MODELING THE IMPACT OF TRAFFIC INTENSITY ON NO_X LEVEL ACROSS HIGHWAY

[1]KATERINA MANEVA, [2]FRANTISEK SKACEL

[1,2]University of chemistry and technology Prague, Department of Gas, Coke and Air Protection
E-mail: Katerina.Maneva@vscht.cz, Frantisek.Skacel@vscht.cz

Abstract- This work is focused on the correlation between nitrogen oxides level across highway and the impact of traffic intensity. The main goal was the choice of a representative sampling site without meteorological disturbances. Time series of measured NO_x concentrations was used. Simultaneously measured highly time-resolved NO_x concentration and traffic activity counting were performed. The passing vehicles were classified in different categories. The experimental work yielded reliable results of the mutual correlation of NO_x level and highway intensity with statistical evidence. Emission factors from emission model for road transport were applied and compared with the measurement results.

Keywords- NO_x, highway, traffic intensity, air pollution, emission factor, passing vehicles.

I. INTRODUCTION

Nitrogen oxides are one of the criteria gases of air pollution. NO_x is a group of highly reactive gases, produced from nitrogen and oxygen at high temperatures. In the field of atmospheric chemistry nitrogen oxides (NO_x) express the total sum of nitric oxide NO and nitrogen dioxide NO_2 [1]. Nitrogen oxides play a very important role in the field of atmospheric chemistry. They are included in many reactions in the air and they are precursors of the formation of tropospheric ozone, photochemical smog and acid rain. Emitted NO_x in the atmosphere have many harmful effects on the environment and on human health. Elevated concentration of these gases in the air can cause serious health problems [2-4].

The level of nitrogen oxides in the air is different in different regions and depends on the differences in meteorological conditions and human activities. Nitric oxide (NO) is formed by natural and anthropogenic sources while nitrogen dioxide is present in the atmosphere due to NO oxidation and in small quantities due to emissions during high temperature combustion [5]. The formation of these gases during high temperature combustion processes has the biggest influence on air pollution. Their adverse effects are notable in urban areas where the road traffic is intensive [6]. Among the most polluted areas, motorway and roads are the ones more suitable for measurements.

This work is focused on the determination of the correlation of nitrogen oxides level across highway and the characterization of traffic intensity influence on the generated emission of NO_x. The purpose of this experimental work is to find a remarkable sampling site where, depending on the spatial and temporal variability, the NO_x content will be unaffected by meteorological conditions. For the measurement of NO_x concentration is important to find a representative sampling point that will permit their unbiased analysis. On the chosen site should be possible to obtain highly time-resolved measurement of NO_x concentration and the traffic activity, performed with simultaneous measurement. For the calculation of the passing vehicles were chosen different categories of motor vehicles. For the determination of the reliability of the results of the mutual correlation of NO_x level and highway intensity, were used statistical analyses. To determine the vehicle fleet structure, emission model for road transport was applied. The measured values and the modelled emission factors were compared.

II. DETAILS EXPERIMENTAL

2.1. Sampling site

The aim of this experimental work is to measure the overall NO_x level in a location where high traffic intensity occurs. The chosen sampling site was a bridge (short tunnel) of semi-circular form preserving inner air composition. The main advantage of tunnel measurements is that the conditions in a road tunnel are well defined and meteorological effects are eliminated. Due to limited air circulation it keeps the constituents that are released from transportation.

The bridge is located in Pardubice region, near village Chýšť, eastern of Prague, in Czech Republic. It is positioned on highway D11, at a distance 77 km from Prague.



Fig.1. Semi-circular bridge/tunnel used for the ambient air sampling

2.2. Measuring system and data processing

Measurement of the concentrations of NO_x was carried out using one of the Horiba's AP-360 series of air pollution monitoring system, APNA-360 Nitrogen Oxide Analyser based on chemiluminiscence principle. Standard sampling train for the ambient air quality monitoring was used. The analysed air was drawn to the analyser through a probe positioned in the middle of the highway. This analyser uses the multi-flow modulation method that approves synchronic, continuous and separate measurement of NO, NO_2 and NO_x [7].

All the experimental results were processed using the analysis of variance (ANOVA). ANOVA is used to test the equality of two or more population means by analysing the variance of the samples that are taken. This method makes possible to determine whether the differences between samples are due to random errors or due to systematic treatment effects. Systematic treatment effects cause the mean in one group to differ from the mean in another. ANOVA is usually used to compare the equality of three or more means [8, 9].

