COMPARISON OF NO_X EMISSIONS CALCULATED USING ROAD TRAFFIC EMISSION MODEL (MEFA) WITH EMISSIONS DERIVED FROM TUNNEL MEASUREMENTS IN CZECH REPUBLIC

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Vehicles activity contribute significantly to NO_x emission. Numerous mathematical models performing emission assessment of road-related pollutants were developed. These traffic emission models are characterized by emission factors (EF), which quantify the amount of the emitted pollutant. A comprehensive emission model for the calculation of the EF for Czech fleet composition is used. Emission factors were calculated with the emission model MEFA 13. Here, we present a comparison of NO_x emission calculations in MEFA 13 model and NO_x tunnel measurements. Simultaneous measurements of NO_x concentration and traffic activity counting were performed in short tunnel (Zelený most), in the Czech Republic. Emission factors for road transport derived from the Czech emission model MEFA 13 were applied.

Keywords: NO_x emission, emission model, emission factors, vehicles

Došlo 22. 2. 2018, přijato 8. 6. 2018

1. Introduction

The combustion of fossil fuels by vehicles is one of the most significant sources of primary air pollutants. Traffic-related air pollutant exposures results with adverse effects on human health and on the environment [1, 2]. These pollutants include nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOC), sulfur dioxide (SO_2). Nitrogen oxides, expressed as the total sum of nitric oxide and nitrogen dioxide, have an important role in the atmospheric chemistry [3]. Included in various complex reactions in the lower layer of the atmosphere, NO_x are precursors of the tropospheric ozone formation, secondary particulate matter, acid rain and, photochemical smog [4-10]. In urban areas where intensive traffic occurs, the concentration levels of NO_x are increased. The average concentration level depends on the meteorological conditions, wind direction but most dominantly on the distance from the source, e.g. highways [11].

Due to the increased interest in air quality, emission monitoring has been more required in the recent years. Most studies which are focused on air quality and pollutants emission, deal with mobile emission sources. Therefore, numerous mathematical programs have been developed to model the emission of traffic-related pollutants. Based on the implementation of specific parameters, emission models are used to estimate pollutant emissions. For the calculations of the road traffic emission, implementation of vehicle and fuel types, frequency of individual vehicle types, fuel consumption, driving pattern and average traveling speed is needed [12, 13].

Emission models use emission factors (EF) to describe the amount of emitted air pollutants. Emission factors for road traffic emission modeling express the emitted mass (g) of particular pollutant per driven distance (km) of a vehicle [14]. EF are calculated by emission models which use aggregated data based on legislative conditions and emission measurements of single vehicles [15]. These measurements of a large sample of different types of vehicles are usually performed in laboratory conditions. Hence, some emission models also include real on-road driving measurements based on different driving and road conditions [16].

During the past few decades many mathematical emission models were developed in several European countries, the United States and Canada. Among them is the Czech emission model MEFA based on emission data measurements characteristic for the traffic representatives in the Czech Republic.

The best approach to estimate the real traffic emission is to perform real air pollutant emission measurements and compare with modeled emission factors. In this paper, we compare the results of NO_x emission from tunnel measurements in Czech Republic with road traffic emission model MEFA 13.

2. Experiment

2.1. Modeling of the EF with the traffic emission model MEFA

The emission model MEFA (MEFA 02) was created by a team of employees from the University of Chemistry and Technology of Prague, ATEM, and DINPROJEKT. The model calculates the emission factors of traffic-related pollutants for each vehicle type with vehicles characterization as fuel type and emission standards. MEFA model makes it possible to calculate the total mass flow of particular air pollutant in a given section of the road. The updated model MEFA 13 is actual from year 2013. It includes calculations of emissions during cold start-ups, emissions from dust resuspension on the road with

an implementation of climate data, emissions from tire and brake wear and future traffic emissions until 2040. Due to the technical development of vehicles, in this model are included vehicles complying with Euro 5 and Euro 6 emission regulations [17]. In addition, the updated version of the MEFA model includes the participation of heavy-duty vehicles, expressed as a percentage, for the calculation of EF for heavy-duty vehicles.

