Основна кількість викидів забруднюючих речовин до атмосфери на залізничних станціях здійснюються маневровими локомотивами. Питома кількість цих викидів залежить від позиції контролера машиніста, на якій працює тепловоз, так як кожній позиції контролера відповідає певна частота обертання та потужність дизеля. Досліджено вплив застосування накопичувача енергії у силовому ланцюзі маневрового локомотиву на рівень викидів забруднюючих речовин в атмосферу при виконанні ним різних видів маневрових робіт. Встановлений зв'язок між рівнями викидів забруднюючих речовин в атмосферу та видами маневрових робот, що виконуються. Отримані статистичні дані щодо часу роботи маневрового тепловозу на кожній позиції контролера машиніста при виконанні різних видів маневрових робіт. Це дозволяє оптимально підібрати параметри накопичувача енергії для маневрового локомотива, який задовольняє як технічним, так і екологічним вимогам. В результаті проведених досліджень встановлено, що при використанні накопичувача енергії у силовому ланцюзі маневрового тепловоза кількість викидів в атмосферу оксиду вуглецю CO, оксиду азоту NO_x, діоксиду сірки SO_2, сажі та вуглеводнів зменшується на 20...30 % в залежності від виду виконуваних маневрових робіт та ємності застосованого накопичувача енергії. Зменшення вказаних викидів дасть змогу поліпшити екологічний стан в межах станції.

Ключові слова: викиди забруднюючих речовин, маневрова робота, модернізація маневрових локомотивів, накопичувач енергії, гібридний привід

UDC 504.61
DOI: 10.15587/1729-4061.2019.176908

THE EFFECT OF USING AN ENERGY ACCUMULATOR ON THE LEVEL OF EMISSIONS OF POLLUTANT SUBSTANCES BY A SHUNTING LOCOMOTIVE

R. Yarovoy
Senior Lecturer
Department of Computer Science and Control Systems
Ukrainian State University of Railway Transport
Feierbakha sq., 7, Kharkiv, Ukraine, 61050
E-mail: yasons@bigmir.net

N. Chernetskaya-Beletskaya
Doctor of Technical Sciences, Professor,
Head of Department*
E-mail: logistyka.snu.edu.ua@gmail.com

E. Mikhailov
PhD, Associate Professor*
E-mail: mihaylov.evv@gmail.com
*Department of Logistics and Traffic Safety
Volodymyr Dahl East Ukrainian National University
Tsentralnyi ave., 59-a, Severodonetsk, Ukraine, 93400

Received date 12.04.2019
Accepted date 01.08.2019
Published date 30.08.2019

1. Introduction

Shunting locomotives at railroad stations account for most emissions of pollutants into the atmosphere. The composition of exhaust gases from the locomotive diesel engines includes the following basic components: water vapor, oxygen, carbon dioxide, nitrogen dioxide and monoxide, hydrogen, hydrocarbons, sulfuric anhydride, aldehydes, and soot. Emissions of locomotive diesel engines at shunting operations exert a negative impact on the environment. Therefore, the implementation of resource-saving and environmentally-friendly technologies is one of the major tasks in modernizing and building new shunting locomotives for railroad transportation. It is a relevant task to address further improvement and development of the use of such resource-saving and environmentally-friendly technologies as the technology of accumulation and subsequent utilization of recuperation energy and excessive energy by rolling stock.