2.3. Handbook Emission Factors for Road Transport (HBEFA)

Handbook Emission Factors for Road Transport (HBEFA) is the most complete road traffic emission model used in Germany, Austria, Switzerland, Norway and France. This model can be applied for road traffic emission analyses in Czech Republic due its close location to these countries. The program uses emission factors to precisely inform the contribution of road traffic emission or of different vehicle category emissions. Emission factor describes the average emission rate for a given pollutant corresponding to a specific activity of a particular emission source. Emission factors (EFs) for road traffic express the emitted mass of a pollutant per driven distance (g/km). They can be applied for one vehicle category as well as for more categories or for whole vehicle fleet. EFs are influenced by many variable components such as vehicle size and type, driving speed, road gradient, type of exhaust technology, fuel mode of the vehicle etc [10, 11].

The HBEFA program presents many variable parameters for the creation of the traffic scenario including usual driving conditions with different speed limits (highway, rural, urban driving, stop and go traffic) for different route gradients. The superiority of this database is its service of variable case definitions with different driving cycles. This program method provides the pollutant emissions of all adequate categories of road vehicles: passenger cars, heavy and light commercial vehicles, urban buses, motorcycles etc. The diversity of these factors helps to create a complete description of the road traffic measurement. The program offers the possibility to choose which pollutant/pollutants the EFs will represent (NO_x, CO, CO_2, PM, SO_2, t-VOC, several VOC components, Pb, NH_3, N_2O, toluene, xylene, soot, fuel consumption). In order to acquire emission factors for a given traffic emission measurement it is important to incorporate the collected data for the chosen vehicle category in the emission models. The measurement has to contain information which is adaptable to real driving scenario. Therefore this method is suitable for the evaluation of data gathered from on-road traffic measurement [10, 11].

III. RESULTS AND DISCUSSION

3.1. Measurement scenario and representative sampling point

The work is based on short-term daily measurements that do not allow an evaluation of the long-term development of road traffic emission. All the measurements were performed in the specifically chosen sampling site (short road tunnel). The conditions in a road tunnel are well defined where meteorological effects are almost negligible. The measurements for this work were performed during the years 2013 to 2015. In order to measure the dependence of NO_x concentration on various traffic intensities, different week days at varying meteorological conditions were chosen. Measurements were carried out at different hours during the course of the day.

To specify the sampling point, NO_x concentration was measured at different heights. The representative sampling point was chosen on the position where the highest concentration of NO_x was detected, situated at 2 m above the ground level. The typical course of a day measurement is described for Thursday, November 14, 2013 (Fig.2).

3.2. Time series

Fig. 2 shows the NO, NO_2 and NO_x concentration progress during the whole experimental work.

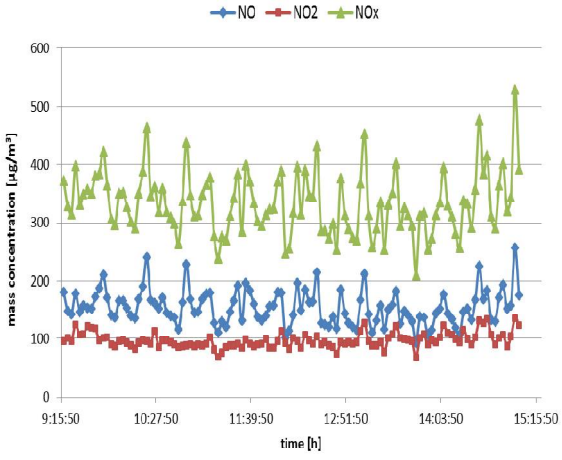


Fig.2. Time course of the concentration progress for the monitored compounds (November 14, 2013)

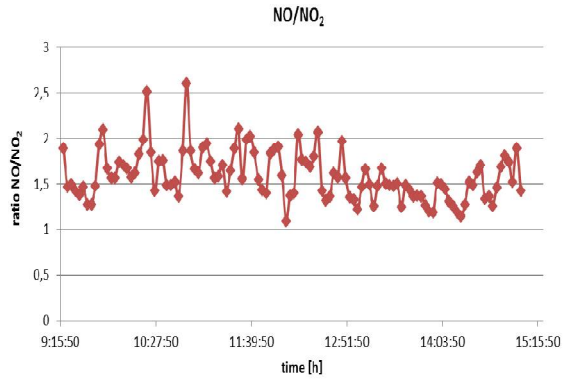


Fig.3. Time course of the progress of the ratio concentration of NO and NO_2 (November 14, 2013)

