Effects of Cold Start and Driving Behavior during On-road Driving on NH_3 Emissions from Gasoline Vehicle

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Tokyo Tech

Niterra
日本特殊陶業

2024 OSAR Conference

Research Background & Objective

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✓ Three-way catalyst (TWC) for stoichiometric gasoline vehicle

- Simultaneous conversion for NOx, CO and THC
- Generation of Ammonia (NH_3) inside TWC

✓ In EURO 7, NH_3 is also subject to the Real Driving Emissions (RDE) regulation, and reduction of its emissions is required.

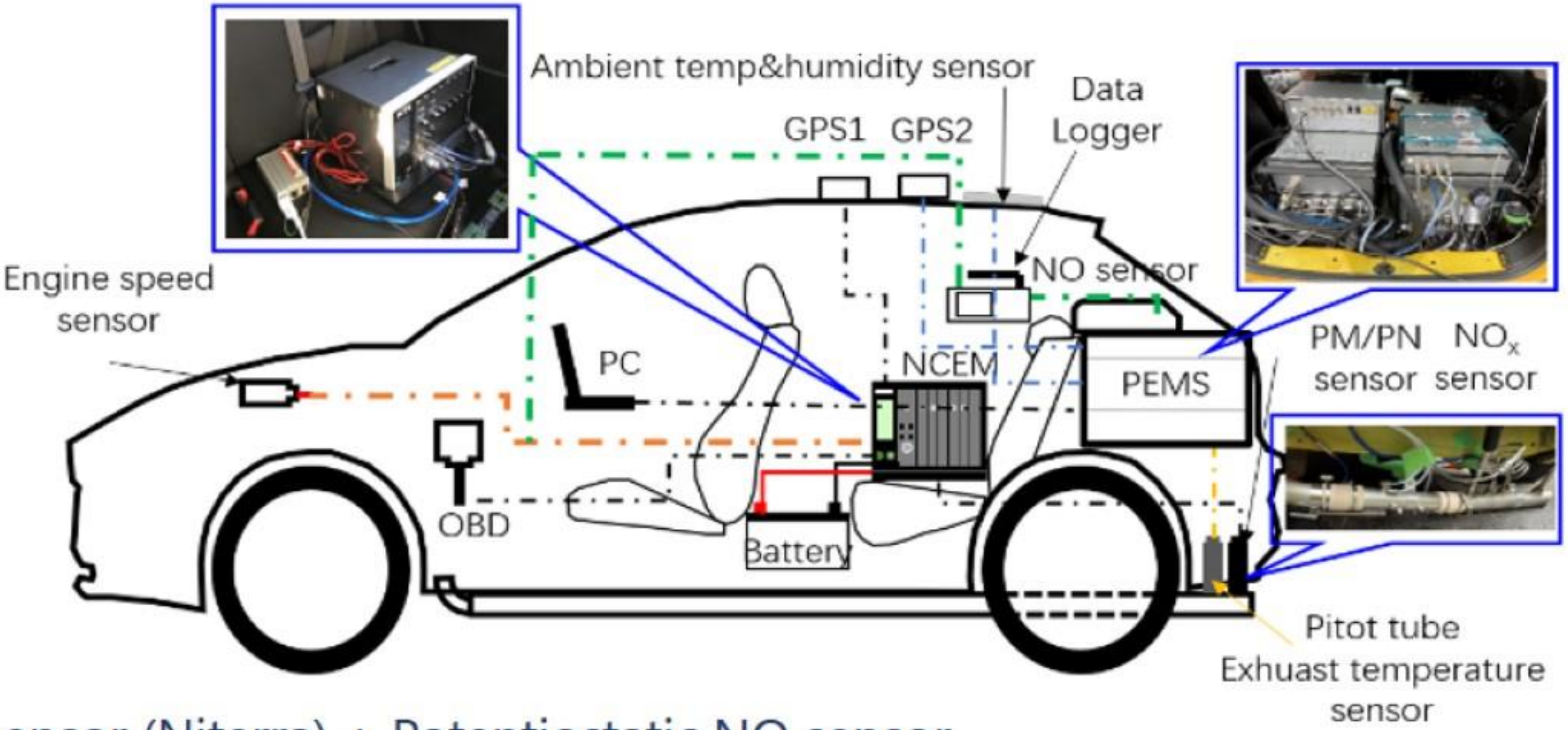
* Commission proposes new Euro 7 standards, https://ec.europa.eu/commission/presscorner/detail/en/ip_22_6495

➢ Objective

To clarify the effects of cold start and driving behavior difference on NH_3 emission with simultaneous measurement of Portable Emission Measurement System (PEMS) and Sensor-based Emission Measurement System (SEMS) in the real-world conditions

Test Vehicle and On-board Emission Measurement System

Engine Type	Turbocharged Direct Injection Gasoline
Riding capacity [people]	5
Displacement [L]	1.6
Aftertreatment system	TWC
Vehicle weight [kg]	1560
Model year [y]	2014
Emission regulation	Japanese 2009 regulation

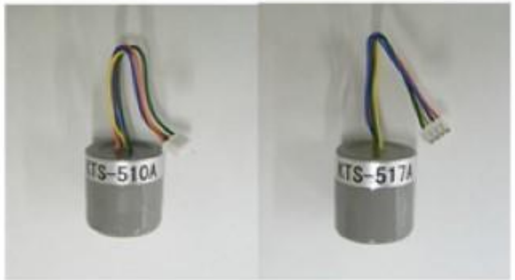


- ✓ SEMS: NCEM NOx sensor (Niterra) + Potentiostatic NO sensor
  NOx (NOx + NH_3), NO, GPS
- ✓ PEMS: OBS-ONE (HORIBA)
  NOx, CO, CO_2, GPS, OBD
- ✓ Mass conversion of gaseous emissions
  Exhaust flowrate calculated from intake mass air flowrate (OBD)

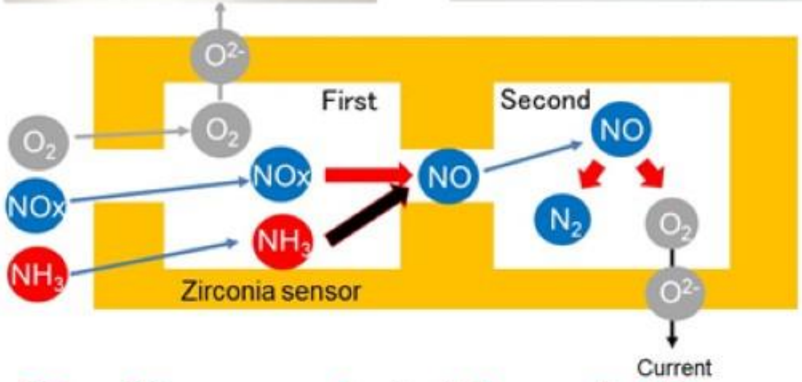
NH_3 Concentration Calculation

NOx sensor (NCEM)

Potential sensor for NO,NH_3



NH3 sensor for diesel



- Signals obtained from NOx sensor include those derived from NO and NH_3.
- Potential sensor for NO can measure the NO concentration.