2. Literature review and problem statement

Many scientific papers have focused on reducing the emissions of pollutants by vehicles into the atmosphere. Thus, study [1] determined the quantitative and qualitative indicators for the emission of pollutants into the atmosphere during operations of mobile sources of emissions, and the impact of these emissions on humans. In terms of their impact on humans, they can be divided into two groups: non-toxic and toxic. The non-toxic substances include nitrogen, oxygen, water vapor, hydrocarbon dioxide, and hydrogen. The toxic substances include hydrocarbon carcinogens that accumulate to critical concentrations and stimulate the development of malignant tumors. In addition, the toxic substances include the groups of hydrocarbons (especially olefins) that form smog. They also participate in the reaction with nitrogen oxides under the influence of solar radiation to form ozone and other biologically active substances, which cause diseases of the eye and human nasopharynx, as well as exert a detrimental impact on the flora and fauna. One should note, however, that the cited study did not consider specific sources of such a pollution, that is shunting locomotives. Paper [2] investigated reducing the emissions of pollutants related to the use of electric vehicles and hybrid cars. The authors analyzed characteristics of the hybrid and electric vehicles and their impact on reducing harmful emissions. Authors of work [3] examined the environmental aspects related to the reduction of pollutant emissions and their impact on the environment. Determining the influence of nitric oxide and its compounds on the environment was addressed in paper [4]. In terms of a dangerous influence on humans and nature, nitrogen oxides are the most harmful emissions from the diesel engines. Nitrogen, when binding with oxygen, can form 5 compounds: NO, NO_2, NO_3, NO_4, NO_5. NO_x directly affects humans by the incubation period. The danger is the fact that when a person works in air with a high content of NO_x, he feels almost nothing at first, but eventually he may get seriously sick. The main negative effect from NO_x is exerted by forming, in nasopharynx, nitric and nitrous acids due to reaction with water. The degree of NO_x influence on humans is almost 10 times stronger than that from carbon monoxide.

An analysis of prerequisites to modernize shunting diesel locomotives with a hybrid power installation was presented in [5]. The authors found a decrease in harmful emissions when using diesel locomotives with a hybrid power unit; they, however, did not determine quantitative indicators of such a reduction, nor the correlation among factors that influence it. A research into the influence of main factors at operation of locomotive diesel engines on pollutant emissions was reported in paper [6]. The authors analyzed methods for reducing the amount of emissions from shunting locomotives. Studies [7, 8] addressed the analysis of emission volumes of carbon oxide and solids during operation of diesel engines depending on the conditions for their operation. The content of carbon monoxide in the exhaust gases from diesel engines is relatively small compared with the carburetor engines, as the main products of incomplete combustion in exhaust gases are released in the form of soot. When entering human body, carbon monoxide combines with hemoglobin of the blood and produces a strong compound – carboxyhemoglobin, which affects the process of gas exchange and leads to oxygen starvation. Soot, which is released in the form of smoke from the exhaust gases, characterizes the completeness of fuel combustion. Particles of soot pollute the environment and impede the fluxes of photons and light energy. Carbon that forms in this case does not burn due to the high activation energy and is released, together with other products of combustion, with exhaust gases. A study of change in the amount of nitrogen oxide emissions depending on operational characteristics of the diesel engine and the environmental parameters is reported in [9]. Authors of [10] determine the effect of exhaust gas treatment systems on the volume of harmful emissions into the environment. However, the analysis dealt only with cleaning systems for automotive engines. Article [11] considered the issue of calculating the emissions of harmful substances with exhaust gases from locomotive diesel engines. Different approaches to calculations were considered, as well as the procedures for their implementation.

Our analysis of available scientific literature has revealed that the specified subject has been studied enough; however, the cited papers have almost not considered a change in the amount of polluting emissions depending on the position of the driver's controller and the type of a shunting operation. When examining operational characteristics of a hybrid shunting diesel locomotive with an energy collector, the dependence between the parameters of the energy accumulator applied and a decrease in the amount of harmful emissions by the diesel engine has not been explored.

3. The aim and objectives of the study

The aim of this study is to determine the effect of applying an energy accumulator within a power circuit of a shunting diesel locomotive on the reduction of emissions of pollutants into the atmosphere when performing different types of shunting operations.

To accomplish the aim, the following tasks have been set:

– to determine the average time of a shunting diesel locomotive's operation at each position of the driver's controller when performing different types of shunting operations;

– to determine the amount of emissions of pollutants into the atmosphere during operation of a shunting diesel locomotive at each position of the driver's controller when performing different types of shunting operations;

– to define the effect of applying an energy accumulator within a power circuit of a shunting diesel locomotive on the level of emissions of pollutants into the atmosphere by comparing appropriate results for a locomotive with an energy accumulator and a locomotive with a standard execution of the power circuit.

