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EMISSION MEASUREMENT OF UNIVERSITY FLEET VEHICLES THROUGH ON-ROAD REMOTE SENSING AND IDENTIFICATION OF HIGH NO_X EMITTERS

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***Abstract*—Remote sensing emission measurement is a method to measure real driving emissions to identify high emitter vehicles. High NOx emitter vehicles are recognized among the selected 14 vehicles of the University of Alberta fleet. By combining remote sensing and on-board diagnostics (OBD) data, an understanding of vehicle operation and its emission signature was developed. Out of 28 measured samples, seven samples from seven different vehicles had high NOx emissions. The results show that vehicles working in part-load operational conditions are more likely to produce more NOx. In contrast, no high NOx emitter was identified among the vehicles driven with medium or high load.**

***Index Terms*—Remote Sensing, Real Driving Emission Measurement, On-board Diagnostics, High NOx Emitters**

I. Introduction

Air pollution is a significant health concern in the most populated cities. According to the World Health Organization (WHO), ambient air pollution is responsible for more than 3 million deaths around the world each year [1]. Transportation is the major contributor to air pollution, mainly due to tailpipe emissions from vehicles [2]. According to Environment and Climate Change Canada, the source of more than 48% of pollutant emissions is transportation and mobile equipment [3].

Policy-makers and manufacturers have made many efforts to reduce the tailpipe emissions from internal combustion engines. The 1971 Motor Vehicle Safety Act administered by Transport Canada established exhaust emission limits for on-road vehicles in Canada. Since 2000, Environment Canada has had the authority to regulate emissions from on-road engines, harmonizing with the United States Environmental Protection Agency (EPA) federal standards. In the US, the 1970 Clean Air Act was the beginning for successive vehicle emissions standards to control vehicular emissions including carbon monoxide (CO), nitrogen oxides (NOx), volatile organic compounds (VOC), and particulate matter (PM) [4]. These efforts have led to a considerable reduction in vehicular emissions. According to the US Environmental Protection Agency (EPA), new vehicles in 2021 are roughly 99% cleaner than those in 1970. In Europe, the Euro emission standard has regulated passenger car emissions since 1992. This standard, targets CO, HC, NOx, particulate matter mass (PM), and particle number (PN) and mandates the manufacturers to produce cars with lower emissions [5]. Both European and North American tailpipe emission standards have become more stringent over time.

Although new cars are getting cleaner every year, urban air pollution is still a major problem, with more than 90% of the world's people breathing air recognized to be polluted by WHO [1]. New Canadian ambient air quality standards (CAAQS) for monitoring and controlling air pollutants have been updated recently and come in force in 2025. If current trends continue, Alberta will exceed CAAQS in 2025. One problem is vehicles on the road do not meet emission standards during normal driving because the tests for emission standards are done under a predefined laboratory procedure called the emission test cycle. During test cycles, the engine goes through a driving procedure simulated by dynamometers and the emissions are measured and compared to the reference values. In a real driving situation, the engine might experience a much different driving profile resulting in different emission patterns [6]–[8]. That's why real driving emission (RDE) measurement has been proposed to capture emission trends of vehicles in real-world driving conditions. In RDE test, emissions are measured by portable emission measurement systems (PEMS) during normal on-road driving [9], [10].

PEMS are expensive and and only useful to test a few vehicles in a fleet. [11], [12]. A method to measure and monitor vehicle emissions in a large fleet is remote sensing (RS). This method measures the emissions using a ultraviolet (UV) and infrared (IR) beams as the vehicle drives by. It has low disruption to the road traffic process and is very cost-effective for a large scale measurement [13], [14]. RS measurement results are used in emission factor (EF) development [12], [15], [16], evaluation emission control technologies and regulations [17]–[19], and identification of high emitter vehicles [14], [20]–[23].