[NOx sensor] –
[Potential sensor for NOx]
≈ NH_3

When NOx sensor and potential sensor for NO are used, ammonia emitted from gasoline vehicles will be measured.

➡ Sensor signals were compared with those obtained by FT-IR and laser-based measurement system.

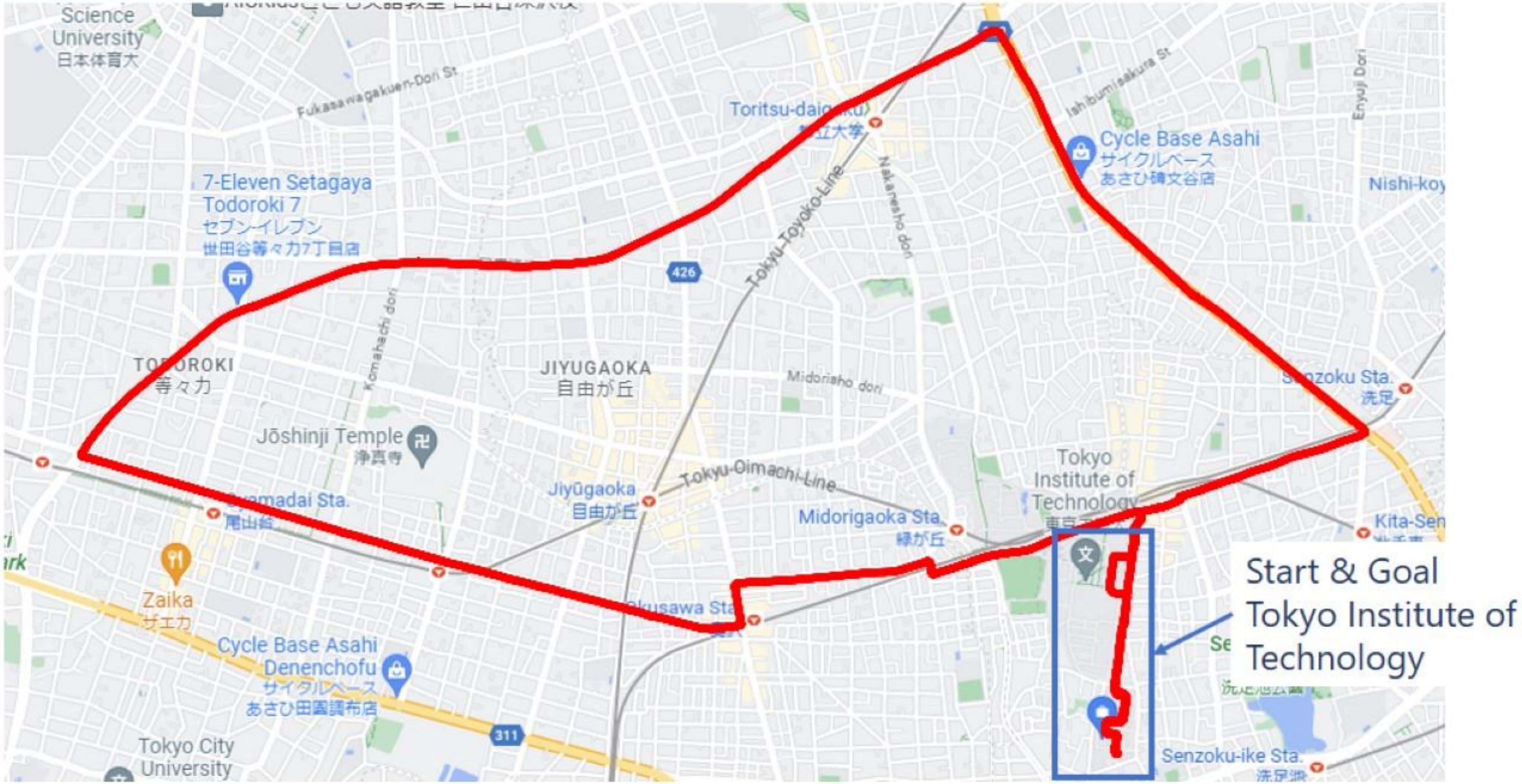
$$C_{NH3} = \frac{C_{NOx,S} - C_{NO,S}}{k}$$

Where,

C_{NH3} :	NH_3 Concentration
$C_{NOx,S}$:	NOx sensor detected concentration
$C_{NO,S}$:	NO sensor detected concentration
k:	Sensitivity correction value, 0.9

Tanaka, K., "Ammonia Measurements in Exhaust Using PEMS and SEMS", PEMS 10th Annual Virtual Conference (2021)

Test Route



Distance: 10 km
Urban route

On-road Driving Tests Conditions

Driver	Start condition	Time [s]	Distance [km]	Average Speed [km/h]	Start coolant temp. condition [°C]
A	Cold	2170	10.81	17.94	26
	Hot	2283	10.83	17.07	95
	Cold	2292	10.83	17.01	21
	Hot	1997	10.80	19.49	96
B	Cold	2495	10.67	15.11	25
	Hot	2445	10.92	15.96	95
	Cold	2377	10.84	16.3	34
	Hot	2179	10.85	17.94	93