4. Experimental-estimated determination of the amount of emissions of pollutants into the atmosphere during operation of a shunting diesel locomotive at a separate position of the driver's controller

The study was carried out at the shunting diesel locomotive ChME3T-7310 equipped with the diesel engine, capacity 993 kW, service life – 630 hours, and a combined energy accumulator made by firm "Ekond" with a capacity of 150 kW in a power circuit. The research was carried out when the locomotive performed various types of shunting operations at the territory of station Liman of the Donetsk Railroad. Station Liman is the junction no-grade sorting station, which performs all types of shunting operations. Periodic environmental tests of diesel locomotive are conducted in the set intervals over the service life of each diesel locomotive in order to determine specific emissions of the pollutants contained in the exhaust gases from locomotives' diesel engines. Rheostat tests of the shunting diesel locomotive ChME3T-7310 were held in June 2019 at Slovyansk locomotive depot (Ukraine). In this case, we determined specific effective fuel consumption by the diesel-generator, the time of transients, and the environmental operational characteristics of the diesel engine under all modes. Measurement tools and research procedures used were in line with the industry standard GSTU 32.001-94 [12]. Results from determining environmental characteristics of the diesel locomotive ChME3T-7310 are given in Table 1.

Table 1

Results of determining environmental indicators for the shunting diesel locomotive ChME3T-7310

Mode No.	Fuel consumption, kg/hour	Capacity of auxiliary equipment, kW	Power, kW	α	CO_2, ppm	CNO, ppm	CNO_2, ppm	CCO, ppm	CNO_x, ppm	CCH, ppm
xx	2.84	2.28	0	12.24	23.1	310	59	269	369	16
				13.4	21.6	287	53	295	340	15
				12.66	22.2	315	50	271	365	14
1	37.015	19.45	180	1.49	7.4	842	166	244	431	18
			177	1.31	7.1	805	181	261	513	22
			182	1.51	8.0	880	171	227	477	17
2	48.904	23.76	207	1.79	9.4	842	189	194	1,431	28
			215	1.84	9.7	895	208	179	1,513	29
			210	1.81	9.5	900	197	187	1,477	27
3	67.205	31.65	414	1.81	9.5	913	209	307	1,022	31
			415	1.82	9.6	940	208	335	1,048	31
			417	1.9	9.7	950	210	337	1,052	32
4	91.600	38.12	525	2.0	10.5	965	202	338	1,060	32
			525	1.95	10.0	980	210	320	1,055	33
			526	2.07	10.9	985	222	341	1,067	31
5	119.025	47.85	620	2.16	11.4	844	219	365	1,053	32
			623	2.18	11.5	937	213	362	1,140	32
			620	2.20	11.7	990	230	360	1,051	33
6	136.045	61.64	723	2.18	11.5	988	237	370	1,055	35
			722	2.32	11.9	995	239	365	1,060	36
			750	2.36	11.4	938	214	365	1,052	38
7	177.011	95.81	830	2.18	11.5	844	211	344	1,055	37
			835	2.38	11.5	922	246	380	1,085	38
			830	2.42	11.9	957	242	377	1,078	38
8	205.850	137.70	935	2.55	11.8	948	240	381	1,088	38
			930	2.51	11.7	955	244	380	1,090	39
			950	2.54	11.9	947	251	341	1,091	38

The measurement result accepted was the arithmetic mean derived from performing not less than three experiments.

$$C_{cp}=\frac{C_1+C_2+C_3}{3}, \quad (1)$$

where C is the measurement result.

Specific emissions of nitrogen oxides C_{NO_x}, carbon oxide C_{CO}, hydrocarbons C_{eh} in g/(kWh) at each position of the driver's controller are calculated from formulae (2), (3), (4), according to the requirements by the industry standard GSTU 32.001-94 [12]:

$$C_{NO_xj}=\frac{5{,}72\cdot 10^4 C_{NO_x}\left(G_{air}-0{,}000974G_f\right)}{P_{ej}}, \quad (2)$$

$$C_{COj}=\frac{3{,}475\cdot 10^4 C_{CO}\left(G_{air}-0{,}000974G_f\right)}{P_{ej}}, \quad (3)$$

$$C_{ehj}=\frac{5{,}46\cdot 10^4 C_{CH}\left(G_{air}-0{,}000974G_f\right)}{P_{ej}}, \quad (4)$$

where j is the number of the driver's controller position (0–8, 0 – idling); G_{air} is the air flow rate, kg/s; G_f is the fuel consumption, kg/s; P_{ej} is the effective power of the diesel engine under a test mode; C_{CO} is the concentration of oxides of carbon, ppm; C_{NO_x} is the concentration of oxides of nitrogen, ppm; C_{CH} is the concentration of hydrocarbons, ppm.