A remote sensing measurement study in the US (San Jose, Fresno and West Los Angeles) showed a decrease in CO, HC, and NO emitted from the vehicles over the years while the ratio of NO2 to NO was increased to 60% for a fleet of diesel ambulances. [24]. In a study in Tehran, the RS method was used to identify high emitters and compare old cars with new ones. In old cars (more than five years), CO and HC are five times higher than new cars and 20% of high emitter vehicles are responsible for 50% of CO, HC, and NO. There was also no difference between gasoline and natural gas vehicles for a fraction of high emitters. [14]. In Hong Kong, researchers used RS emission measurement to study the effect of engine size and vehicle age on emissions from diesel vehicles. CO emission was higher for larger engines and the fraction of high emitters decreased in newer vehicles with larger engines. The fraction of high emitters and their relationship with age and engine size is different for each pollutant [25].

One of the sensitive urban areas to air pollution is university campuses in which high interactions exist between pedestrians and vehicles in a densely populated area. The concentration of the population and outdoor activities are high. As a case study, the University of Alberta, with more than 40,000 students, has a main campus in a densely populated area of Edmonton. The vehicles of the university fleet are operating on campus. Energy Management and Sustainable Operations (EMSO) at the University of Alberta has a number of initiatives one of which is vehicle emissions and ways to reduce them.

Fourteen vehicles from 170 vehicles of the University of Alberta fleet are selected and driven multiple times on a road equipped with a remote sensing system by Opus company as part of an emission measurement campaign by Clean Air Strategic Alliance (CASA). The project was done as a part of the Roadside Optical Vehicle Reporter (ROVER) III remote sensing project managed by CASA and operated by Opus.

On-board diagnostic (OBD) reader using CAN (Controller Area Network) communication protocol was installed on each vehicle before testing and engine/vehicle operating parameters were collected. Several engine operating parameters are available on OBD ports collected from engine ECU (Electronics Control Unit). They show real-time engine performance [26]. The objective of the study was to identify high emitters using RS technology and to understand the relationship between instantaneous high NOx emissions and engine operating parameters.

II. METHODOLOGY

A. Experimental setup

Table I shows a list of selected vehicles from the University of Alberta fleet, which were equipped with Freematics ONE+ Model B as telematic OBD readers to read and record engine parameters while testing. OBD readers access to engine parameters through the OBD-II port on each vehicle and store data on an SD card. Collected OBD parameters as time series are listed in Table II. The ambient weather conditions during the testings are listed in Table III.

A set of optical instruments are placed on both sides of a single-lane road, slightly uphill. As each vehicle passes through the test section, licence plate, vehicle speed, and acceleration are captured. The optical system emits ultraviolet and infrared light across the road. The specific wavelengths absorbed by the pollutant in the exhaust plume are recorded, and they enable the emission analyzer to measure the concentration of pollutants emitted by the passing vehicle. Fig. 1 shows a schematics and actual pictures of the process of remote sensing emission measurement. Each vehicle was tested according to the test plan shown in Fig. 2. The vehicles move with the speed profile shown and pass the sampling spot at the specified test points. Although attempts have been made to perform 4 test samples for each vehicles, some samples have had results out of the acceptable range and have been removed from the analysis. Table IV lists the parameters measured in the process of remote sensing.

TABLE I: List of tested vehicles

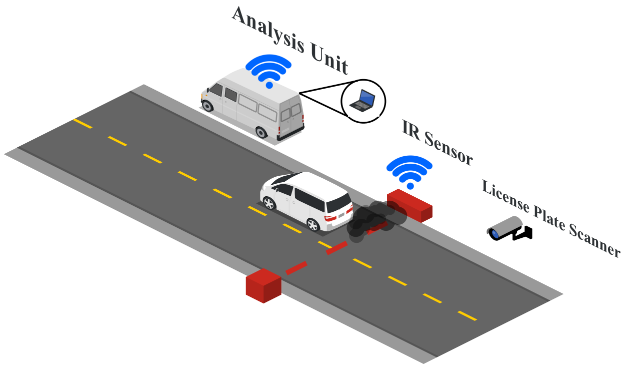
No.	Make	Model	Model Year	Engine Size
1	Dodge	Grand Caravan	2015	3.6 L
2	Ford	Transit	2016	3.7 L
3	Dodge	Grand Caravan	2016	3.6 L
4	Toyota	Prius	2015	1.8 L
5	Dodge	Grand Caravan	2016	3.6 L
6	Nissan	NV200	2019	2 L
7	Chevrolet	Silverado 2500	2020	6.6 L
8	Nissan	NV200	2014	2 L
9	Chevrolet	Silverado 2500	2013	6 L
10	Chevrolet	Silverado	2008	4.8 L
11	Chevrolet	Silverado 2500	2013	6 L
12	GMC	Sierra	2007	6 L
13	Chevrolet	Silverado 2500	2013	6 L
14	Ford	F150XL	2005	4.2 L