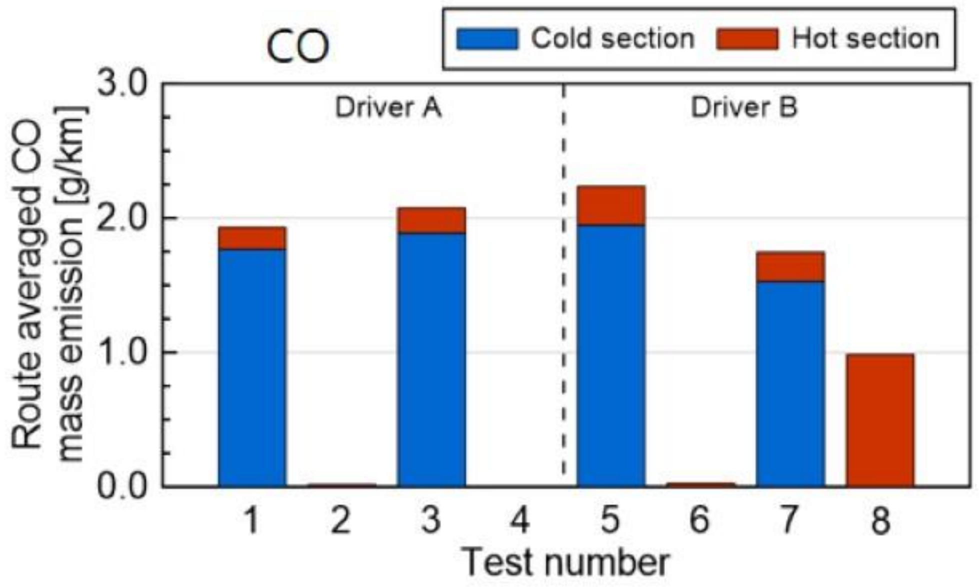
Driver A: familiar driver on the test route
Driver B: unfamiliar driver on the test route

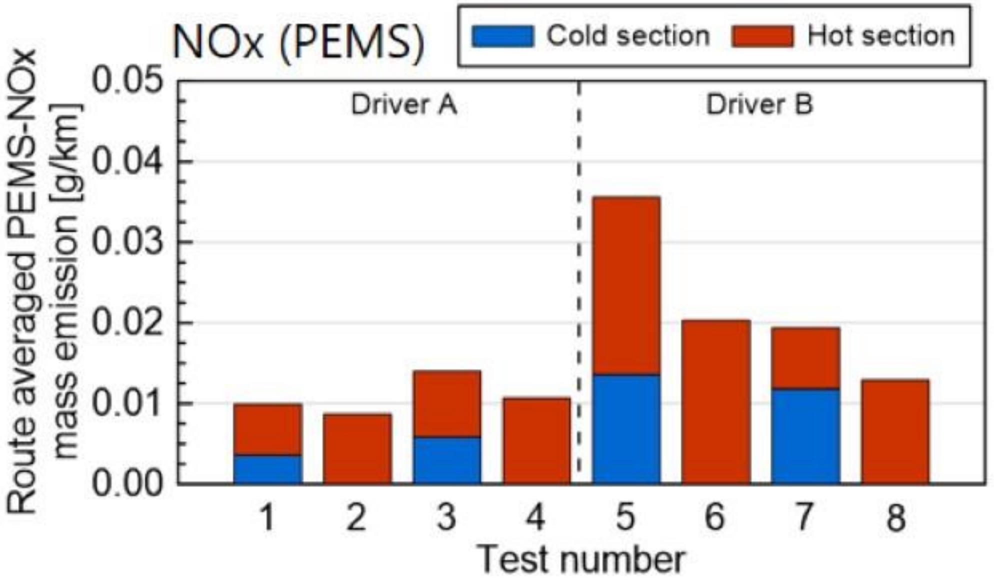
Route Averaged Emissions: Cold Section vs. Hot Section

RDE test: Definition of the completion of the warm-up, "duration of the cold start period is defined from engine start to after the first 5 minutes or engine coolant temperature reaching over 70 °C".

Including cold-start emissions in the Real-Driving Emissions (RDE) test procedure, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC105595/kjna28472enn.pdf

Test number	Start coolant temperature condition [°C]	Coolant temperature after 5 min. [°C]
1	26	69
3	21	65
5	25	67
7	34	76





