MONITORING THE EMISSION STATUS OF A SPARK-IGNITION INTERNAL COMBUSTION ENGINE UNDER VARYING SPEED AND TORQUE

Simona BÁRTOVÁ[1], Juraj JABLONICKÝ[2], Juraj TULÍK[3], Matej CHLEBAN[4]

[1,2, 3, 4] Department of Transport and Handling, Slovak University of Agriculture, Nitra

Abstract
The paper focuses on the possibilities of monitoring the emission parameters of a spark ignition internal combustion engine under varying speed and torque. The loading of the internal combustion engine was carried out on a MAHA MSR 500 dynamometer and the satisfactory technical condition of the tested internal combustion engine with respect to the number of kilometres driven was confirmed. Prior to the start of the tests, the emission status of the internal combustion engine was also monitored in accordance with Decree 138/2018 Coll. of the Ministry of Transport and Construction of the Slovak Republic, which establishes details in the field of emission control. The measurements confirmed the satisfactory condition of the combustion engine in terms of the monitored emissions. In accordance with the measurement methodology, selected components of emissions (CO, CO2, NOX and HC) were monitored at the inferred load and on individual gears. The above emissions were measured with the MAHA MET 6.3 instrument.

Key words: *emissions, spark-ignition combustion engines, exhaust gases, emission measurement, emission limits*

INTRODUCTION

Exhaust gases are waste products produced in the engine as a by-product of engine operation, they are products of oxidation and imperfect combustion of hydrocarbon fuel. If perfect combustion were to take place while maintaining the stoichiometric ratio, the only products of combustion would be carbon dioxide and water. However, this cannot be achieved under realistic conditions and therefore harmful emissions are produced by the engine's operation. This aligns with previous findings which state that combustion engine vehicles release various harmful substances into the atmosphere through exhaust gases *(Janoško, 2025)*.
Exhaust emissions are the main reason for exceeding the permissible concentrations of toxic substances and carcinogens in the atmosphere of large cities, in the form of smog, which are a common cause of poisoning in enclosed spaces. The number of pollutants emitted into the air by vehicles is determined by the amount of emission gases and the composition of the exhaust gases. However, exhaust fumes are not the only pollutants that escape into the environment from the vehicle compartment and pollute the air. In addition to these, substances also escape from the vehicle's crankcase and from the vehicle's fuel system as fuel vapours. The amount of these fumes and thus their overall impact on the environment is much less than that of exhaust fumes and so the focus will be primarily on emissions emanating from the exhaust system of the car *(Sassykova, 2019)*.
If we talk about the composition of the exhaust gases, they are largely composed of nitrogen. In spark-ignition engines, then, a significant proportion is made up of carbon dioxide and water. For power units that use petrol as fuel, the amount of oxygen contained in the exhaust gases is considerably lower than for diesel engines, at only 1% of the total exhaust gas content. It is the pollutants that have the smallest share in the emissions content, less than one per cent of the total. In the most modern versions of internal combustion engines with the most advanced exhaust gas treatment technologies, this value is below 0.5% of the pollutant content *(Aakko-Saksa, 2017)*.
Although harmful substances make up only a very small percentage of the total number of substances present and it would seem that their impact on the environment is therefore negligible, this is not the case. Many of these substances are hazardous, toxic or severely damaging to the environment. They can therefore cause serious health and environmental hazards in small concentrations. These harmful

substances include *(Aakko-Saksa, 2017)*: Carbon monoxide, Nitrogen oxides and other nitrogen-containing compounds, Particles consisting of elemental carbon, organic compounds, anions *(sulphates, nitrates)* and metals, Hydrocarbons, Carbonyl compounds, Polycyclic aromatic compounds *(Mejia-Centeno,2007) (EEA, 2012)*.
Exhaust emissions can be reduced in several ways. An important factor affecting the production of pollutants is the design of the vehicle itself, the engine and especially the combustion chamber. Low emissions can be achieved by proper design and adjustment of engine operating parameters and fuel distribution. Design features and parameters that affect emissions include: Compression ratio, Shape of the combustion chamber, Location of the spark plug, Valve timing, Engine revolutions, Load and engine temperature *(Jablonický, 2019)*. Therefore, the aim of the study was to examine the possibilities of monitoring the emission parameters of a spark ignition internal combustion engine under varying speed and torque.

