emission rates is shown in Figure 6. The PN emission distributions of the three GDI vehicles when affected by torque and speed are similar. The PN emission rates of the three vehicles increase with torque. The high PN emission rates mainly occur under high torque conditions. For engine speed, high PN emissions are concentrated in low speed (<1400 rpm) and high speed (>2000 rpm) conditions. Fuel combustion is more complete at a medium engine speed, so the PN emissions are lower, which has been verified on the bench test [36]. Increasing the engine speed under high torque condition can increase the PN emissions, and the PN emission rates reach the peak values at the engine speed of 2600 rpm and torque of 140 Nm. From Figure 3, the three vehicles have different proportions under high speed and high torque conditions, which lead to higher real-world emissions. Under high torque conditions, GDI engines spark in advance, producing more unburned fuel vapor and carbon particles [37]. He et al. [38] studied the effects of gasoline direct injection engine operating parameters on particle number emissions, and also found that the PN emission rates increased with an increase in traction power. The Golf was tested over the NEDC, where the driving conditions are much gentler, making it easier to meet the emission limits in regulations, so the Golf only shows a high PN emission rate (15.2 × 10^{10} #/s) at the engine speed of 1000 rpm and torque of 140 Nm.



(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 6. PN emission rates vs. engine speed and torque.

Figure 7 shows the distribution diagram of the PN emission rates vs. the vehicle speed and throttle opening of three vehicles. The PN emission rates of the three vehicles are sensitive to throttle opening, and the PN emissions gradually increase with throttle opening, especially when the throttle opening is larger than 50%. Under high speed and high throttle opening conditions, the PN emissions reach the peak value, which corresponds to Figure 4. Higher acceleration leads to high throttle opening and high speed, resulting in the increase in PN emissions. When the vehicle is under the acceleration condition, it needs more oil to burn to provide power, so the throttle opening should increase accordingly, which leads to the increase in speed. The local rich mixture and wet wall phenomenon are the major reasons for this, and the local enrichment of the mixture and wet wall are worsened with throttle opening. In addition, too high of a throttle opening under low speed conditions (10 km/h, 70%) significantly increases PN emissions. However, the Focus shows lower PN emissions at low speed and high throttle opening conditions, because the Focus has a larger engine size and higher compression ratio, such that the fuel can burn more fully at low speed conditions, reducing PN generation.

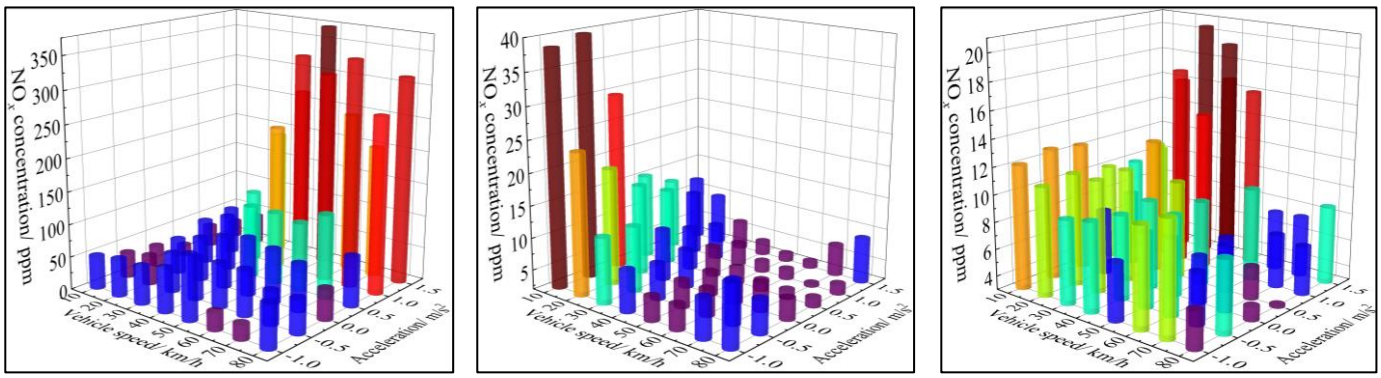


(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 7. PN emission rates vs. vehicle speed and throttle opening.