In Fig. 3 the ratio of NO and NO_2 mass concentration is given. In Fig. 3 is depicted that the ratio of NO and NO_2 oscillates with a mean of approximately 1.6.
The motor vehicles were divided in two categories: passenger cars and trucks + buses. The total number of passing motor vehicles was calculated in 9 minute intervals. The variations of the traffic activities for each of the vehicle categories are shown in Fig.4. The graph shows changing traffic intensity during the measurement.

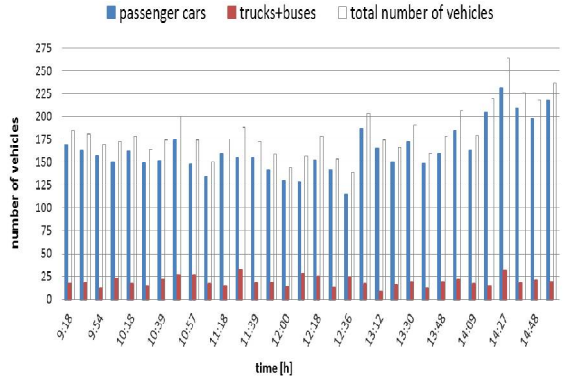


Fig.4. Total number of all vehicle categories during measurement time in 9 minute intervals (November 14, 2013)

During all measurement campaigns, the background mass concentration of NO_x was determined. The resulting values were almost stable and confirming the minimal output of NO_x from the tunnel space. The mean mass concentration of NO, NO_2 and NO_x were 25.5 µg/m^3, 50.3 µg/m^3 and 89.4 µg/m^3, respectively.

3.3. Correlation

An important part of this work is to determine the correlation of nitrogen oxides level across highway profile and to characterize the influence of traffic intensity on the generated NO_x emission. Simultaneous measurements were performed that obtained highly time-resolved measurement of NO_x concentration and calculation of the number of passing vehicles. In Fig.5-7 the dependence of NO_x mass concentration on the number of passing vehicles for the example case (November 14, 2013) is shown.

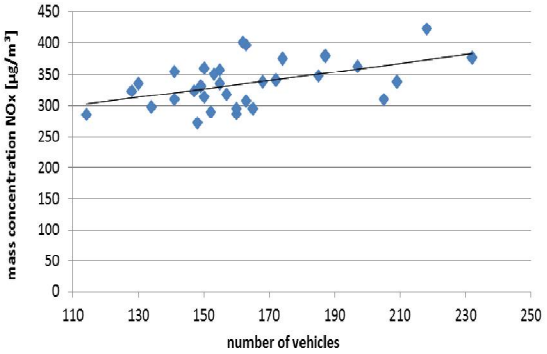


Fig.5. Correlation of NO_x mass concentration dependence and number of passing passenger vehicles (November 14, 2013)

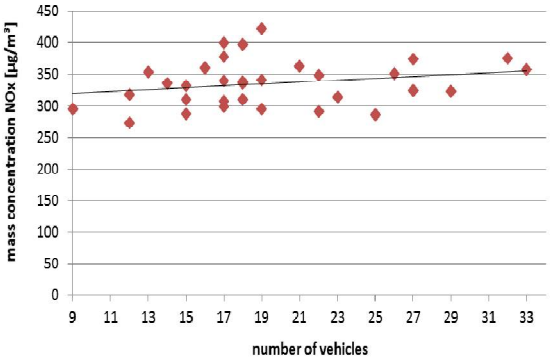


Fig.6. Correlation of NO_x mass concentration dependence and number of passing trucks and buses (November 14, 2013)