TABLE II: List of OBD parameters collected as time series during the tests

Parameter	Unit
Engine Load	%
Engine Speed	rpm
Vehicle Speed	km/h
Coolant Temperature	°C
Catalyst Temperature	°C
Intake Manifold Absolute Pressure	kPa
Mass of Air Flow	g/s
Throttle Position	%
Intake Manifold Temperature	°C
Fuel Trims (Short and Long Term)	-

TABLE III: Weather conditions during the testing time

Parameter	Value
Ambient Temperature	13 to 13.4 °C
Relative Humidity	30 to 33%
Wind Speed	0 to 4 m/s
Ambient Pressure	93.3 kPa
General Condition	Cloudy



(a) Schematics of RS experiments.

(b) RS testing at the University of Alberta, South Campus.

Fig. 1: Remote sensing emission measurement.

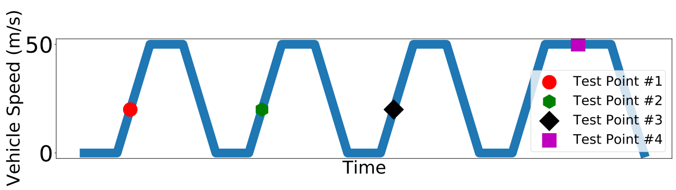


Fig. 2: Test driving cycle and sampling points for each vehicle.

B. Method of analysis

1) Vehicle-specific power (VSP): Vehicle-specific power (VSP) is used in the evaluation of vehicle emissions. It is the sum of the loads resulting from aerodynamic drag, acceleration, rolling resistance, and hill climbing, normalized by the mass of the vehicle. Conventionally, it is reported in kilowatts per ton, the instantaneous power demand of the vehicle divided by its mass. VSP, combined with dynamometer and remote-sensing measurements, is used to determine vehicle emissions

TABLE IV: List of collected parameters by remote sensing system

Parameter	Unit
CO	g/(kg of fuel)
HC	g/(kg of fuel)
NO	g/(kg of fuel)
NO2	g/(kg of fuel)
Vehicle Speed	km/h
Acceleration	m/s^2

[27], [28]. Since emissions and VSP are shown to be highly correlated, VSP is calculated for each measured point. To calculate VSP at each tested point, (1) is used based on studies which categorized vehicles by size [16], [29].

$$VSP = 1.08\ v\ (1.04\ a + g\ Grade) + \frac{2500 + 1.08\ (R_0\ v + R_1\ v^2 + C_d\ A\ 0.5\ \rho\ v^3)}{m\ 1000} \quad (1)$$

Where VSP is vehicle-specific power (kW/ton); m is vehicle mass (ton); a is vehicle acceleration (m/s^2); v is vehicle speed (m/s); C_d is aerodynamic drag coefficient; A is frontal surface area (m^2); ρ is density of air (kg/m^3); R_0 and R_1 are road load coefficients (N and N.s/m); g is standard gravity (m/s^2); and $Grade$ is road grade. Road load and drag coefficients are provided in Table V for average vehicles in categories based on vehicle size.

TABLE V: Average road load and drag coefficient for different vehicle size classes [16]

Vehicle class	**R_0 (N)**	**R_1 (N.s/m)**	**C_dA (m^2)**
A,B	106	0.67	0.538
C	139	0.85	0.618
D	154	0.94	0.689
E,F,J	175	1.01	0.810
Van	114	0.71	0.601

2) High emitter criteria: To identify high NOx emitters, a criterion must be defined. Different test cycles are used for various emission standards to have reference values of allowed emissions. So, vehicles of a certain emission standard, produce different amounts of emission in other operating points of their engines. A European study by International Council on Clean Transportation (ICCT) has developed a model of NOx emission versus VSP for different European standards [30]. This model will be used to determine the NOx emission limit in any amount of VSP for each vehicle.