3.3. Real-World NO_x Concentration Distributions

Figure 8 shows the distribution diagram of the NO_x concentration vs. vehicle speed and acceleration of the three vehicles. Statistically, the Golf has a higher NO_x concentration, with a maximum concentration reaching 360 ppm. On the other hand, the Peugeot and Focus have NO_x emissions lower than 40 ppm. Ricardo et al. [5] indicated that the vehicles on the NEDC test cycle emitted more NO_x than the vehicles on the WLTC test cycle. The NO_x concentrations of Peugeot are below 10 ppm when the vehicle speed is higher than 40 km. In this paper, the NO_x concentration of GDI vehicles tended to be high at the low speed conditions. This is caused by a drop in the exhaust temperature, which results in a reduction of the catalytic efficiency of TWC [39]. From Figure 2, the low speed conditions of the three vehicles account for large proportions, so the NO_x emissions of low speed conditions cannot be ignored. Regarding the Golf, the peak NO_x concentration is under the conditions of high speed and high acceleration. Aggressive driving of the Golf has more impact on its NO_x emissions than those of the Peugeot and Focus due to more NO_x formations and saturation of TWC catalyst [39].

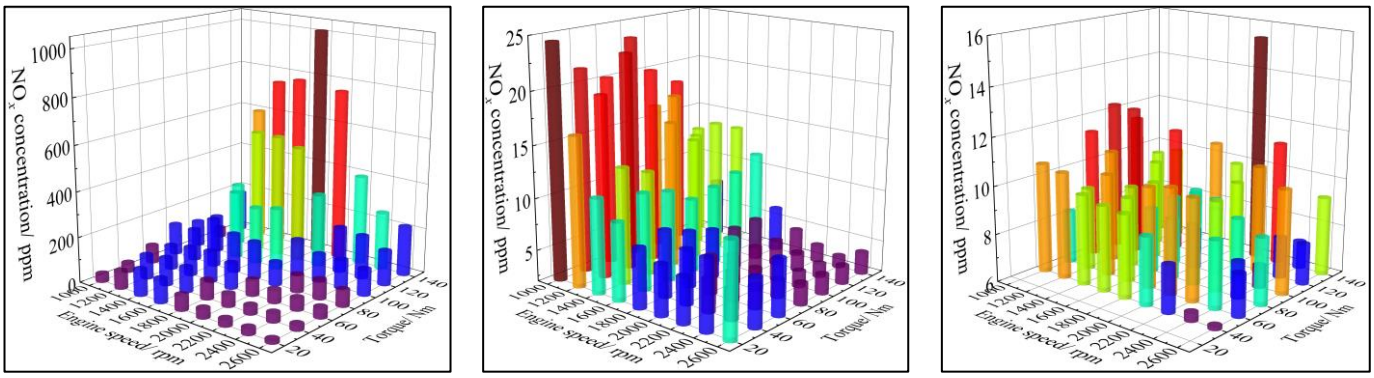


(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 8. NO_x concentration vs. vehicle speed and acceleration.

The influence of engine speed and torque on NO_x concentration is shown in Figure 9. When the engine speed is lower than 1800 r/min, more NO_x emissions of GDI vehicles can be generated, which is related to a lower catalyst temperature. Similarly, three vehicles account for a large proportion at low engine speed in Figure 3. From bench test, high torque conditions lead to increase the cylinder temperature and produce more NO_x, resulting in catalyst saturation and the peak of NO_x emission [9]. Lou et al. [40] revealed that gasoline vehicles are more likely to exceed the TWC ability of NO_x reduction, further generating peak NO_x emissions at high load conditions. O'Driscoll et al. [41] also pointed out that the

