Original Research

Experimental Investigations and Evaluation of Pollutant Emissions into Ambient Air by Rolling Stock Engines

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Abstract

Emissions by rail transport account for around 1% of total pollutant emissions. The greatest negative influence on human health is made by PM, NO_x, and others pollutants. Our article describes the methodology for measuring emissions (CO, NO_x, PM, and CH) into the air by rolling stock on which the experimental measurements of emissions are based. Comparison of emissions by the stock company Lietuvos geležinkeliai old (TEP70BS), re-motorized (2M62K), modernized (2M62M, ČME3ME, ČME3MG), and new (ER20CF) locomotives, railcars (620 M), and diesel trains (RA-2) into the atmosphere is carried out. As the study carried out in 2009 shows, the tested emissions into the air by diesel locomotive engines (pollutant kg/fuel ton) decreased significantly (up to 40%) when compared to the study carried out in 2003. Emissions of sulphur dioxide into the air from rolling stock in 2009 significantly decreased against 2003 as the allowable sulphur content in diesel fuel decreased from 0.2% to 0.001%.

Keywords: rail transport, emissions, locomotives, CO, NO_x, PM and CH

Introduction

Environmental pollution poses an enormous problem for all countries, including developing ones [1, 2]. Rail transport belongs to the group of mobile atmospheric polluters. Rail transport mainly pollutes air, but soil is also polluted with various pollutants, such as heavy metals and others [3-8]. The influence of rail transport on soil pollution was studied by Lithuanian scientists R. Idzelis and D. Paliulis [9]. Air pollution caused by rail transport was investigated by Lithuanian scientists P. Baltrėnas [10], S. Vasarevičius [10], A. Katkus [11], P. Lingaitis [12, 13], S. Pukalskas [12–14], A. Pikūnas, G. Bureika, J. Grabys, and Š. Mikaliūnas [15]. Air pollutants emitted by rail transport have been investigated by others [16-20]. Research on rail transport emissions carried out by VGTU (Vilnius Gediminas Technical University) scientists R. Vaiškūnaitė and S. Vasarevičius served as the basis for developing LAND (Lithuanian normative document of environmental protection) 18-2003/M-03. Recently, emissions from rail transport have accounted for 1% of the total emissions generated by all kinds of vehicles. When compared to other types of transport carrying passengers and cargo, rail transport engines are among the least polluting options [21-25]. The engines of this transport discharge harmful pollutants into the ambient air (nitrogen oxides (NO_x)), carbon monoxide (CO), volatile organic compounds (CH), particulate matter (PM) and sulphur dioxide (SO_2). Some gases (carbon dioxide, nitrogen oxides, methane, etc.) entering the atmosphere during organic fuel combustion can cause the greenhouse effect [26-29]. CH emissions from stationary pollution sources increased in Lithuania approximately

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Table 1. Biofuels for transport consumption volumes in the period 2005-10 provided for by legislation.

Year	2005	2006	2007	2008	2009	2010
Requirements for the quantity of biofuels for transport, (%)	2.00	2.75	3.50	4.25	5.00	5.75

4 times – from 5.952 to 22.208 thousand tons in recent years (1998-2006) [28].

There are two types of rolling stock – diesel and electric. Currently, in Europe rolling stock with electric engines accounts for around 85% and diesel – about 15%. The biggest shortcoming of diesel engine-operated rolling stock is a high level of air pollution. Air is most polluted by old non-modernized rolling stock engines emitting the biggest amounts of harmful pollutants into the air. Therefore, a rolling stock park needs to be renewed on a regular basis.

In 2004-09, SC Lietuvos geležinkeliai renewed its rolling stock park: modernized and re-motorized the rolling stock and acquired new rolling stock. Emissions into the ambient air from this rolling stock air were not evaluated and therefore it has become necessary to measure them. In order to reduce pollutant emissions into the ambient air in Lithuania, an increasing share in the fuel balance is taken by biofuels for transport.

The production and use of biofuels for transport in Lithuania is promoted by the Law on Biofuel, Biofuels for Transport, and Bio-oils of the Republic of Lithuania. Directive 2003/30/EC of the European Parliament and of the Council envisages the promotion of the use of biofuels and other renewable fuels for transport. To implement the Law, in 2004 the government of Lithuania approved the Programme for the Production and Use of Biofuel for 2004-10, which envisages measures and the responsibilities of individual authorities in developing the production and use of biofuels for transport until they reach the volumes of use of biofuels for transport established by the law. The development of consumption of biofuels for transport provided for in the Lithuanian legislation is presented in Table 1.