To calculate the emission factors of motor vehicles in a given road section, the following input parameters must be entered:

- selection of years for which the EF are calculated,
- vehicle category (light-duty vehicles LDV, heavy-duty vehicles HDV and buses),
- vehicle characterization (fuel type: gasoline, diesel, LPG and CNG, emission standards: Euro 1/I to Euro 6/VI including vehicles produced before 1992),
- characteristics of traffic conditions (level of traffic flow in a range from 1 to 10 and road gradient in a range from -10 % to +10 %) and
- speed limit (max. 130 km/h).

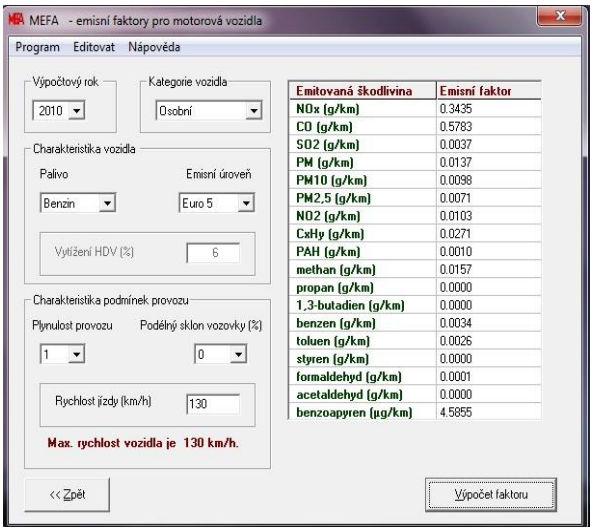

Fig. 1 Overview of the emission model MEFA 13

2.2. Tunnel measurements and sampling site

In order to determine the impact of the traffic intensity on NO_x concentration level in the air, NO_x concentration measurements should be provided in the vicinity of highways. For the purpose of this study, the sampling location was chosen to be a tunnel (Zelený most). The advantage of tunnel measurements is the tunnel structure that limits the air circulation and meteorological effects can be excluded. The tunnel is located in Pardubice region on highway D11 in Czech Republic. Zelený most is one bore tunnel with two lanes of traffic in each direction (Fig. 2). The concentration of NO, NO_2 and the summary NO_x was measured with the Horiba APNA-360 Nitrogen Oxide Analyzer based on chemiluminiscence principle.

Fig. 2 Sampling site on highway D11, Zelený most

The analyzer gives continuous on-line data on concentration level with synchronic and separate measurements of NO, NO_2 and NO_x [18]. The sampled air was drawn to the analyzer through a probe positioned in the middle of the highway.

To be able to determine the mutual correlation of the NO_x concentration level in the tunnel and the vehicles that pass in that section, vehicle counting is required. The passing vehicles were divided in two categories: light vehicles (cars and vans) and heavy-duty vehicles (trucks and buses). The total number of vehicles was calculated in 9 minute intervals.

3. Results and discussions

3.1. Emission factors for NO_x

The emission factors for nitrogen oxides were calculated in MEFA 13 emission program. The input parameters for the calculation of EF for individual vehicles are shown in Tab 1. The vehicle types are selected in two categories, LDV and HDV. In the first category, passenger cars and light vehicles are comprised. While the HDV category counts for heavy-duty vehicles and buses.

The EF are calculated for road gradient 0 % corresponding to the real tunnel gradient where the vehicle speed limit is 130 km/h for LDV and 100 km/h for HDV. The modeled emission factors for NO_x have different values, listed in Tab. 2 and Tab. 3, depending on the vehicle's fuel type and the emission standard.