Route Averaged NH_3 Emissions: Cold Section vs. Hot Section

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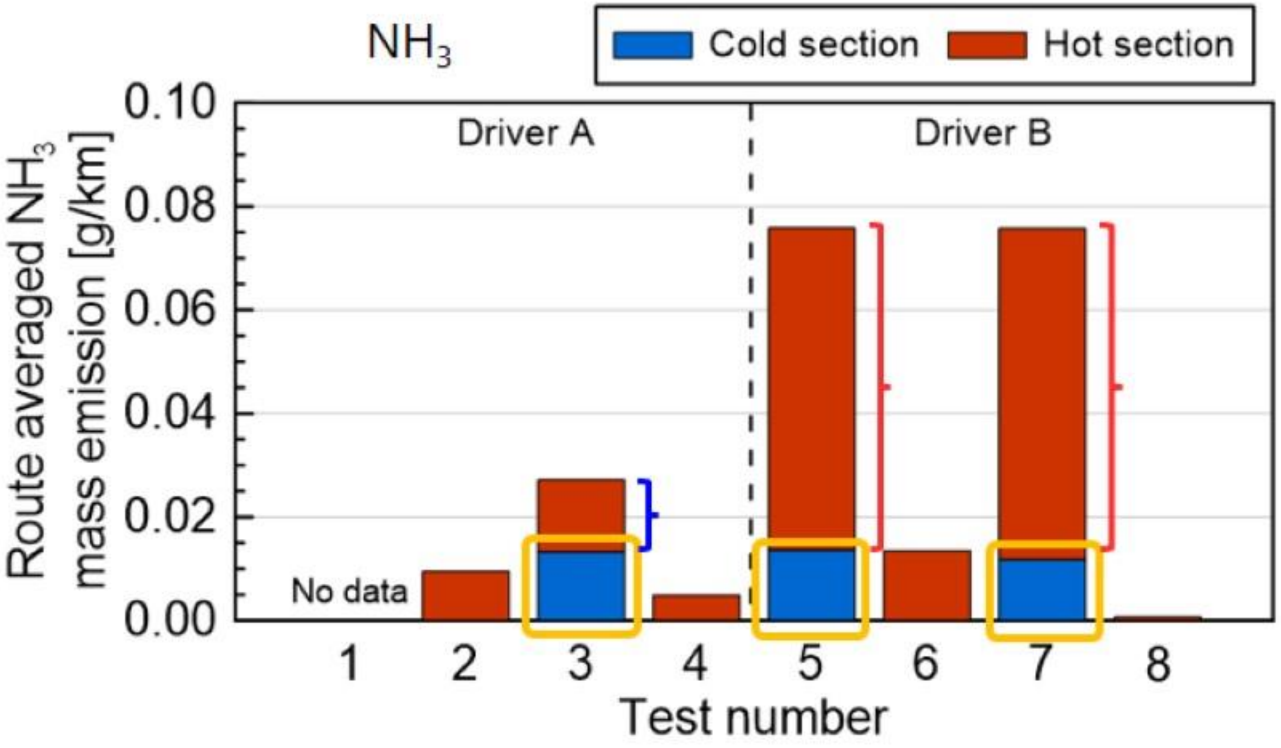
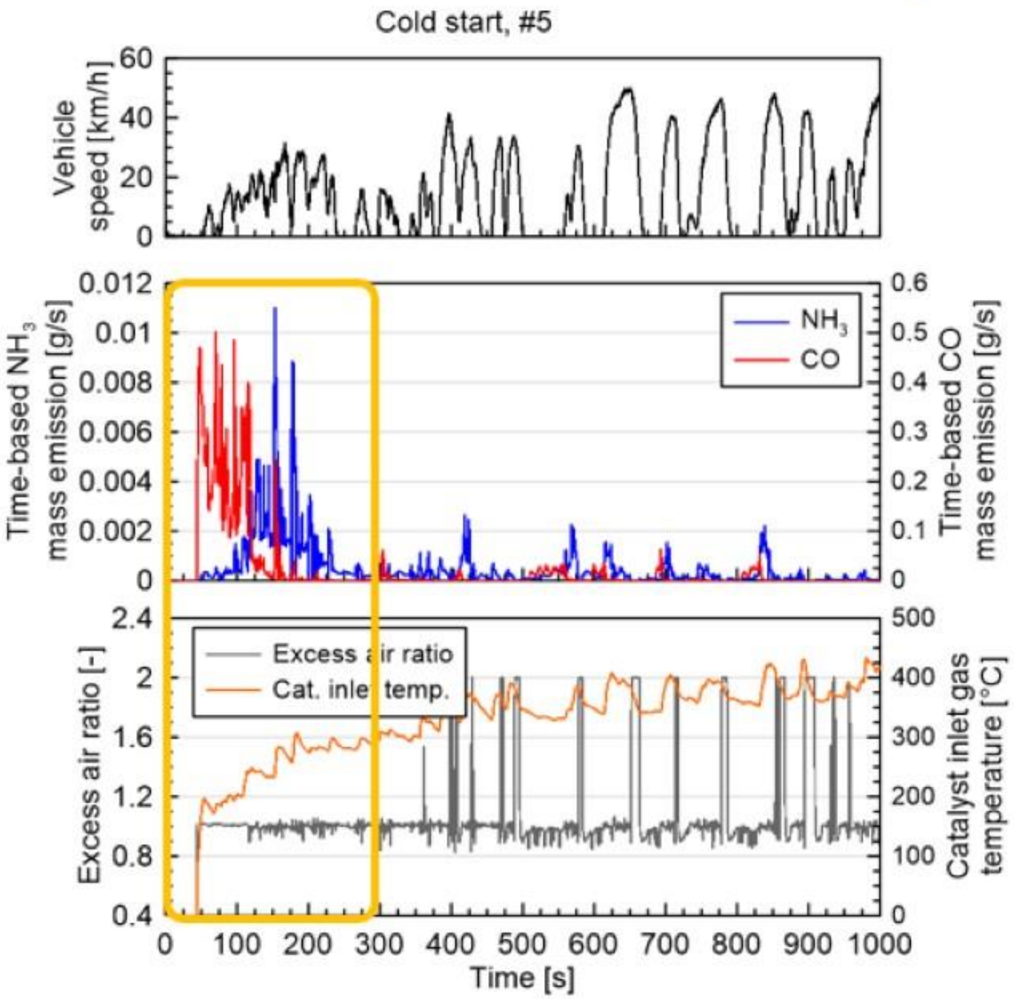
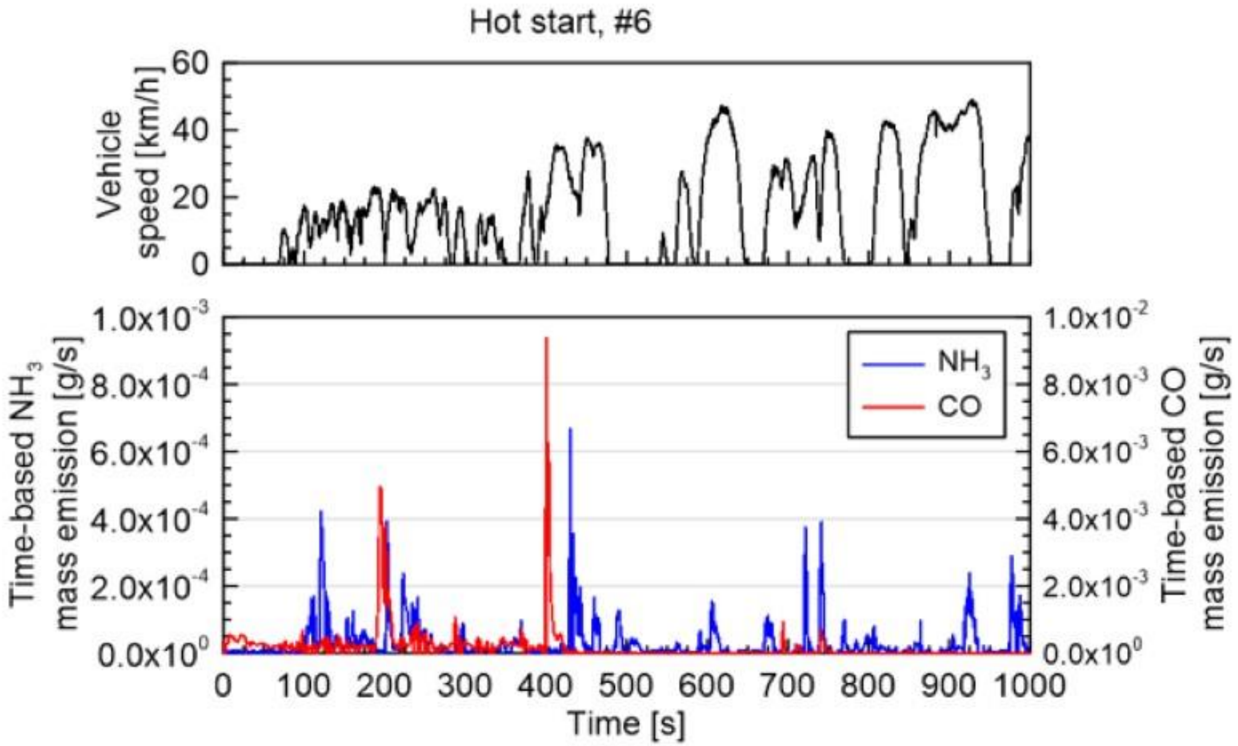
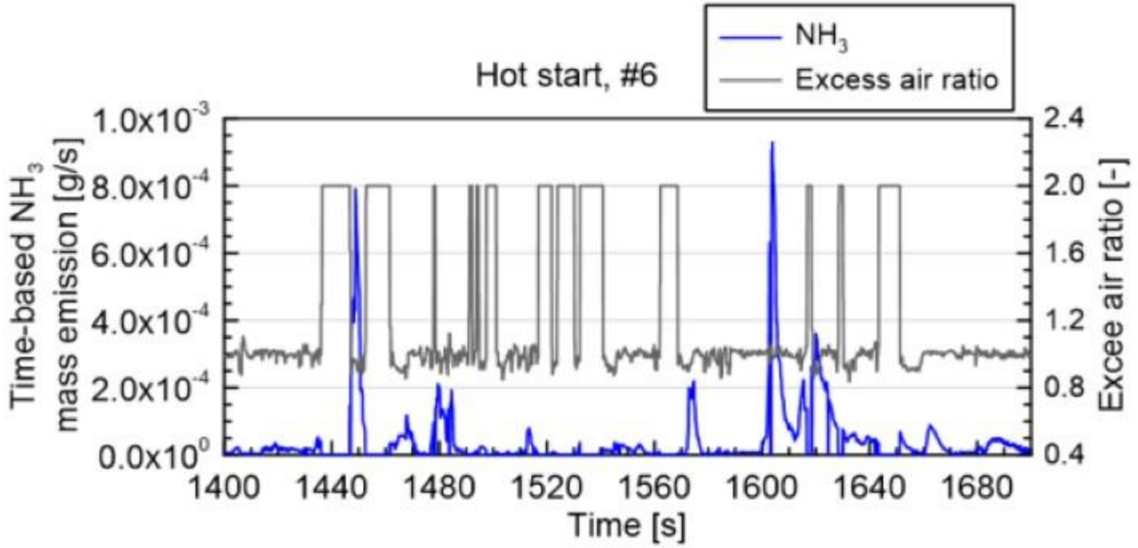