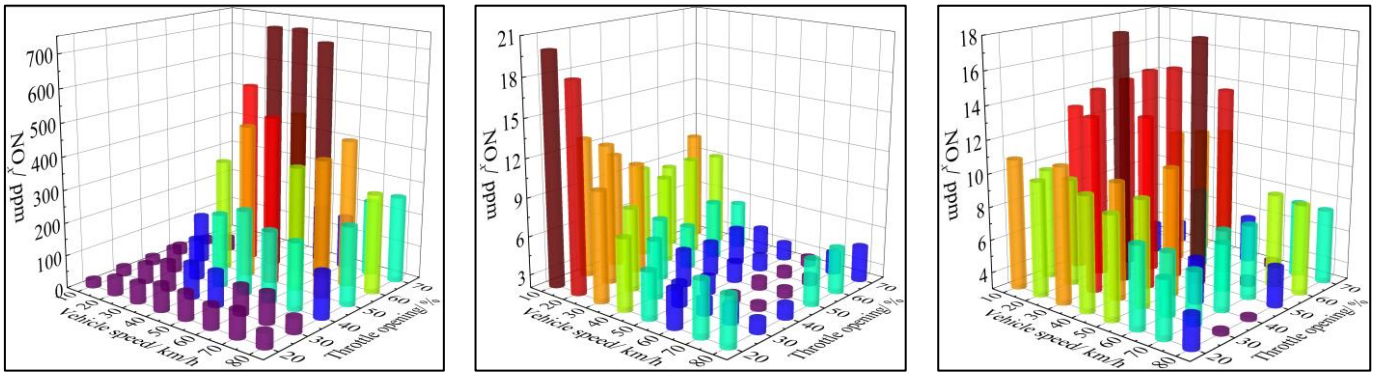
greater power demand of GDI vehicles leads higher NO_x concentration, which agrees with the authors' results in this section.



(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 9. NO_x concentration vs. engine speed and torque.

Figure 10 shows the distribution diagram of NO_x concentration distribution vs. vehicle speed and throttle opening of three vehicles. Similar to Figure 8, the low speed conditions of GDI vehicles cause higher NO_x emissions. In addition, high throttle opening also result in higher NO_x emissions, especially for the Golf. In this condition, excessive fuel injection leads to an increase in the combustion temperature of the cylinder, and produces NO_x emission; meanwhile, the catalyst tends to be saturated.

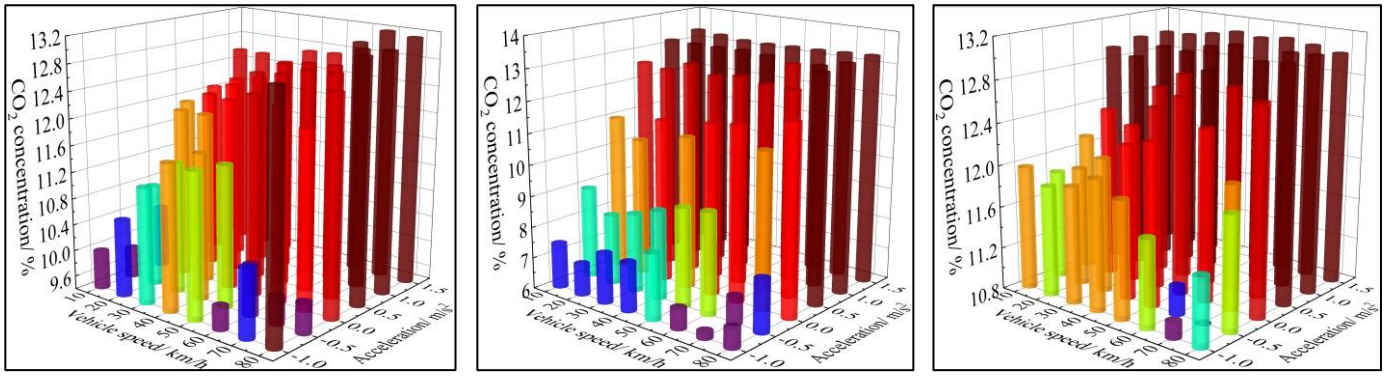


(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 10. NO_x concentration vs. vehicle speed and throttle opening.