Tab. 1 Input parameters for the calculation of EF in MEFA 13

Input parameters	Calculation of emissions for individual vehicles	
Selection of year	2017	
Selection of pollutant	NO_x	
Vehicle category	LDV	HDV
Vehicle characterization (fuel type)	Gasoline Diesel LPG CNG	Diesel
Vehicle characterization (emission standards)	pre-1992	pre-1992
	Euro 1	Euro I
	Euro 2	Euro II
	Euro 3	Euro III
	Euro 4	Euro IV
	Euro 5	Euro V
	Euro 6	Euro VI
Level of traffic flow	1 (free flow)	
Road gradient	0 %	
Speed limit	130 km/h	100 km/h

Additionally, the average mean values of the emission factors are calculated due to the unknown vehicle mix in the tunnel section (Tab. 2, Tab. 3). Therefore, $EF_{average}$ is the average value of the EF for emission regulations Euro 1/I to Euro 6/VI. Whilst, $EF_{t.average}$ is the average value of the EF for emission regulations Euro 1/I to Euro 6/VI, including the pre-1992 vehicle emission level.

3.2. NO_x emission from tunnel measurements

The measurements of NO_x concentration were performed on May 4, 2017, in the short tunnel-Zelený most. The measurements were carried on for four hours. To specify the sampling point, the NO_x concentration was measured at different heights of the tunnel. The sampling point was chosen to be in the position where the highest concentration of NO_x was detected. The highest concentration was detected at 2 m above the ground level. The height dependency of NO_x mass concentration is depicted in Fig. 3.

In Fig. 4 the mass concentration progress for the analyzed compounds i.e. NO, NO_2, NO_x in 3 minute intervals is shown. Additionally, for the comparison of the NO_x concentration level on the road and in the near surrounding air, the background mass concentration of NO_x was determined in 100 m distance northern from the sampling site. The resulting values were almost stable and the mean mass concentration of NO, NO_2 and NO_x were 18.2 $\mu g/m^3$, 51.4 $\mu g/m^3$, 79.3 $\mu g/m^3$, respectively.

The variations of the traffic activities, for each of the vehicle categories counted simultaneously with the NO_x concentration measurements, are shown in Fig. 5.

Tab. 2 NO_x emission factors for LDV calculated with MEFA 13

LDV		
Fuel type	Emission standard	Emission Factor (g/km)
Gasoline	pre-1992	8.4209
	Euro 1	2.3641
	Euro 2	1.0220
	Euro 3	0.6581
	Euro 4	0.4372
	Euro 5	0.3435
	Euro 6	0.2536
Diesel	pre-1992	1.9272
	Euro 1	1.3374
	Euro 2	0.7835
	Euro 3	0.4797
	Euro 4	0.3042
	Euro 5	0.2871
	Euro 6	0.1038
LPG	pre-1992	2.2777
	Euro 1	0.5283
	Euro 2	0.2284
	Euro 3	0.1471
	Euro 4	0.0977
CNG	Euro 2	0.2284
	Euro 3	0.1471
	Euro 4	0.0977
$EF_{average}$= 0.5184		
$EF_{t.average}$= 1.0216		

Tab. 3 NO_x emission factors for HDV calculated with MEFA 13

HDV		
Fuel type	Emission standard	Emission Factor (g/km)
Diesel	pre-1992	12.5658
	Euro 1	7.7655
	Euro 2	5.9071
	Euro 3	0.6564
	Euro 4	0.3705
	Euro 5	0.1478
	Euro 6	0.0818
EFaverage= 2.4881		
EFt.average= 3.9278		

Simultaneous measurements were performed that obtained NO_x mass concentration detection and calculation of the number of passing vehicles. In Fig. 6 the correlation of the NO_x mass concentration and the total number of passing vehicles (LDV and HDV) is shown. The

correlation coefficient between the two variables is 0.405.