- ✓ NH_3 emissions in the cold section were constant regardless of the driver.
- ✓ NH_3 emissions in the hot section vary depending on driving behaviors.

NH_3 & CO Emission Behaviors under the Hot Start Condition





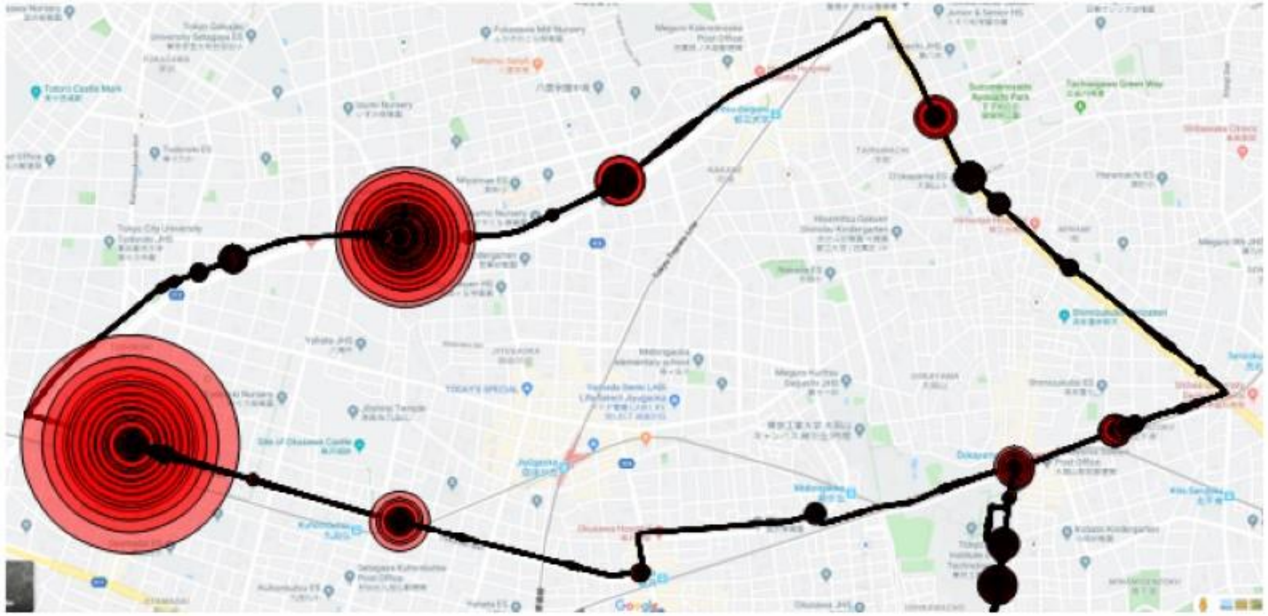
$$CO + H_2O \rightarrow CO_2 + H_2$$
$$2NO + 2CO + 3H_2 \rightarrow 2NH_3 + 2CO_2$$
$$2NO + 5H_2 \rightarrow 2NH_3 + H_2O$$

Barbier et al., Applied Catalysis B Environmental, Vol. 4, p. 105-140, 1994

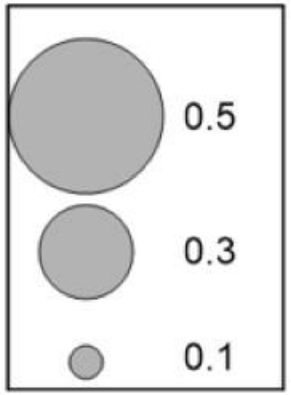
Distance-based NH_3 Emissions: Driver A vs. Driver B

Driver A, Test #4 (hot start)

Driver B, Test #6 (hot start)



Distance-based NH_3 emission [g/km]