The main fiscal measures promoting the use of renewable sources of energy are the value added tax, excise duties on fuel, income taxes, the natural resources tax, taxes on oil and gas resources, and pollution taxes. In our country fiscal measurements are laid down in the following legislation: the Law on Excise Duty of the Republic of Lithuania which provides for excise duty relief on energy products produced from biomass, including bioethanol and fatty acid methyl esters. Mixtures with mineral fuels are subject to the excise rate reduced by the share (%) that is proportional to the part of the biological origin component in a product ton; the Law on Pollution Tax of the Republic of Lithuania stipulates that natural and legal persons polluting the environment from mobile sources of pollution from motor vehicles using bio-fuels for transport and that meet the established standards and have submitted the documents evidencing the consumption of bio-fuels for transport shall be released from the tax on pollution. In 2006 the European Commission published the Communication on an EU Strategy for Biofuels, which set out the strategic axes in the area of the production and use of biofuels for transport for a further period (2020-30). The performed evaluation of pollutant emissions in Europe, the USA, and Japan showed an ongoing successful development of various projects on this topic worldwide. As the results of such projects show,

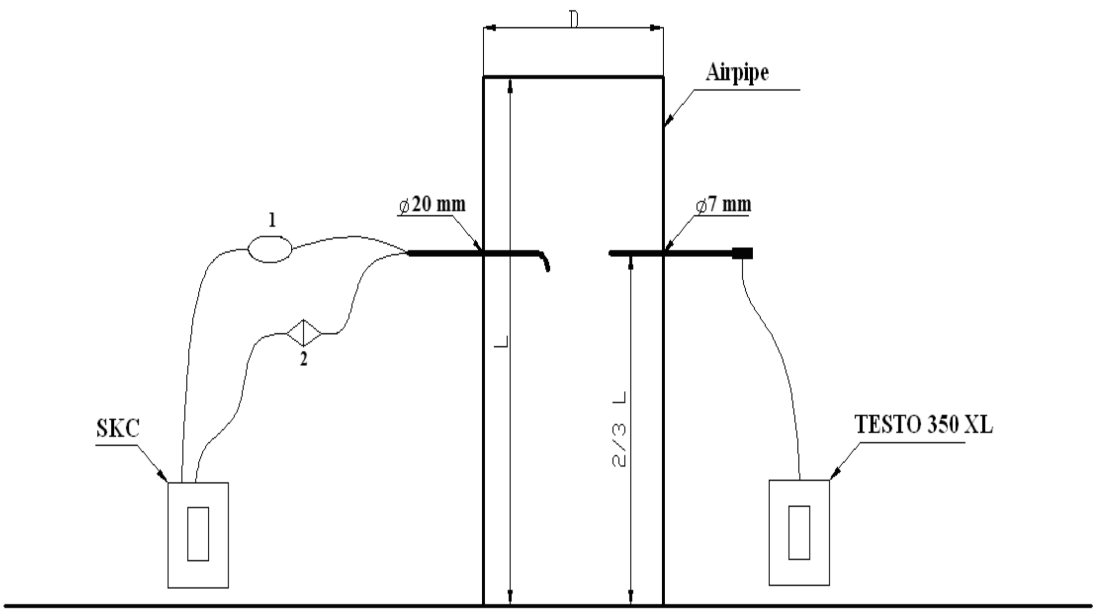

Fig. 1. Scheme of rolling stock emission measurement:
1 – Tedlar bag for CH sampling, 2 – filter holder with filter for particulate matter sampling, D – diameter of air duct, L – length of air duct; TESTO 350 XL – CO, O_2, NO_x, SO_2 analyzer of temperature and airflow velocity, SKC – air sampling pump.

much less pollution of the ambient air by specific pollutants, such as nitric oxides (NO_x) and particulate matter (PM), is generated by rail transport using diesel fuel compared to road transport vehicles [30-34].

Concentration of CH can be measured by applying different analytical technique [35-37]. Mathematical modelling programs can be used for transport pollutants spreading calculations in ambient air [10].