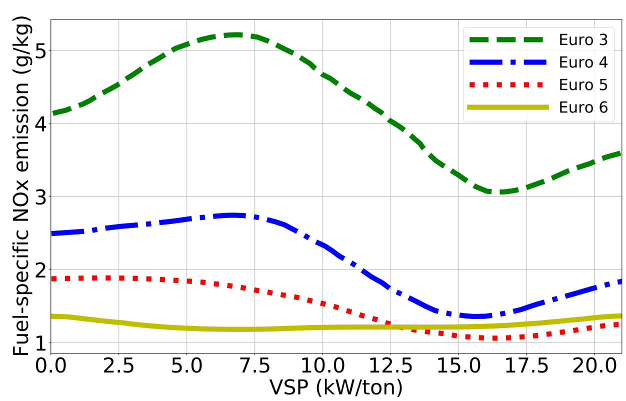
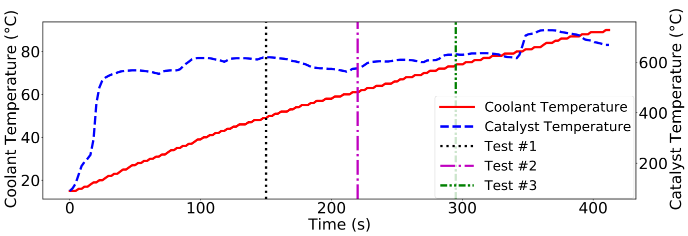


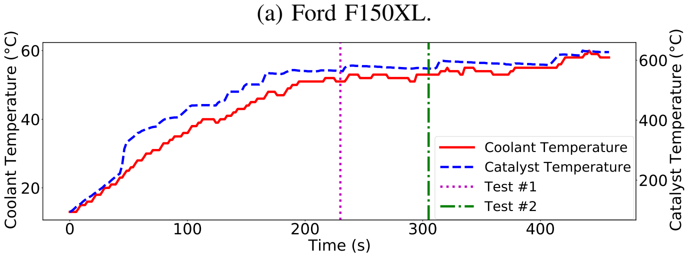
Fig. 3: Models developed for NOx emission limits vs VSP for different emission standards based on the data from reference [30].

III. Results and Discussion

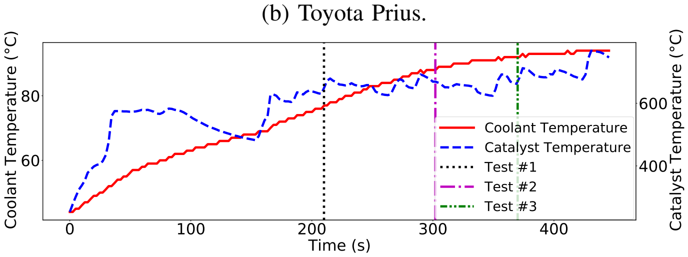
At first, using OBD data from all vehicles ensures that the measurements are not conducted during the cold start period. In the cold start period, vehicle emissions are considerably higher than normal operation. As a result, most of the engine emissions in a standard emission measurement cycle are from the cold start period. Cold start leads to incomplete atomization of fuel, less vaporization, defective air-fuel mixing, re-condensation of fuel droplets on cold surfaces and poor combustion. Besides, engine torque is increased because of the high viscosity of engine oil at cold temperatures. On the other hand, after-treatment systems are not fully active in cold temperatures which causes the emissions to increase [31]. For three selected vehicles, Fig. 4 shows the coolant and catalyst temperatures during the test. It shows the catalyst is fully warmed-up for all the test points. Even though the coolant temperature still increases during these tests, it is not considered a cold start since the catalyst is warmed up.



(a) Ford F150XL.



(b) Toyota Prius.



(c) Chevrolet Silverado 2500.

Fig. 4: Engine coolant temperature and three-way catalyst temperature of the selected tested vehicles.