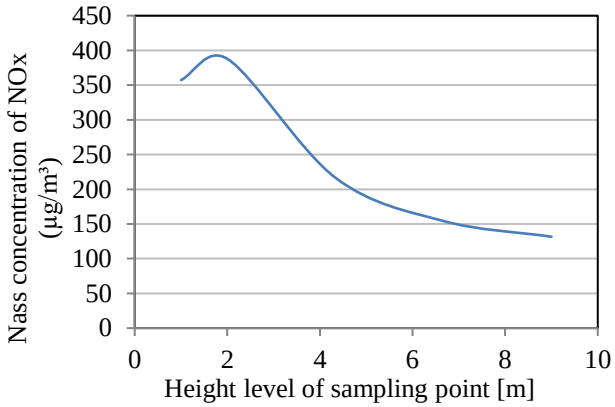

Fig. 3 Height dependency of NO_x mass concentration measured in the tunnel above the ground level

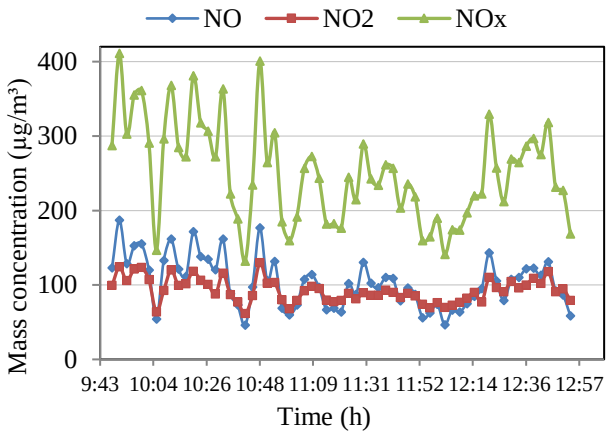

Fig. 4 Evolution of the NO, NO_2 and NO_x mass concentration measured in 3 minute intervals (May 4, 2017)

3.3. Comparison of the modeled and measured NO_x emission

In order to compare modeled and measured emission, the model has to contain information which is adaptable to real driving scenarios. Hence, these data have to be used and implemented for the calculation of the EF.

The measured data correspond with the selection of parameters in the MEFA 13 model. Therefore, the results of the emission factors and the tunnel measurements, were compared. The correlation of the calculated NO_x mass from the measured NO_x concentration and the number of LDV passing through the chosen section is shown in Fig. 7. Additionally, in Fig. 7 the values of the calculated NO_x mass by the modeled $EF_{average}$ and $EF_{t.\ average}$ are depicted. The NO_x mass was calculated from the tunnel's dimensions and the measured NO_x mass concentration.

In Fig. 8 the correlation of the measured NO_x mass and the number of passing HDV is depicted.

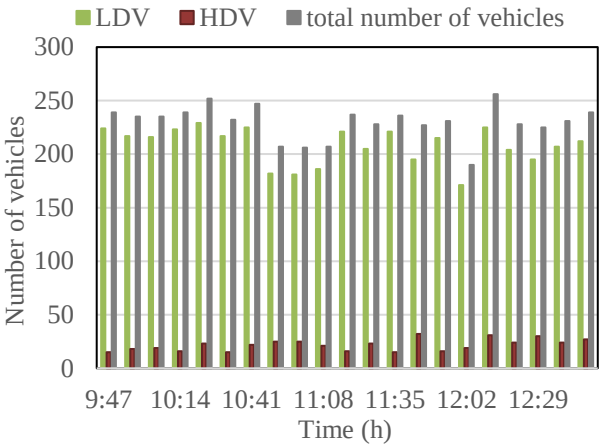

Fig. 5 Total number of all vehicles categories counted in 9 minute intervals (May 4, 2017)

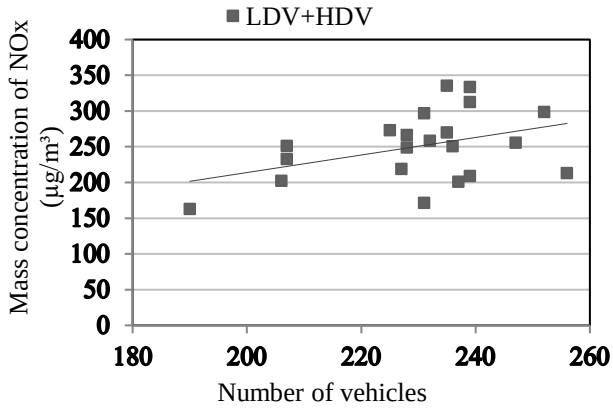

Fig. 6 Correlation of the NO_x mass concentration and the total number of passing vehicles (May 4, 2017)