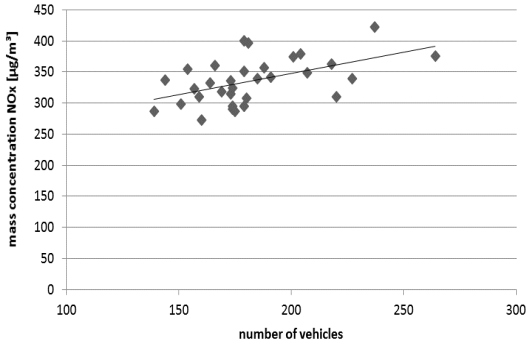


Fig.7. Correlation of NO_x mass concentration dependence and number of passing vehicles of all categories-passenger cars, trucks and buses (November 14, 2013)

A statistical technique was used to determine the reliability of the results and to examine if the correlation between the measured data is linear. The form of dependence of the NO_x concentration on the number of passing different categories of vehicles, passenger cars, trucks+buses, total number of passing vehicles, was detected. For multiple comparisons, ANOVA-analysis of variance is the most useful technique. The analysis of variance compares whether or not the controlled factor has a significant effect [9]. In this work ANOVA is used to compare

whether the number of the passing motor vehicles has a significant effect on the NO_x mass concentration growth, i.e. a measure of linearity.

ANOVA data interpretation is based on the value of the F-test. The linearity test is done by calculating the F-value and comparing it with the tabulated value of F-test. For the size of data set, i.e. result of the measurement trials described in this work, [9] the tabulated critical F-test value was 1.65. The calculated F-values were different for each of the vehicle categories and monitored compounds. In Table I are presented all the calculated values for example case (November 14, 2013). If the calculated F-value is smaller than the corresponding tabulated critical F-value, a linear correlation between the measured values of NO_x concentration and traffic intensity with 95% probability is confirmed [9, 12].

Table.I. Analysis of variance for example case (November 14, 2013)

3 minutes intervals		F_{calc}	F_{crit}
NO	Passenger cars	1.429	1.65
	Trucks + Buses	1.539	
	ΣPC+ (T + B)	1.365	
NO_2	Passenger cars	1.04	1.65
	Trucks + Buses	2.036	
	ΣPC+ (T + B)	1.114	
NO_x	Passenger cars	1.141	1.65
	Trucks + Buses	1.443	
	ΣPC+ (T + B)	1.085	

The correlation of Trucks+Buses traffic intensity and NO_2 concentration does not show a linear behaviour. This result is expected since the number of Trucks+Buses vehicles makes up only for a small part of the total number of vehicles. Except this single deviation all the other results, more importantly the total vehicle number, show a strong linear correlation with the emitted compounds. From the tabulated results follows the prevailing impact onto the air quality across the highway profile have the passenger car traffic.

3.4. HBEFA calculation

To get more comprehensive data in order to reach more concrete results of these measurements, Handbook Emission Factors for Road Transport (HBEFA Version 3) was used. In order to acquire emission factors, the measurement has to contain information which is adaptable to real driving scenario and the collected data of the chosen vehicle category to be incorporated in the emission models. All the measured data corresponds with the selection of parameters in HBEFA program. Therefore this method is appropriate and the measured values and modelled emission factors by HBEFA V3, were compared.

The case definition was created for the two vehicle categories that were numbered during the measurements. Passenger cars in the category first and tracks and buses are in the second. The years 2005, 2010 and 2015 were selected as years chosen for the realization of the traffic compositions. The individual traffic scenario was constructed according to the measurement in the chosen location-rural area, free flow motorway with speed limit of 130 km/h and road inclination gradient 0%. The emission factor for the first vehicle category (passenger cars), calculated for year 2005 is 0.794. For year 2010 is 0.515 and 0.415 for 2015. These factors are valid for this specific traffic circumstances. The calculated NO_x mass, defined by the EF (emission factor), number of vehicles and the tunnel length, varies depending on the different number of passenger cars, counted during the 9 min measurement intervals. All the calculated average mass values are higher than the measured average NO_x mass. In Fig.8 the correlation of the NO_x mass dependence and number of vehicles is depicted. Additionally in Fig.8 the calculated NO_x mass for the different EFs on the number of the passenger cars is depicted.