MATERIALS AND METHODS

The main component monitored was the exhaust emissions of a spark ignition internal combustion engine in a Hyundai Getz vehicle with a G4HG engine. These measurements were performed using laboratory equipment with valid certification and calibration. The characteristics of the object of interest, the measuring equipment and the methodology and the course of measurements are described in the following section.
The following methodology was established for the measurements:

- Performing a continuous load power measurement

Simulating driving loads with the discrete load method and conducting driving tests with emission production measurements for individual vehicles at:

- speeds of 20-40 km.h^{-1} in 2nd gear,
- speeds of 40-50 km.h-1 in 3rd gear,
- speeds of 50-90 km.h-1 in 4th gear,
- speeds of 90-130 km.h-1 in 5th gear,

Carrying out emission checks to determine the emission status of vehicles

The vehicle to be measured must be in good technical and emission condition so that the results can be further evaluated and processed. The area of emission inspections is regulated by Act No 106/2018 Coll. on the operation of vehicles in traffic and on amendments and supplements to certain acts, as amended. The emission control was carried out in accordance with the valid regulations pursuant to Decree 138/2018 Coll. of the Ministry of Transport and Construction of the Slovak Republic, which establishes details in the field of emission control. These measurements were carried out using MAHA MET 6.3 exhaust gas analysis equipment in cooperation with the MAHA Emission Software evaluation system.

Simulating driving loads with discrete measurements and performing driving tests with emission production measurements

Before the actual measurement, the parameters according to which the measurement takes place were set. These parameters were the speed or RPM at the beginning and end of the measurement, the step length and the time of the point measurement. Setting a suitable point measurement time, at which the instrument holds a constant speed or RPM, ensures a stable point to properly record the observed values. Once all the necessary parameters have been entered, we move on to the actual measurement. Accelerate steadily to the starting speed and then depress the accelerator pedal fully. When the device reaches the first measurement point, the eddy brake will maintain the desired speed or RPM at the set value for the duration of the selected measurement point time. After this time has elapsed, the speed will begin to increase to the next measuring point. This procedure is applied up to the final set speed. The simulated load measurements were performed on a MAHA MSR 500/4WD cylindrical power tester.

Characteristics of the measured vehicle

For the measurements in this thesis, a Hyundai Getz vehicle with engine identification number G4HG, emission standard EURO 4 will be used. I decided to choose this vehicle because of the suitable

ISBN 978-80-213-3541-7

parameters of the vehicle due to the nature of the measurement, and also due to the availability of the vehicle for the purpose of measurement.

RESULTS AND DISCUSSION

Carrying out an emission check to determine the emission status of the vehicle

The initial emission control was carried out in accordance with Act No. 106/2018 Coll. on the operation of vehicles in traffic and on amendments and supplements to certain acts, as amended. The results of the emission control are presented in tab. 1 and indicate a satisfactory emission status of the tested vehicle.

Tab. 1 Results of the emission control of the Hyundai Getz

Exam	Unit	Required minimum value	Required. max. value	Actual value	Result
Engine temperature *(engine oil)*	°C	80	-	81	OK
Measurement at increased speed					
Revolutions	min^{-1}	2500	3500	3305	OK
CO	%volume	-	0,3	0,25	OK
HC	ppm	-	60	53	OK
Lambda	-	0.97	1.03	1.01	OK
O_2	%volume	-	-	0.49	-
CO_2	%volume	-	-	14.93	-
Measurement at idling speed					
Revolutions	min^{-1}	750	950	780	OK
CO	%volume	-	0.3	0.09	OK
HC	ppm	-	60	48	OK
Lambda	-	-	-	1.009	-
O_2	%volume	-	-	0.3	-
CO_2	%volume	14.5	16	15.14	-

Carrying out continuous load simulation to determine the technical condition of vehicles.

In order to determine the technical condition of the vehicle, a continuous load test was carried out to determine the performance values of the measured vehicle and these were compared with the values given by the manufacturer. To process the measured results of the effective power, a power correction according to EWG 80/1269 was applied.