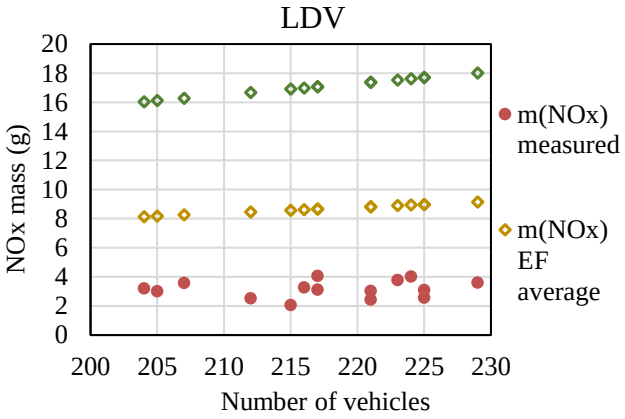

Fig. 7 Correlation of the NO_x mass and the number of passing light-duty vehicles (May 4, 2017)

Additionally, in Fig. 8 the values of the calculated NO_x mass by the modeled $EF_{average}$ and $EF_{t.\ average}$ for HDV category, are depicted.

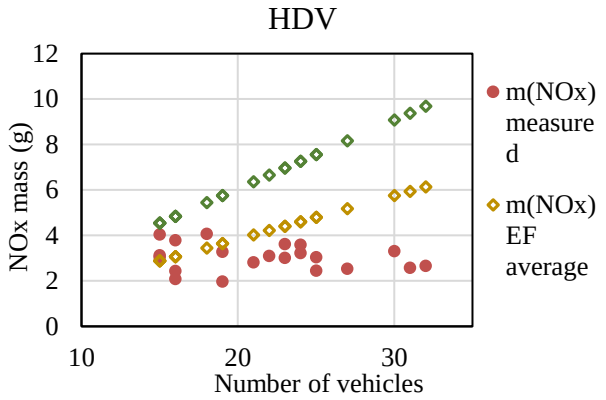

Fig. 8 Correlation of the NO_x mass and the number of passing heavy-duty vehicles (May 4, 2017)

4. Conclusion

Emission factors from road traffic emission model MEFA 13 were calculated for Czech fleet composition and road driving conditions on D11 highway. Additionally, the average mean values of the emission factors were calculated due to the unknown vehicle mix in the sample section. The tunnel measurements have shown a positive linear correlation with a correlation coefficient of 0.405 between the NO_x concentration level and the number of passing vehicles. Modeled NO_x emissions for LDV and HDV were compared with NO_x tunnel measurements in Zelený most.

The results obtained by the MEFA 13 model for light-duty vehicles are significantly different from the tunnel measurement results. The NO_x mass calculated by the emission factors for LDV showed an overestimation for the $EF_{average}$ and considerable overestimation for the average EF including the pre-1992 light-duty vehicles. Thus, in general, the real LDV fleet seems to be cleaner than the Czech fleet assumed in the MEFA 13. It follows that average emission factors cannot be taken into consideration for calculations of NO_x emission from light-duty vehicles.

The results derived from the $EF_{average}$ of NO_x for heavy-duty vehicles are in good agreement with the tunnel results. However, the comparison of measured and calculated NO_x mass including the pre-1992 HDV, resulted with overestimation of calculated NO_x mass with the $EF_{t.\,average}$. This can be explained by the technical condition (age) of the HDV representatives in the fleet mixture. But also the fact that heavy-duty vehicles make a small contribution with only 9 % of the total number of vehicles must be taken into account.

The results of the comparison of the emission model MEFA 13 with the tunnel measurements showed that uncertainties are existing when average EF for NO_x emission calculation are used. This method is not applicable due to the large number of non-identified vehicles that influence the EF calculations. This study suggests further traffic measurements and comparisons with emission modeling.

Acknowledgment

The presented work was financially supported by IGA VŠCHT (A2_FTOP_2017_030).

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