The aim of the work is to carry out experimental investigations on the quantities of pollutants, such as nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (CH), particulate matter (PM), and sulphur dioxide (SO_2) discharged into the ambient air by the engines of SC Lietuvos geležinkeliai re-motorized (2M62K), modernized (2M62M, ČME3ME, ČME3MG), old (TEP70BS), and new (ER20CF) traction rolling stock, railcars (620 M), and diesel trains (RA-2), and to present evaluation thereof.

Research Methods

Air pollutant emissions by Lietuvos geležinkeliai traction rolling stock were measured during rheostat tests in September-October 2009 by establishing the conditions of operational mode that correspond to different engine loads. The measurement scheme is presented in Fig. 1.

The following physical parameters were measured: temperature of exhaust gas, movement velocity of the exhaust gas airflow, and emissions of the pollutants CO, NO_x, CH, and PM (particulate matter). Measurements were performed in the air duct (or chimney). When selecting the air duct, the main criterion was the ratio of its length to diameter: i.e. its length L had to be by three times or more larger than its diameter D. Openings 7 mm or 20 mm in diameter were drilled in the air duct or chimney at a distance corresponding to half of the diameter from each other. These openings were drilled at a distance of 1/3 of L from the top of the air duct or chimney.

The concentrations of CO, O_2, and NO_x were measured through an opening, 7 mm in diameter, with TESTO 350 XL, while air temperature and airflow velocity were recorded using special probes.

Using an SKC air sample pump, air was sucked through an opening, 20 mm in diameter, and there were taken samples of particulate matter (on filter) and CH (to Tedlar bag) that were analyzed in the Environmental Science Chemistry Laboratory of the VGTU Department of Environmental Protection. Each measurement of pollutant concentration and physical parameters (temperature and airflow velocity) was repeated three times. Arrangement of measurement points in the air duct was selected according to LAND 28-98/M-08. The characteristics of the engines of the rolling stock investigated are presented in Table 2.

Gas volume flow rate, V m^3/s, in the air duct was calculated by determining the average gas flow velocity and the cross-section area of the air duct according to the formulas given in LAND 27-98/M-07.

Table 2. Characteristics of the rolling stock investigated in 2009.

Locomotive	Number of cylinders	Nominal capacity, KW
2M62K Kolomna (Russia)	12	1470
2M62M Modernized in Lithuania (Caterpillar engine – USA)	12	1700
TEP70 BS (Russia)	16	2942
ER20CF Siemens (Germany)	16	2000
620 M Matrice Poland (engine Germany)	6	382
RA-2 Russia (2 engines Germany)	6	360
ČME 3 ME Modernized in Lithuania (Caterpillar engine – USA)	8	970
ČME 3 MG Modernized in Lithuania (Caterpillar engine – USA)	12	1700

Results and Discussion

Upon evaluating emissions by SC "Lietuvos geležinkeliai" locomotives on the rheostat test stand the comparative pollution by traction rolling stock with diesel engines (kg/t) (Figs. 2-5) was calculated and compared to the results of the research studies carried out by VGTU scientists in environmental protection R. Vaiškūnaitė and S. Vasarevičius in 2003. The measurement results were recalculated for a unit of consumed fuel (1 t) as these relative values allow a comparison of the characteristics of emissions by traction rolling stock engines of the same and different makes and reflect the amount of the pollutant emissions by engines under different conditions of operation clearer and more exactly. In the meantime, SO_x concentrations depend only on the quantity of sulphur compounds in the fuel consumed and therefore the combustion of 1 kg of fuel in any operation mode of the engine should result in equal emissions of these oxides.

A comparison of the quantities of pollutants discharged into the air by 2M62M and 2M62 engines shows that CO emission into the air by 2M62M decreased, on average, from 9.6%; NO_x emissions into the air by 2M62M decreased, on average, from 9.8%; CH emissions into the air by 2M62M decreased, on the average, from 11.4%; and particulate matter emissions into the air by 2M62M decreased, on the average, by 12.4% (Fig. 2-5).

Emissions by 2M62K engine were compared to emissions by rolling stock engine 2M62. The comparison shows that CO emissions into the ambient air by 2M62K practically did not change, NO_x emissions into the air by 2M62K decreased, on average, by 12,7%; CH emissions into the ambient air by 2M62K decreased, on average, by 5.8%; and particulate matter emissions into the ambient air by 2M62K decreased, on average, by 9.5% (Figs. 2-5).