When measuring the power output by the continuous loading method of an on-board internal combustion engine designated G4HG, a range of measured speeds from 1475 to 6195 min^{-1}. The recorded speed interval was 5 min^{-1}. The engine power output stated by the manufacturer is 48.5 kW at 5500 min^{-1}. The corrected motor power obtained by measurement was 52.7 kW at 5640 min^{-1}. The maximum torque was measured at 3645 min^{-1} with a value of 101.1 Nm. The manufacturer gives maximum torque values of 99 Nm at 3200 min^{-1}. The deviation of these values is indicative of the good technical condition of the measured vehicle and was due to the inaccuracy of the measuring equipment within ±2% and the way the revs are recorded by the OBD.

Simulating driving loads by discrete measurement and conducting driving tests with emission measurement of the G4HG internal combustion engine on a Hyundai Getz

The following measurement was performed in several driving modes, with respect to the vehicle speed, namely:

- at speeds of 20 to 40 km/h^{-1} in 2nd gear,
- at speeds of 40 to 50 km/h^{-1} in 3rd gear,
- at speeds of 50 to 90 km/h^{-1} in 4th gear,
- at speeds of 90 to 130 km/h^{-1} in 5th gear.

These measurements evaluated the emission production during loading of the on-board combustion engine over a specified speed range.

Evaluation of NOx emission production by measuring the G4HC engine under discrete load

Fig. 2 shows the NOx emission pattern with respect to torque at different speeds. The average NOx production over the measured torque range is 542.1 ppm at an average torque of 98.1 Nm. The average NOx production at speeds of 20 kmh^{-1} to 40 kmh^{-1} is 631.9 ppm at an average torque of 94.4 Nm. At speeds of 40 kmh^{-1} to 50 kmh^{-1} the average NOx production is 533.1 ppm at an average torque of 97.4 Nm. At speeds of 50 kmh^{-1} to 90 kmh^{-1}, the average NOx production is 492.1 ppm at an average torque of 100.3 Nm. In the speed range of 90 kmh^{-1} to 130 kmh^{-1}, the average NOx production is 511.3 ppm at an average torque of 100.4 Nm. Thus, the lowest average NOx production was recorded in fourth gear in the speed range of 50 kmh^{-1} to 90 kmh^{-1}, namely 4921 ppm at an average torque of 100.3 Nm. Thus, the highest average NOx production was recorded in second gear over the speed range of 20 $km \cdot h^{-1}$ to 40 $km \cdot h^{-1}$, namely 631.9 ppm at an average torque of 94.4 Nm. The observed trend of increasing NOx emissions with higher engine load corresponds to the well-known dependence of nitrogen oxide formation on combustion temperature and air–fuel mixture conditions *(Saxena & Bedoya, 2013)*.

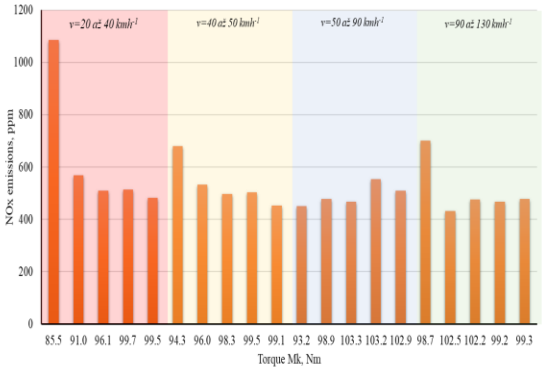

Fig. 1 NOx emissions at different driving modes under engine load

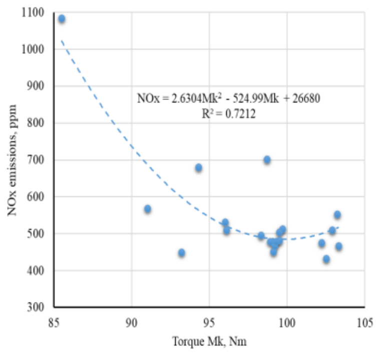

Fig. 2 NOx production in each gear at the torque convergence

Figure 2 shows the dependence of NOx emissions on torque. The recorded NOx emission values were translated by a second order polynomial function, where the value of the coefficient of determination reaches 72.1%.