$$E_{comp,x} = E_{comp.t} / v_t$$

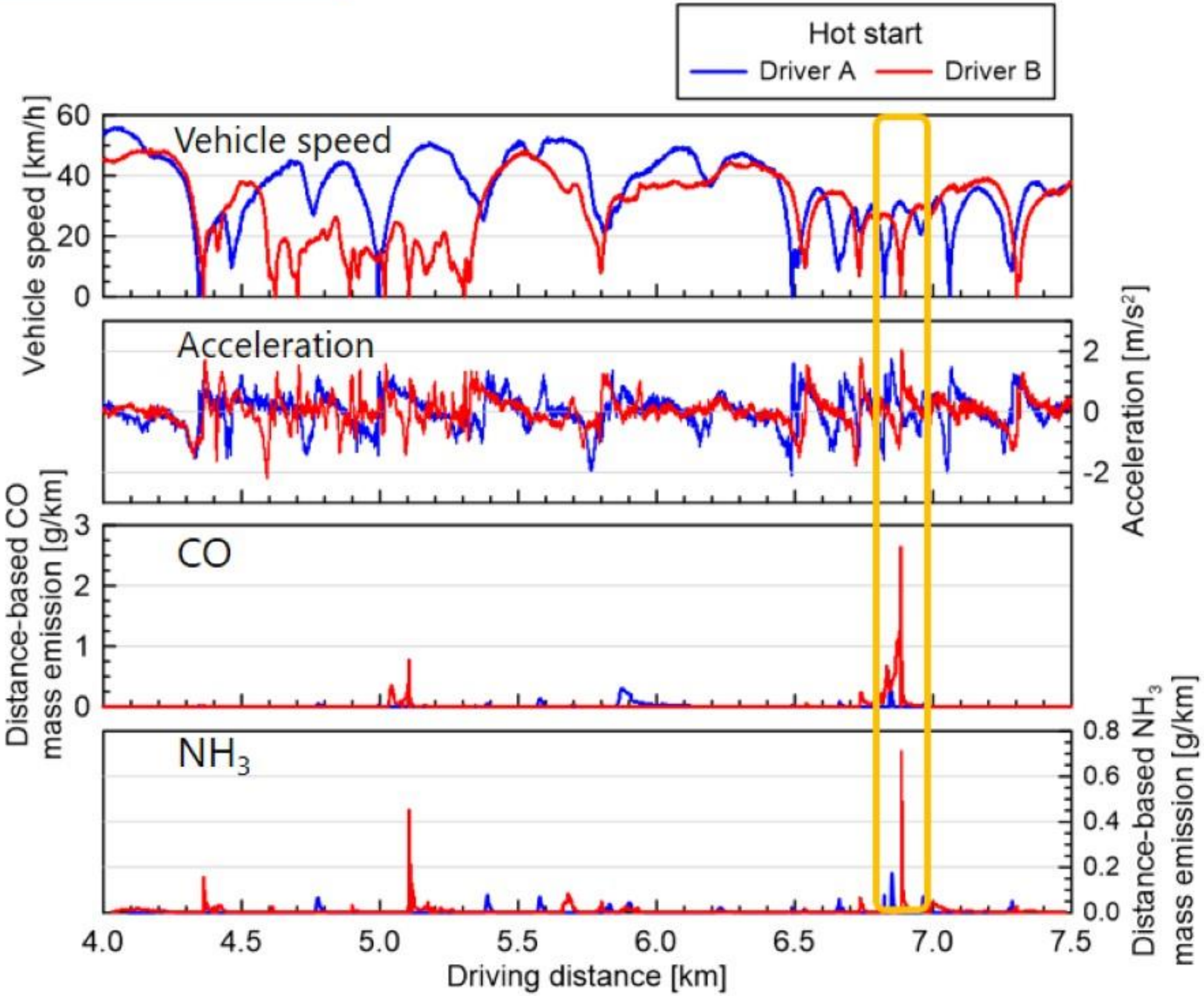
Where,

$E_{comp,t}$: Time-based mass emission for each component [g/m]

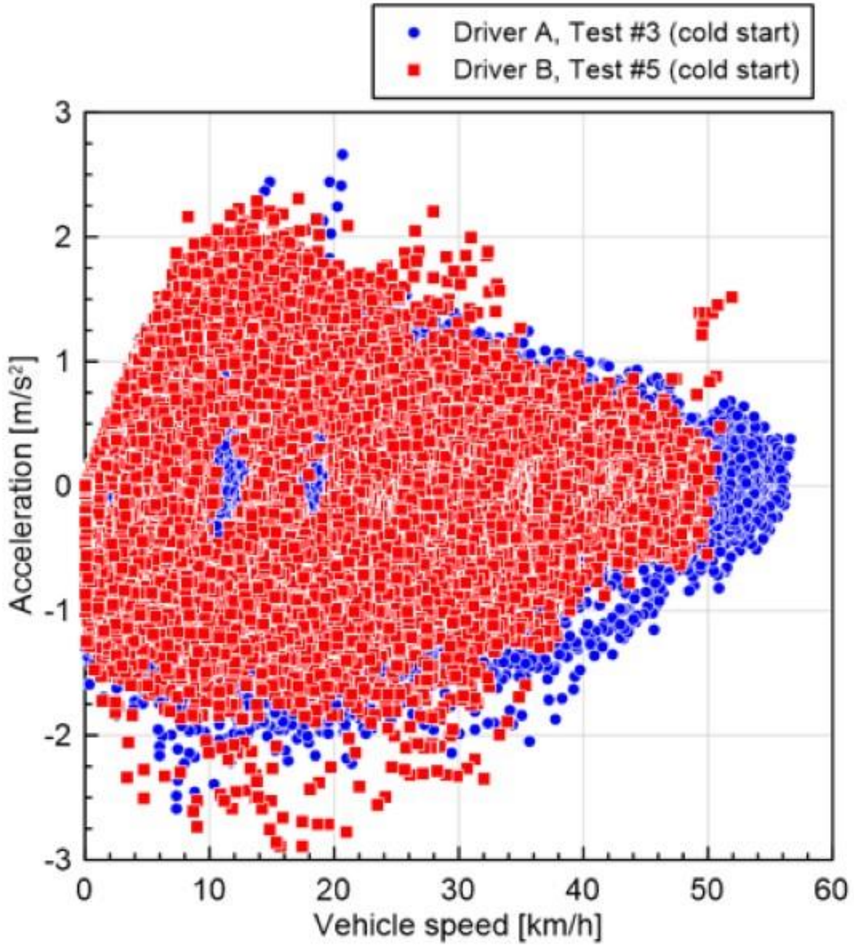
$E_{comp,x}$: Distance-based mass emission for each component [g/m]

v_t : Vehicle speed [m/s]

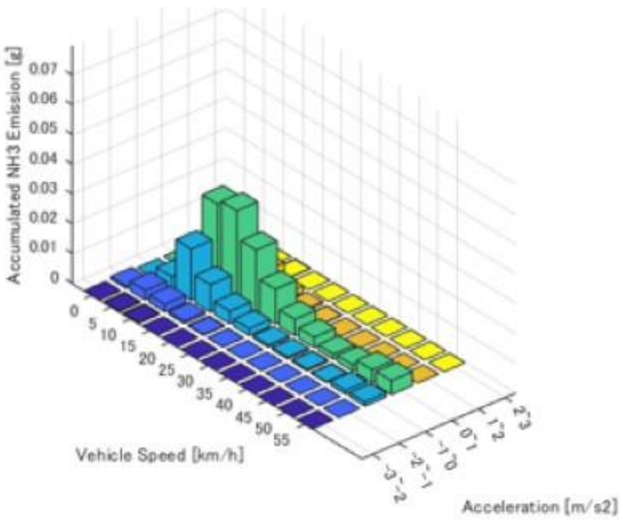
Driving Behaviors and Emissions Comparison between Drivers