3.4. Real-World CO_2 Emission Rate Distributions

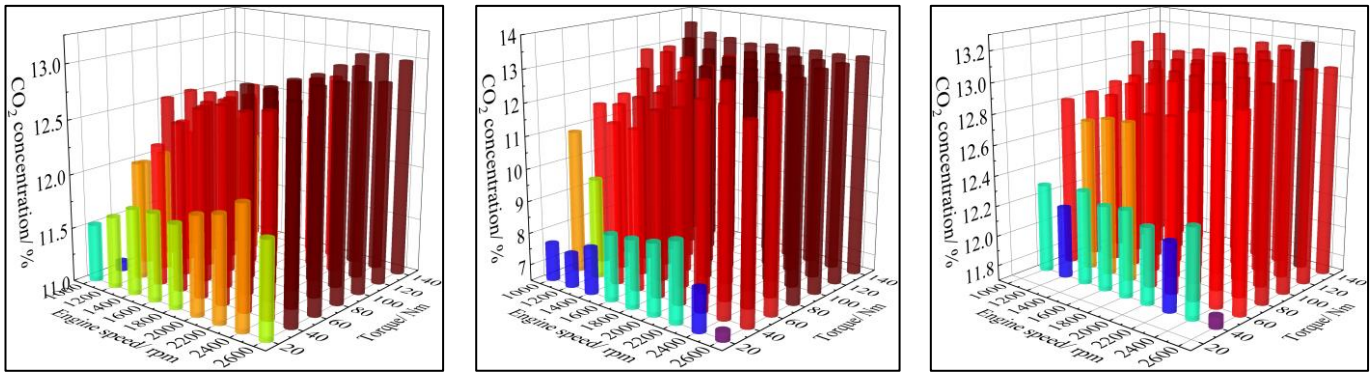
Figure 11 shows the distribution diagram of CO_2 concentration vs. vehicle speed and acceleration of three vehicles. The GDI vehicles are reported to have lower CO_2 emissions than PFI vehicles due to their higher thermal efficiency [42]. However, the peak CO_2 emissions of the three GDI vehicles are all higher than 13% in this study. Because there is no limit of CO_2 emissions, the CO_2 emission distributions of the three vehicles are similar. The CO_2 emissions of three vehicles are more sensitive to acceleration. Once the vehicles under the acceleration conditions, the CO_2 emissions increase rapidly. From Figure 2, the three vehicles have large proportions under the 0.5 m/s^2 acceleration condition, which will increase the real-world CO_2 emissions. In the deceleration process, the CO_2 emissions are quite low because of the small quantity of fuel delivery. Additionally, more fuel is burned at high acceleration conditions, resulting in higher CO_2 emissions. Higher acceleration leads to more CO due to the less complete combustion of the fuel in GDI vehicles. Due to the function of TWC, it is widely accepted that it is easier to oxidize CO to CO_2 [43], and CO emission is not the focus of the investigation.



(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 11. CO_2 concentration vs. vehicle speed and acceleration.

The effect of engine speed and torque on CO_2 concentration is shown in Figure 12. Compared with the engine speed, the CO_2 emissions of the three GDI vehicles are more sensitive to torque. When the torque is higher than 20 Nm, the CO_2 emission increases sharply. Under such conditions, more fuel is delivered into combustion chamber of gasoline engines, result in more CO, which is confirmed in the bench test [44]. Small torque operation may be a good option for GDI vehicles to reduce CO_2 emissions, being consistent with the conditions of small acceleration.



(**a**) Golf (**b**) Peugeot (**c**) Focus

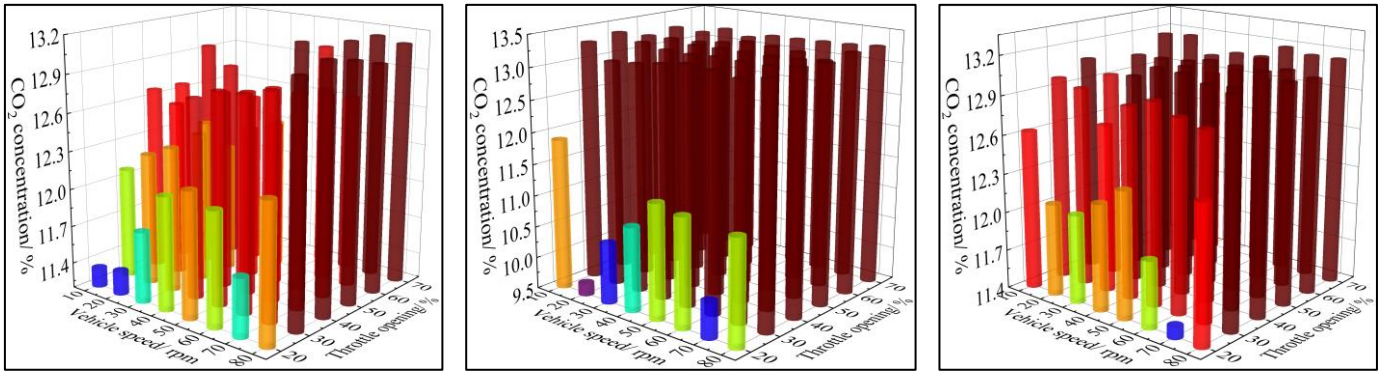
Figure 12. CO_2 concentration vs. engine speed and torque.