Comparison of the quantities of pollutant emissions into the air by ČME3ME and ČME3 shows that CO emissions into the air by ČME3ME decreased from 10.3% to 17.8% in all operation modes of the engine, NO_x emission into the air by ČME3ME decreased from 14.0% to 22.1% in all operation modes of the engine, CH emissions into the air by ČME3ME decreased from 14.0% to 22.4% in all operation modes of the engine, and particulate matter emissions into the air by ČME3ME decreased from 10.0% to 25.3% in all operation modes of the engine (Figs. 2-5).

Emissions by the engine of traction rolling stock ČME3MG were compared to the quantities of pollutants discharged by ČME3. As investigation results show, CO emissions into the air by ČME3MG decreased from 4.1% to 13.1% in all operation modes of the engine, NO_x emissions into the air by ČME3MG decreased from 7.4% to 13.0% in all operation modes of the engine, CH emissions into the area by ČME3MG decreased from 6.0% to 12.8% in all operation modes of the engine, and particulate matter emissions into the air by ČME3MG decreased

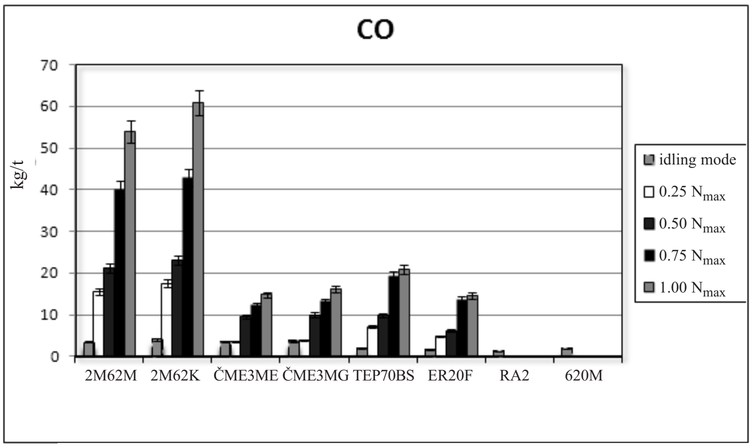

Fig. 2. Comparative pollution of diesel locomotives according to CO, when the engine is running in different modes, kg/t.

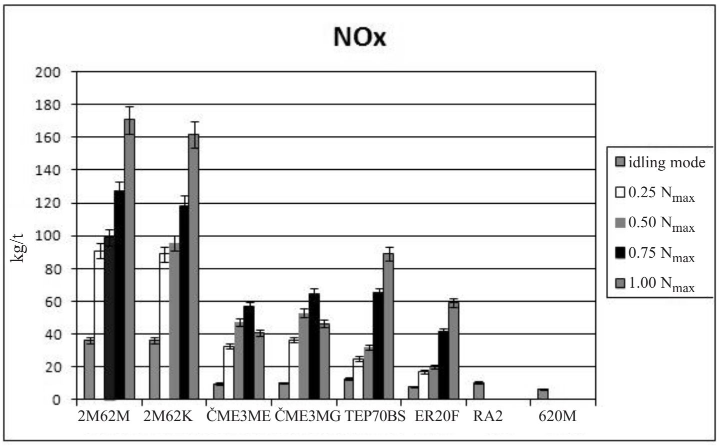

Fig. 3. Comparative pollution of diesel locomotives according to NO_x, when the engine is running in different modes, kg/t.

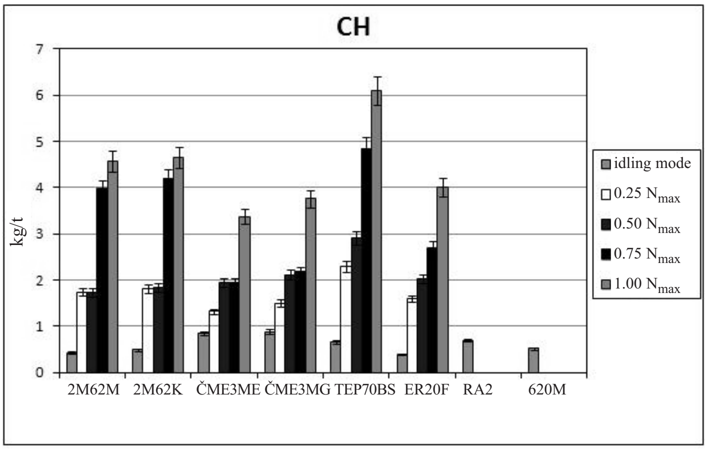

Fig. 4. Comparative pollution of diesel locomotives according to CH, when the engine is running in different modes, kg/t.