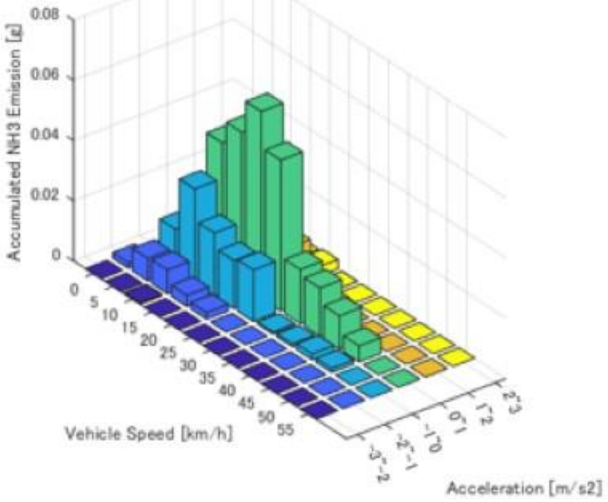
Operating Regions and NH_3 Emissions Comparison between Drivers



Driver A, Test #3 (cold start)



Driver B, Test #5 (cold start)



Summary

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In this study, PEMS and SEMS were installed in a direct-injection gasoline vehicle equipped with a TWC and tested on actual road conditions to analyze NH_3 emission and effect of different driving behaviors on NH_3 emissions.

1. NH_3 emissions in cold start tests were higher than those in hot start tests, and a comparison of NH_3 emissions among drivers revealed that emissions tended to be higher for a driver with higher acceleration/deceleration frequency for both cold and hot starts.

2. Classifying the results of the cold start test into a cold section before the warm-up is completed and a hot section after the warm-up is completed, it was found that the NH_3 emissions in the cold section were constant regardless of the driver.

3. The difference in NH_3 emissions between the different drivers can be attributed to driving with increased acceleration and deceleration, which increased the number of times the driver entered the rich condition, resulting in higher CO emissions and consequently higher NH_3 emissions.

For more details: "Effects of Different Driving Behavior during Actual Road Driving on Ammonia Emissions from Gasoline Vehicles", SAE paper 2023-32-0095

Future Works

It has been reported that NH_3 emission behavior vary depending on the precious metal type of TWC. The real-world NH_3 behavior of various types of gasoline vehicles needs to be investigated.

iPEMS and NOx sensor will be used for the analysis of NH_3 emissions for various gasoline vehicles.

iPEMS

+

NOx sensor

National Traffic Safety & Environment Laboratory

Ibaraki University

Thank You for Your Attention!

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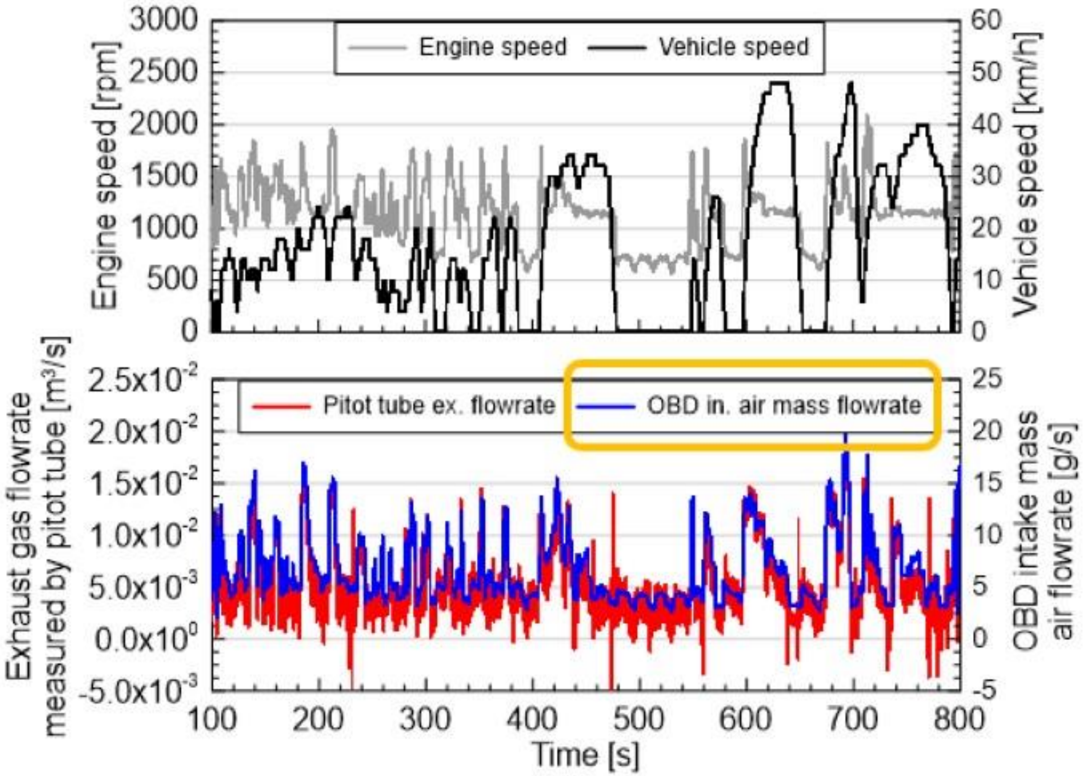
Mass Emission Conversion Method



$$Q_{ex,cal} = G_{ex} / \rho_{ex}$$

$$G_{ex} = G_a + G_f = G_a (1 + 1/AF)$$

$$G_f = G_a / AF$$

$$\rho_{ex} = f(AF, n_{HC})$$

AF: air/fuel ratio [-]
G_{ex}: exhaust mass flowrate [g/s]
n_{HC}: hydrogen/carbon ratio [-]
ρ_a: air density [g/m^3]