Figure 13 shows the distribution diagram of CO_2 concentration vs. vehicle speed and throttle opening of three vehicles. Throttle opening has a highly positive correlation with CO_2 emissions. The CO_2 emissions of GDI vehicles rapidly increase to peak values when the throttle opening is larger than 30%. The increase of throttle opening is accompanied by the increase of fuel injection, leading to the generation of more CO; meantime, the CO concentrations are high at high speed conditions, and the catalyst is fully warmed up. It can catalyze the oxidation of more CO into CO_2.

3.5. Real-World Emission Factors

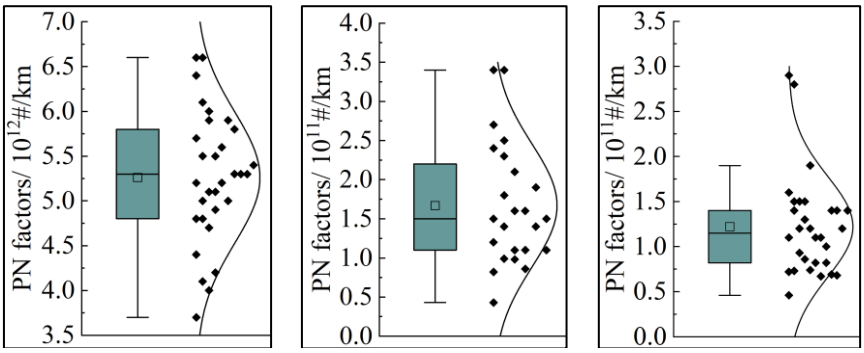
In this section, the emission factors of GDI vehicles during the whole real-world driving process are analyzed to explore the differences between vehicles. In addition, the effect of different drivers is also analyzed. Figure 14 shows the average PN emission factors of three vehicles, and the explanations of the bars and lines in box plots are presented in the work [45]. Suarez-Bertoa et al. [5] revealed that PFI vehicles have the highest PN emission factor (2×10^{12} #/km) in real-world driving; however, the PN emission factor of GDI vehicles with GPF is the lowest (1×10^{10}–2×10^{10} #/km). In this paper, the average PN emission of the Golf is the highest, being up to 5.27×10^{12} #/km due to the lack of DPF

and less strict test approval cycle. The Focus, with a stricter PN emission standard, has the lowest average PN emission (1.24×10^{11} #/km), which is 0.32×10^{11} #/km lower than that of the Peugeot equipped with a GPF. The vehicles with higher PN emissions are more susceptible to the difference between drivers. The highest PN emission value of the Golf is 6.7×10^{12} #/km, but the lowest emission is only 3.4×10^{12} #/km.



(**a**) Golf (**b**) Peuge (**c**) Focus

Figure 13. CO_2 concentration vs. vehicle speed and throttle opening.

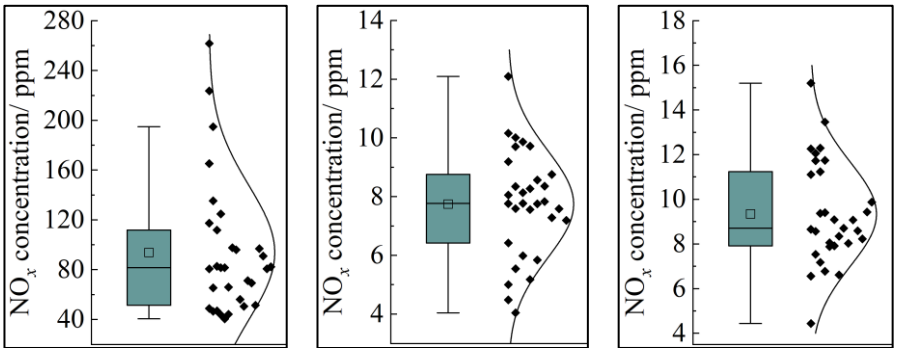


(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 14. Average PN emission.