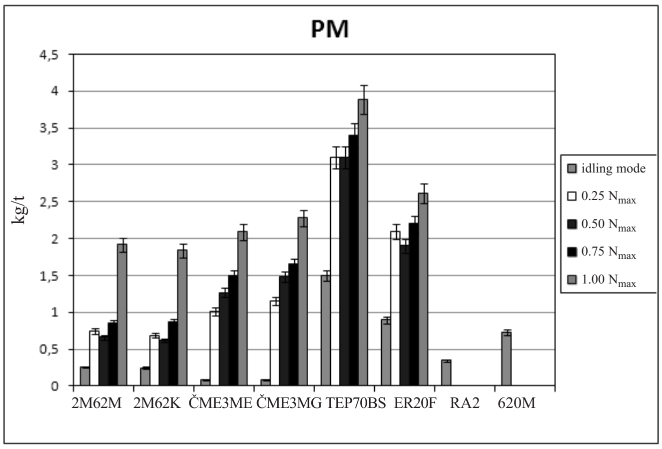

Fig. 5. Comparative pollution of diesel locomotives according to PM, when the engine is running in different modes, kg/t.

from 5.0% to 12.9% in all operation modes of the engine (Figs. 2-5).

Emissions by TEP70BS engine were compared to emissions by TEP70. It has been determined that CO emissions into the air by TEP70BS increased up to 10.0% in some operation modes of the engine, and decreased up to 2.5% in others, NO_x emissions into the air by TEP70BS decreased from 2.1 to 3.5%, CH emissions into the air by TEP70BS increased up to 1.7% in some operation modes of the engine, while decreasing up to 5.7% in others, particulate matter emissions into the air by TEP70BS increased up to 3.3% in some operation modes of the engine, while decreased up to 6.3% in others (Figs. 2-5).

ER20CF was acquired by SC Lietuvos geležinkeliai after 2003 and a comparison of emissions from its engine with results of the previous studies, therefore, was impossible. An evaluation of the quantities of pollutants discharged into the ambient air by ER20CF shows that CO emissions into the air by ER20CF increase from 1.65 to 14.7 kg/t; NO_x emissions into the air by ER20CF increase from 8.2 to 59.3 kg/t; CH emissions into the air by ER20CF increase from 0.4 to 4.0 kg/t; while particulate matter emissions into the air by ER20CF increase from 0.9 to 2.61 kg/t when the traction capacity of rolling stock grows from idling running to the nominal capacity (Figs. 2-5).

As it was technically impossible to connect diesel train RA-2 and railcar 620M to the test, rheostat measurements of emissions by their engines were carried out with the engine in idling mode only.

A comparison of the quantities of pollutants discharged into the air by diesel trains D1 and RA-2 shows that CO emissions into the air are by 37.1% lower when the RA-2 engine is running in idling mode, NO_x emissions into the air by RA-2 are lower by 11.7%, CH emissions into the air by RA-2 and D1 do not differ, while particulate matter emissions into the air by RA-2 are lower by 78.1% (Figs. 2-5).

Table 3. The consumption of fuels by Lietuvos geležinkeliai rolling stock engines, when the engine is running in different modes, kg/h, investigated in 2003* and 2009.

Type and series of traction rolling stock	In idling mode	0.25 N_{max}	0.50 N_{max}	0.75 N_{max}	1.0 N_{max}
2M62M	12.92	34.34	78.71	283.1	358.11
2M62 K	8.50	34.34	78.71	283.1	357.00
TEP70BS	16.00	132.60	265.20	397.80	530.40
ER20CF	50.10	105.00	210.00	300.00	404.00
ČME3ME	10.20	43.35	83.30	136.85	194.65
ČME3MG	9.35	63.75	127.50	199.75	288.15
RA-2	2.5	–	–	–	–
620M	4.00	–	–	–	–
ČME3*	12.0	48.7	97.35	146.03	194.70
D1*	8.0	28.5	57.0	85.5	114.0
AR2*	4.0	17.0	35.0	52.0	69.0
2M62*	25.00	69.85	139.7	209.55	279.4

A comparison of the quantities of pollutants discharged into the air by AR2 and 620M railcars shows that CO emissions into the air by 620 M in idling mode are higher by 5.6%, NO_x emissions into the air by 620M are higher by 4.8%, CH emissions into the air by 620M are higher by 30.0%, and PM emissions into the air by 620M are higher by 9.0%. The difference between the emissions of the railcars in question can be explained by a measurement error for all pollutants except for CH (Figs. 2-5).