Measured points are compared to a European database of NOx emissions collected by a remote sensing system to identify high NOx emitters among the tested fleet. Data is reported as the average fuel-specific NOx versus VSP in different European emission standard categories (Euro 3 to Euro 6). The vehicles tested in this study correspond to the year of European regulation adoption based on the vehicle production year as listed in Table VI.

TABLE VI: European standards with the vehicle production year

European emission standard	Production year
Euro 3	2000 to 2005
Euro 4	2006 to 2009
Euro 5	2010 to 2014
Euro 6	2015 to present

The measured NOx points in tested vehicles manufactured after 2014 are shown in Fig. 5. The measured points, except for 3 of them, are very close to the average line of Euro 6 vehicles or below it. Three different vehicles (Dodge Grand Caravan MY2016 #1, Dodge Grand Caravan MY2016 #2, and Chevrolet Silverado 2500 MY2020) have high NOx emissions. High emitter points are marked on Fig. 5 by red circles.

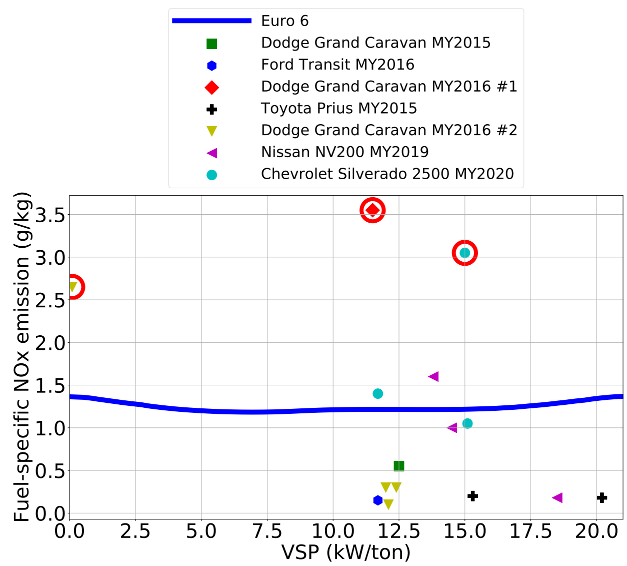


Fig. 5: High emitter identification for model years after 2014.

For vehicles manufactured before 2015 (corresponded to Euro 3, Euro 4, and Euro 5 emission standards), the NOx vs VSP results are plotted in Fig. 6. The marked points are high NOx emitters compared to their emission standards (Euro 5 for Chevrolet Silverado 2500 MY2013 #1 and #3, Euro 4 for GMC Sierra MY2007, and Euro 3 for Ford F150XL MY2005).

OBD data was used to plot the engine operational point of each tested vehicle on the engine load/engine speed diagram. Fig. 7 and Fig. 8 show these diagrams for vehicles manufactured after 2014 and before 2015, respectively. Again high emitter points are shown with red circles. As observed, many high NOx emitters are among the vehicles operating at part-load conditions. When the engines work with a low load, they produce more NOx in a specific VSP. One reason could be the lack of proper tuning of NOx emissions at part-load, primarily related to a performance close to the cold start and not a fully warmed-up catalyst. As a result, it's imperative to use vehicles of suitable class for each application to preserve the vehicle

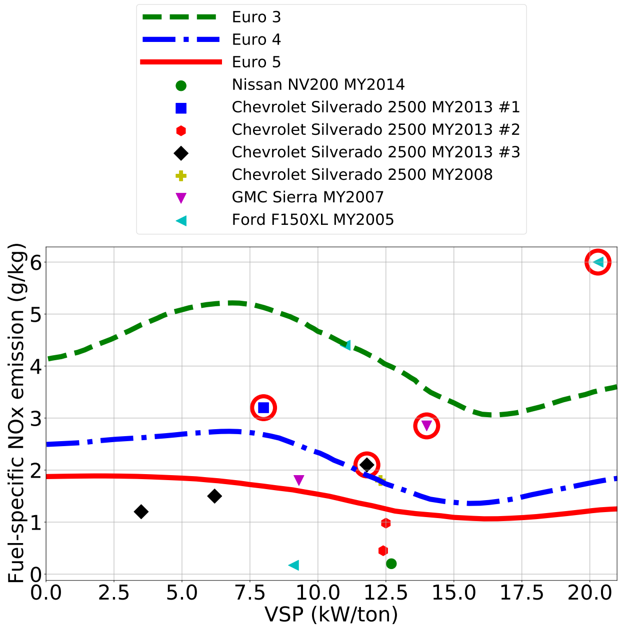


Fig. 6: High emitter identification for model years before 2015.