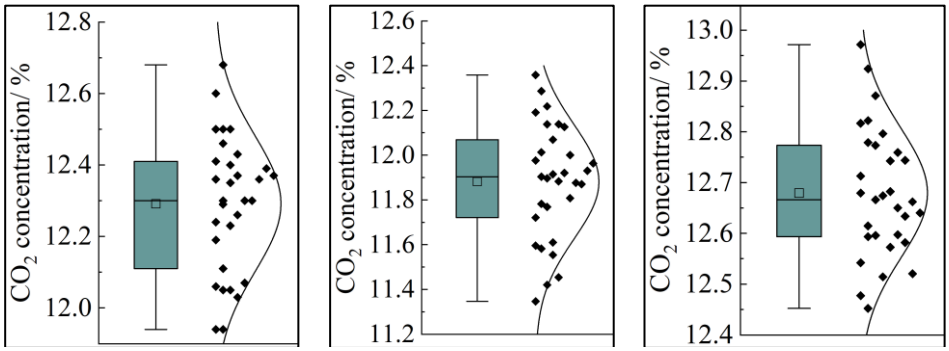
Figure 15 shows the average NO_x emission factor of the three vehicles. Gao et al. [22] concluded that the NO_x emission factor of GDI vehicles was lower than diesel vehicles, and the emission factors of two GDI vehicles were about 0.010 g/km. In this paper, the average NO_x emission of the Golf is the highest (approximately 92 ppm), and the difference between drivers is the most significant (160 ppm), which is similar to that of PN emission, the higher the average NO_x concentration, the more susceptible to drivers. The Peugeot and Focus have low average NO_x emission factors, with the value of 7.8 ppm and 8.6 ppm, respectively.

Figure 16 shows the average CO_2 concentration of the three vehicles. The average CO_2 concentration of the three GDI vehicles have minor difference, being approximately 12%; additionally, the variability in drivers is similar. The overall air-fuel mixture is the same for the three vehicles for the purpose of TWC performance. The difference in CO_2 emissions among the three vehicles is mainly caused by the driving variability. The focus has the highest average CO_2 concentration (12.67%); however, the Peugeot has the lowest average value (11.87%).



(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 15. Average NO_x concentration.



(**a**) Golf (**b**) Peugeot (**c**) Focus

Figure 16. Average CO_2 concentration.

4. Conclusions

In this paper, sixteen drivers and three GDI vehicles with vehicle technique and aftertreatment were tested in real-world driving, and the variability of the relationships between driving behaviors and emissions are analyzed. In addition, the emission factors are analyzed statistically to discuss the emission variations by drivers. The following conclusions are obtained:

(1) High acceleration and high speed conditions are major conditions for the PN emissions of GDI vehicles, and PN emissions are significantly increased when the acceleration is higher than 1.0 m/s^2. The PN emission rates reach peak values when the vehicles operate in the range of 70–80 km/h and with an acceleration of 1.5 m/s^2. The PN emission rates of the three vehicles increase with torque and throttle opening.

(2) The NO_x emission distributions of different GDI vehicles are slightly different, and the NO_x emissions under the speed of 40 km/h cannot be ignored. The catalyst temperature and catalyst saturation are important factors affecting NO_x emission. In addition, high torque and high throttle opening conditions also lead to higher NO_x emissions.

(3) Due to the lack of limit of CO_2 emissions, the peak CO_2 emissions of GDI vehicles all exceed 13% in real-world driving. The CO_2 emissions are positively correlated with acceleration, torque and throttle opening. Once the vehicles under the acceleration conditions, the CO_2 emissions increase rapidly, which make it difficult to control real-world CO_2 emissions.

(4) GDI vehicle with lower emission standards and less test cycle has worse real-world emission performance. The operating parameter variations of the three vehicles caused by drivers are low. However, the GDI vehicles with higher average emissions are more easily affected by drivers over real-world driving, which is a hindrance to effective exhaust emission control.

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Abbreviations

CO	carbon monoxide
CO_2	carbon dioxide
DPF	diesel particulate filter
EC	European Commission
GDI	gasoline direct injection
GPF	gasoline particulate filter
HC	hydrocarbon
NEDC	New European Driving Cycle
NO_x	nitrogen oxides
PEMS	portable emission measurement system
PFI	port fuel injection
PM	particulate matter
PN	particulate number
RDE	real driving emissions
WLTC	Worldwide Light-duty Test Cycle
TWC	three-way catalytic converter

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