It appears that the consumption of fuels by traction rolling stock increases with the engine load increasing from idling mode to the nominal load (Table 3). As investigation results show, upon renewing and re-motorizing traction rolling stock (according to the research results of 2009) the consumption of fuels by engines decreased when compared to the data obtained from research carried out in 2003. The comparative pollution by the engine of traction rolling stock (kg/t) depends on fuel consumption when the engine is running. Table 3 presents the consumption of fuels by Lietuvos geležinkeliai traction rolling stock engines when they are running under different loads.

As the results of the investigations of rolling stock engine emissions into the air carried out in 2009 (Figs. 2-5) show, generally the values of pollutant emissions into the air increase when engine load is growing from idling running to the maximum load; however, it has been determined that the highest comparative pollution in nitrogen oxides by rolling stock engines ČME3ME and ČME3MG was recorded at 0,75Nmax. These regularities of investigation results are confirmed by the results of the investigations carried out by VGTU scientists R. Vaiškūnaitė and V. Vaišis in 2003. Based on the results of the performed investigations, it has been determined that the biggest polluters of ambient air among the locomotives currently operated by Lietuvos geležinkeliai are: by NO_x – 2M62M, 2M62K and 2M62, the biggest quantities of CO are discharged by 2M62M, 2M62K, 2M62, CH – 2M62M, 2M62K, 2M62, TEP70, and TEP70BS, while the biggest polluters by particulate matter are TEP70, TEP70BS and diesel train D1.

When the consumption of fuels decreases, the comparative pollution by traction rolling stock engines also decreases.

It is apparent from the comparison of the data about locomotive (2M62) emissions presented in LAND 18-2003/M-03 of 2003 and the emissions by new rolling stock engines (ER20CF) are fairly lower than those of (2M62). According to the performed comparison, in 2009 against 2003, sulphur dioxide emissions into the ambient air from traction rolling stock significantly decreased as the content of sulphur dioxide in fuel fell from 0.2% to 0.001%. Based on the measurements of the emissions into the ambient air (pollutant kg/fuel t) by diesel traction rolling stock engines carried out in 2009, it can be stated that emissions into the air by the diesel traction rolling stock engines investigated (locomotive 2M62M, locomotive 2M62K, locomotive ER20CF, locomotive ČME3ME, locomotive ČME3MG, locomotive TEP70BS, railcar 620 M, and diesel train RA-2) decreased compared to the investigations carried out in 2003.

Conclusions

1. According to the data of scientific investigations carried out in 2009 compared to 2003, pollutant emissions into the ambient air (pollutant kg/fuel t) by 2M62M when compared to 2M62 differ as follows: CO emissions into the ambient air by 2M62M are lower, on average, by 9.6%, NO_x emissions into the ambient air by 2M62M are lower, on average, by 9.8%; CH emissions into the ambient air by 2M62M are lower, on average, by 11.4%; and particulate matter emissions into the ambient air by 2M62M are lower, on average, by 12.4%.
2. According to the data of scientific investigations carried out in 2009, CO emissions into ambient air by 2M62K practically did not change; NO_x emissions into the ambient air decreased, on average, by 12.7%; CH emissions into ambient air decreased, on average, by 5.8%; and particulate matter emissions into ambient air decreased, on average, by 9.5% when compared to the emissions (pollutant kg/fuel t) by traction rolling stock engines 2M62 measured in 2003.
3. According to the 2009 data, the emissions into ambient air by traction rolling stock engine TEP70BS, when compared to the emissions by TEP70 measured in 2003, differ as follows: CO emissions into ambient air by TEP70BS are higher, on average, by 3.7%; NO_x emissions into the air by TEP70BS are lower, on average, by 2.8%; CH emissions into ambient air by TEP70BS are lower, on average, by 2.0%; and particulate matter emissions into ambient air by TEP70BS are lower, on average, by 1.5% (pollutant kg/fuel t).
4. According to the data of scientific investigations carried out in 2009, when compared to the data of 2003, pollutant emissions into the ambient air (pollutant kg/fuel t) by ČME3ME, when compared to those by ČME3, differ as follows: CO emissions into the ambient air by ČME3ME decreased, on average, by 14.1%, NO_x emissions into the ambient air by ČME3ME decreased, on the average, by 18.1%, CH emissions into the ambient air by ČME3ME decreased, on average, by 18.2%; and particulate matter emissions into the ambient air by ČME3ME decreased, on average, by 17.7% (pollutant kg/fuel t).
5. Pollutant emissions into ambient air by traction rolling stock engine ČME3MG (measured in 2009) were compared to emissions by traction rolling stock engine ČME3 (measured in 2003). The following differences were identified: CO emissions into the ambient air by ČME3MG decreased, on average, by 8.6%, NO_x emissions into the ambient air by ČME3MG decreased, on average, by 10.2%; CH emissions into ambient air by ČME3MG decreased, on average, by 9.4%; while particulate matter emissions into ambient air by ČME3MG decreased, on average, by 9.0% (pollutant kg/fuel t).