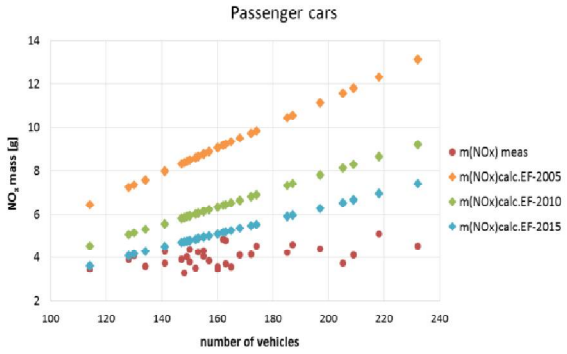


Fig.8. Correlation of the NO_x mass dependence and number of passing vehicles (November 14, 2013)

The emission factors for the second chosen category (Trucks + Buses) are EF_{2005}=5.946, EF_{2010}=2.878 and EF_{2015}=1.414.

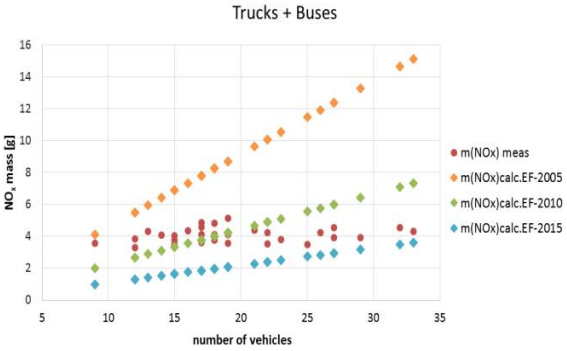


Fig.9. Correlation of the NO_x mass dependence and number of passing tracks and buses (November 14, 2013)

The calculated NO_x mass for EF_{2005} has higher values then the measured NO_x mass. The theoretically calculated NO_x mass values for EF_{2010} are close with the on road measured ones. The measured NO_x mass has higher values then the calculated NO_x mass for EF_{2015}. HBEFA program database contains data from

the past development of the EFs, the EFs after changes in fleet composition and after-treatment technology changes. This explains the real traffic situation for the heavy commercial vehicles. Older heavy commercial vehicles or HCV without advanced technologies occur on road.

As follows from the HBEFA calculations the passenger vehicle fleet structure passing the sampling site corresponds to the structure of that fleet in HBEFA countries (AT, CH, DE, FR, NR) related to 2015. Heavy trucks and buses fleet composition passing the sampling site corresponds to the structure of that fleet in HBEFA countries related more likely to 2010.

REFERENCES

[1]. 1. Atkinson, R., Atmospheric chemistry of VOCs and NOx. Atmospheric Environment, 2000. 34(12–14): p. 2063-2101.

[2]. 2. D.Ehhat and M. Prather, Atmospheric Chemistry and Greenhouse Gases, in Climate Change 2001-The Scicentific Basis, Contribution of Working Group 1 to the Third Assesment Report of the Intergovernamental Panel on Climate Change. 2001, Cambridge University: Cambridge. p. 239-287.

[3]. 3. WHO, Air Quality Guidelines: Global Update 2005 : Particulate Matter, Ozone, Nitrogen Dioxide, and Sulfur Dioxide. 2006: World Health Organization.

[4]. 4. Manahan, S.E., Environmental Chemistry, Ninth Edition. 2009: CRC Press.

[5]. 5. Seinfeld, J.H. and S.N. Pandis, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. Second ed. 2012: John Wiley & Sons.

[6]. 6. Annamalai, K. and I.K. Puri, Combustion Science and Engineering. 2006: Taylor & Francis.

[7]. 7. Kato, J. and A. Yoneda, Air Pollution Monitoring Systems AP-360 Series Readout HORIBA Technical Reports. 1997.

[8]. 8. Dohnal, L., Desatero pro porovnávání výsledků dvou metod, in Štatistické metódy pre klinickú epidemiológiu a laboratórnu prax. 2008, APRILLA s.r.o. Košice pre Knihy Hanzluvka: Košice, Slovakia.

[9]. 9. Deming, S.N., et al., Chemometrics: A Textbook. 1988: Elsevier Science.

[10]. 10. Hausberger, S., et al., Emission Factors from the Model PHEM for the HBEFA Version 3. 2009, Graz University of Technology: Graz, Austria.

[11]. 11. Colberg, C.A., et al., Comparison of a road traffic emission model (HBEFA) with emissions derived from measurements in the Gubrist road tunnel, Switzerland. Atmospheric Environment, 2005. 39(26): p. 4703-4714.

[12]. 12. D.L. Massart, et al., Chapter 6 Analysis of variance, in Data Handling in Science and Technology. 1998, Elsevier. p. 121-150.

★★★