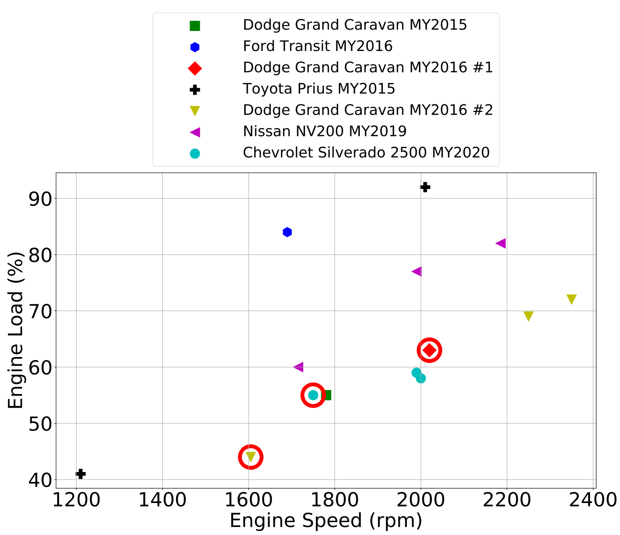


Fig. 7: Engine load vs engine speed for model years after 2014.

performance in an optimal range.

This study provides essential results for the vehicles belonging to the University of Alberta. The university owns many medium-duty vehicles (pick-up trucks, vans, etc.). They are designed for applications that usually require high loads (cargo carrying, highway drive, etc.) but are often used in part-load applications and are driven at very low speeds around the campus without cargo. This study shows choosing the suitable vehicle class (in terms of size and application) is vital to avoid sub-optimal vehicle operations and consequently high harmful tailpipe emissions.

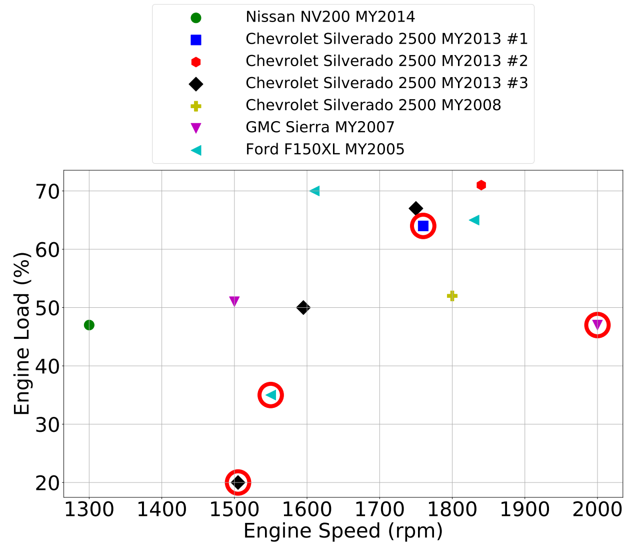


Fig. 8: Engine load vs engine speed for model years before 2015.

IV. Summary and Conclusions

This emissions measurement for a selection of vehicles belonging to the University of Alberta fleet was performed to identify vehicles that produce more NOx emissions. To do this, 28 emission samples were measured from 14 vehicles using remote sensing in campus driving conditions. In addition to emissions, using OBD, vehicle engine information was also recorded for each vehicle.

OBD data for coolant and catalyst temperatures showed that none of the measurement samples were measured during the cold start. By measuring NOx and comparing it with recorded databases, it was concluded that seven measured samples from seven vehicles have high NOx. Then, OBD data revealed that six out of seven high NOx emitter vehicles were in part-loaded operation conditions. Due to operating out of the optimal performance range, they can produce more emissions. Using smaller vehicles for on-campus applications that do not require much load can help improve campus air quality.

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