Evaluation of CO emission production by measuring the G4HC engine under discrete load

Fig. 3 shows the CO emission pattern with respect to torque at different speeds. The average carbon monoxide production over the measured torque range is 5.4% by volume at an average torque of 98.1 Nm. The average CO production at speeds of 20 kmh^{-1} to 40 kmh^{-1} is 4.6 % by volume at an average torque of 94.3 Nm. At speeds of 40 kmh^{-1} to 50 kmh^{-1} the average CO production is 5.4% by volume at an average torque of 97.4 Nm. At speeds of 50 kmh^{-1} to 90 kmh^{-1}, the average CO production is 5.8% by volume at an average torque of 100.3 Nm. In the speed range of 90 kmh^{-1} to 130 kmh^{-1}, the average CO production is 5.9% by volume at an average torque of 100.4 Nm. Thus, the lowest average CO production was recorded in second gear in the speed range of 20 kmh^{-1} to 40 kmh^{-1}, namely 4.6% at an average torque of 94.3 Nm. Thus, the highest average CO production was recorded in fifth gear over the speed range 90 $km \cdot h^{-1}$ to 130 $km \cdot h^{-1}$, namely 5.9% at an average torque of 100.4 Nm. Similar emission characteristics, where CO and NOx were identified as dominant pollutants in petrol engines, were reported by Sassykova et al. *(2019)*, who also highlighted the importance of catalytic neutralisation in reducing their concentrations.

Figure 4 shows the dependence of CO emissions on torque. The recorded values of CO emissions were translated by a second order polynomial function, where the value of the coefficient of determination reaches 86.7%.

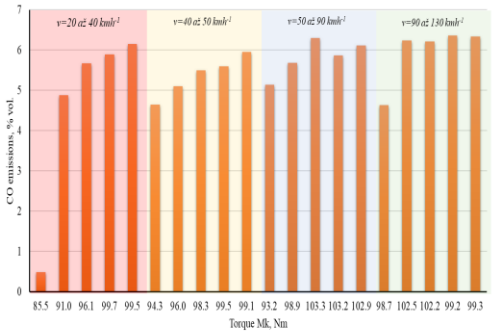

Fig. 3 CO emissions at different driving modes under engine load

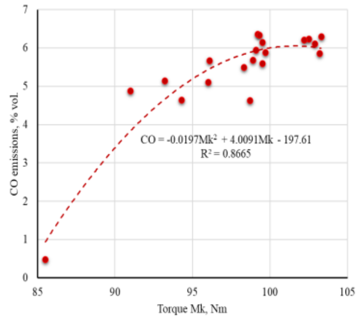

Fig. 4 Production of CO in each gear at the torque convergence

Evaluation of the CO_2 emissions production of a G4HC engine measured under discrete load.
Fig. 5 shows the evolution of the CO_2 emissions with respect to torque at different speeds. The average carbon dioxide production over the measured torque range is 11.8% by volume at an average torque of 98.1 Nm.
The average CO_2 production at speeds of 20 kmh^{-1} to 40 kmh^{-1} is 12.4% by volume with an average torque of 94.3 Nm. At speeds of 40 kmh^{-1} to 50 kmh^{-1} the average CO_2 production is 11.6% by volume at an average torque of 97.4 Nm. At speeds of 50 kmh^{-1} to 90 kmh^{-1}, the average CO_2 production is 11.5% by volume at an average torque of 100.3 Nm. In the speed range of 90 kmh^{-1} to 130 kmh^{-1}, the average CO_2 production is 11.6% by volume at an average torque of 100.4 Nm. Thus, the lowest average CO_2 production was recorded in fourth gear in the speed range of 50 kmh^{-1} to 90 kmh^{-1}, namely 11.5% at an average torque of 100.3 Nm, which is the best in terms of air quality impact. Thus, the highest average value of CO_2 production was recorded in second gear in the speed range of 20 kmh^{-1} to 40 kmh^{-1}, namely 12.4% at an average torque of 94.3 Nm, which is the best in terms of perfect combustion.

Figure 6 shows the dependence of CO_2 emissions on torque. The recorded values of CO_2 emissions were translated by a second order polynomial function, where the value of the coefficient of determination reaches 83.5%.