6. Upon measuring emissions into the air by ER20CF (2000 kW) in 2009, a traction rolling stock of similar power, TEP70BS (2942 kW), was selected for comparison. The performed investigation showed the following difference in the emissions into the ambient air by ER20CF when compared to those by TEP70BS: CO emissions into the air by ER20CF are lower, on average, by 26.4% in all operation modes of the engine, NO_x emissions into the air by ER20CF are lower, on average, by 34.6% in all operation modes of the engine; CH emissions into the air by ER20CF are lower, on average, by 37.3% in all operation modes of the engine; and particulate matter emissions into the ambient air by ER20CF are lower, on average, by 36.2% in all operation modes of the engine (pollutant kg/fuel t).
7. Pollutant emissions into the ambient air by traction rolling stock engine RA-2 (measured in 2009) were compared to emissions by diesel train D1 (measured in 2003). The following differences were identified: CO emissions into the air by RA-2 are lower by 37.1% when the engine is running in the idling mode, NO_x emissions into the air by RA-2 are lower by 11.7% when engine is running in the idling mode, CH emissions into ambient air by RA-2 when the engine is running in the idling mode practically do not differ, while particulate matter emissions into the air by RA-2 are lower by 78.1% when the engine is running in the idling mode (pollutant kg/fuel t).
8. Upon measuring pollutant emissions into the ambient air by railcar 620M in 2009 and comparing with the previously measured emissions by railcar AR2 when the engines of both traction rolling stock are working in the idling mode, the following differences were identified: CO emissions into the air by 620M are higher by 5.6%, NO_x emissions into the air by 620M are higher by 4.8%, CH emissions into the air by 620M are higher by 30.0%, while particulate matter emissions into the air by 620M are higher by 9.0% (pollutant kg /fuel t).
9. Upon evaluating pollutant emissions (pollutant kg/fuel t) by all traction rolling stock engines currently operated by SC Lietuvos geležinkeliai, it has been determined that air is most polluted with CO by 2M62M, 2M62K, and 2M62; with NO_x – by 2M62M, 2M62K, and 2M62; CH – TEP70 and TEP70BS, while with particulate matter – TEP70 and TEP70BS.
10. According to the performed comparison, in 2009 against 2003, sulphur dioxide emissions into ambient air from traction rolling stock significantly decreased as the content of sulphur dioxide in fuel fell from 0.2% to 0.001%.
11. Based on the measurements of emissions into ambient air (pollutant kg/fuel t) by diesel traction rolling stock engines carried out in 2009, it can be stated that emissions into the air by the diesel traction rolling stock engines investigated (locomotive 2M62M, locomotive 2M62K, locomotive ER20CF, locomotive ČME3ME, locomotive ČME3MG, locomotive TEP70BS, railcar 620 M, and diesel train RA-2) decreased compared to the investigations carried out in 2003. Lower emissions into the ambient air in 2009 are predetermined by the fact that the current traction rolling stock park has been rapidly modernized and supplemented with newly bought traction rolling stock or renewed with advanced diesel engine structures since 2003 until now.

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