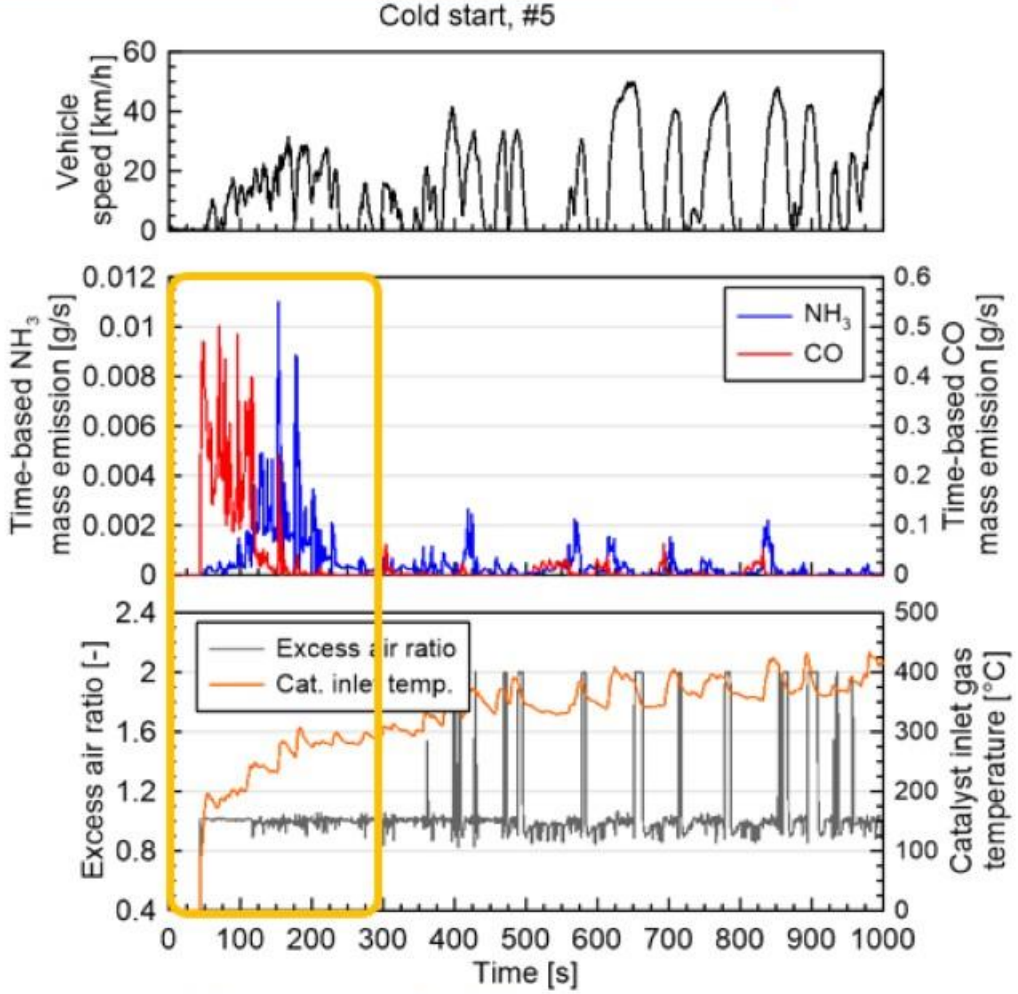
G_a: intake air mass flowrate [g/s] (MAF)
G_f: fuel mass flowrate [g/s]
$Q_{ex,cal}$: calculated exhaust volumetric flowrate [m^3/s]
ρ_{ex}: exhaust gas density [g/m^3]

$$E_{comp,t} = Q_{ex} \times \rho_{comp} \times C_{comp}$$

$E_{comp,t}$: Time-based mass emission for each component [g/s]
Q_{ex}: Exhaust gas volume flowrate [m^3/s]
ρ_{comp}: Density of each component [g/m^3]
C_{comp}: Emission concentration of each component [vol/vol]

Sato, S., Abe, S., Himeno, R., Nagasawa, T. et al., "Real-World Emission Analysis Methods Using Sensor-Based Emission Measurement System", SAE Technical Paper 2020-01-0381 (2020).

NH_3 & CO Emission Behaviors under the Cold Start Condition



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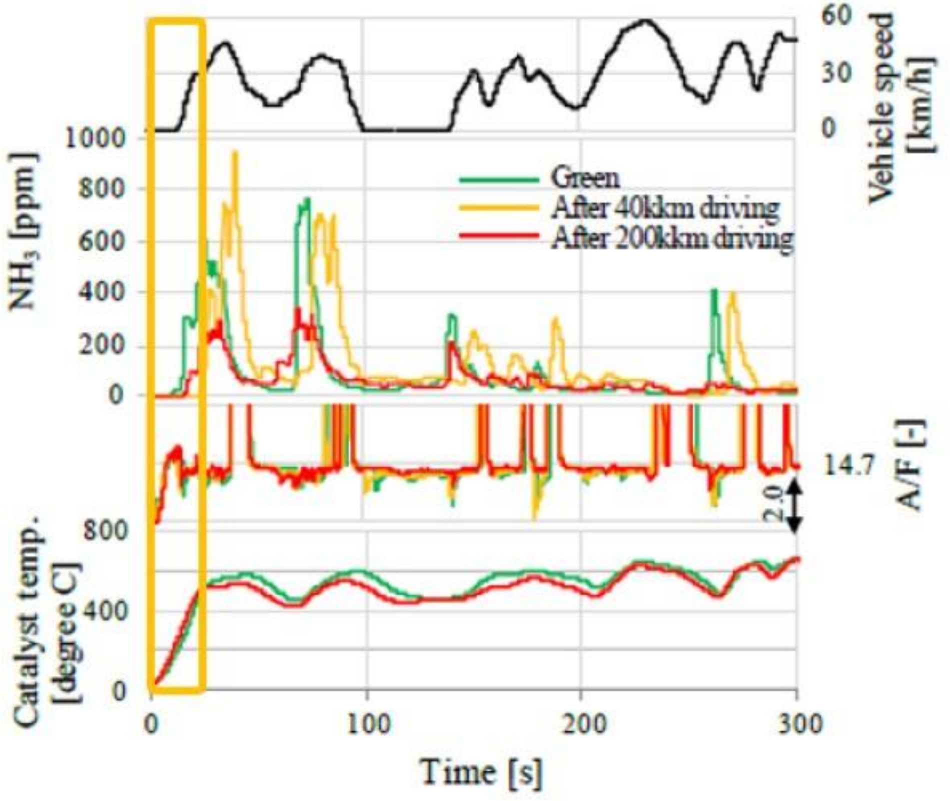

Fig.9 Effect of catalyst deterioration for NH3 emission.

Yokoyama, J., Itoyama, H., and Zhao, H., JSAE Autumn Annual Conference, Proceedings, No. 20226206 (2022)

NA engine chassis dynamometer test results

Barbier et al., Applied Catalysis B Environmental, Vol. 4, p. 105-140, 1994