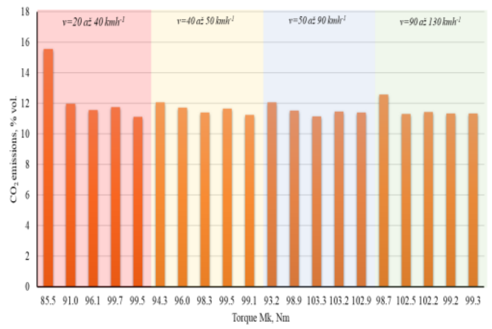

Fig. 5 CO emissions$_2$ for different driving modes at engine load

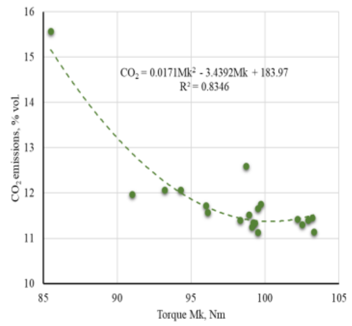

Fig. 6 Production of CO_2 in each gear at the torque convergence

CONCLUSIONS

In the present paper, the emission parameters of a spark ignition internal combustion engine were monitored under varying speed and torque. To meet this objective, a measured emission test was performed to confirm the good emission condition of the vehicle. The emission test was followed by performing a continuous speed and torque simulation in order to determine the technical condition of the vehicles. In this measurement we confirmed the suitable technical condition of the measured object, given the nature of the objective of the work. The main measurement of the work was to simulate the driving load by discrete measurement and to perform driving tests with emission production measurement of the G4HG internal combustion engine on the Hyundai Getz vehicle. In this measurement, the exhaust emission production was observed at different speeds in different gears, from which the dependence of the production of different emission components on varying load was established.

ACKNOWLEDGMENT
This study was supported by project KEGA 026SPU-4/2025 "Integration of Advanced Artificial Intelligence Technologies in Adaptive Learning Systems for Technical Subjects"

REFERENCES

1. Aakko-Saksa, P., Roslund, P., & Koponen, P. *(2017)*. *Development and validation of comprehensive emission measurement methods for alternative fuels at VTT (Research report)*. Espoo: VTT Technical Research Centre of Finland.
2. Divišová, M., Herák, D., Kabutey, A., Šleger, V., Sigalingging, R., & Svatoňová, T. *(2014)*. Deformation curve characteristics of rapeseeds and sunflower seeds under compression loading. *Scientia agriculturae bohemica*, *45(3)*, 180-186.
3. Herak, D., Kabutey, A., & Sigalingging, R. *(2016)*. Mathematical Description of Non-linear Mechanical Behaviour of Materials Under Compression Loading, Case Study: Spruce Bulk Wood Chips. In *The Latest Methods of Construction Design (pp. 405-409)*. Springer International Publishing.
4. Kabutey, A., Herák, D., Chotěborský, R., Sigalingging, R., & Mizera, Č. *(2015)*. Effect of compression speed on energy requirement and oil yield of Jatropha curcas L. bulk seeds under linear compression. *Biosystems Engineering*, *136*, 8-13.
5. Nadvornikova, I., Verner, V., & Valesova, V. *(2014)*. Coffee production in Indonesia: experience from small-scale producers, North Sumatra. In *SGEM2014 Conference On Political Sciences, Law, Finance, Economics and Tourism (pp. 91-98)*. STEF92 Technology.
6. Jablonický, J., Tkáč, Z., Tulík, J., Uhrinová, D., & Polerecký, J. *(2019)*. *Automobilové spaľovacie motory*. Slovenská poľnohospodárska univerzita.
7. Janoško, I. & Krasňanský, M. *(2025)*. Testing of Selected Fuel Additive in Diesel Engine. Acta Technologica Agriculturae, 28*(1)*, 2025. 50-56. https://doi.org/10.2478/ata-2025-0007.
8. Sassykova, L., et al. *(2019)*. The main components of vehicle exhaust gases and their effective catalytic neutralization. *Oriental Journal of Chemistry, 35(1)*, 110–127. https://doi.org/10.13005/ojc/350112
9. Saxena, S., & Bedoya, I. D. *(2013)*. Fundamental phenomena affecting low temperature combustion and HCCI engines, high load limits and strategies for extending these limits. Progress in Energy and Combustion Science, 39*(5)*, 457–488. https://doi.org/10.1016/j.pecs.2013.05.002

Corresponding author:
Ing. Simona Bártová, Institute of Agricultural Engineering, Transport and Bioenergetics, Department of Transport and Handling, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovakia, xbartovas@uniag.sk