Air flow rate through the locomotive's diesel in kg/s is determined from the following dependence:

$$G_{air}=\frac{\alpha_\Sigma L^0_{air}G_f}{1000}, \quad (6)$$

where L^0_{air} is the amount of air that is theoretically required for combustion of 1 kg of fuel, $L^0_{air}=14{,}32$ kg air/kg fuel; α_Σ is the total coefficient of excessive air, determined based on the results from analysis of exhaust gas and the reaction of burning of low-sulfur fuels.

The total surplus air coefficient α_Σ for the average composition of a diesel fuel in the ambient air is calculated from formula

$$\alpha_\Sigma=1+\frac{21-1{,}353C_{CO_2}-0{,}958C_{CO}-0{,}5C_{NO_x}-0{,}63C_{NO}}{C_{CO_2}+0{,}5C_{CO}+0{,}4468\left(C_{CO_2}+C_{CO}\right)+0{,}5C_{NO_x}}, \quad (7)$$

where C_{CO_2} is the carbon dioxide concentration in exhaust gas, ppm; C_{NO} is the concentration of nitric oxide, ppm.

Effective power in kW under a test mode P_e is determined from the following formula:

$$P_e=P_{pm}+P_{am}, \quad (8)$$

where P_{pm} is the power measured on the terminals of a generator, kW; P_{am} is the power of additional equipment and mechanisms in a diesel locomotive (taking into consideration the periodicity of their operation), which have a mechanical drive from the diesel engine (cooling chambers fans, fans for traction engines, a compressor, etc.).

Table 2

The average operating level of specific emissions g/(kWh)

Title of pollut-ant	Positions of the driver's controller								
	0	1	2	3	4	5	6	7	8
CO	0.6	0.61	0.66	0.75	1.42	2.06	4.3	5.41	6.37
NO_x	3.9	5.88	7.02	9.80	10.1	10.60	10.76	11.40	11.7
SO_2	0.03	0.26	0.41	0.72	1.09	1.43	2.15	2.68	2.86
Soot	0.04	0.06	0.07	0.09	0.18	0.31	0.32	0.34	0.36
Hydro-carbons	0.13	1.99	2.11	3.22	5.41	6.45	9.7	11.01	12.9

Effective power in kW, considering an energy accumulator P_e, is determined from the following formula:

$$P_e=P_{pm}+P_{am.}-P_{br}, \quad (9)$$

where P_{br} is the power accumulated as a result of electrodynamic braking (11), kW.

The average operating specific emissions of pollutants in g/(kW·h), depending on the position of the driver's controller and the duration of a locomotive diesel engine operation at this position, are calculated from formula [12]:

$$M_{ce}=\frac{\sum_{i=1}^{n}\sum_{j=0}^{8}\left(C_{ij}t_jP_j\right)}{\sum_{j=0}^{8}\left(t_jP_j\right)}k_vk_fk_t, \quad (10)$$

where C_{ij} is the specific emission of pollutants (NO_x, CO, CH) when the driver's controller operates at the j-th position, g/(kWh) (Table 2);

t_i is the time share of a diesel locomotive operation at the j-th position of the driver's controller;

k_f is the coefficient of influence from the technical state of diesel locomotives. It is assumed to be equal to 1.2 for diesel locomotives in operation over 2 years and equal to 1.0 for diesel locomotives in operation for less than 2 years;

k_t is the coefficient of influence from climatic conditions for diesel locomotives operation. It is assumed to be equal to 1.2 for areas located south of 44 North latitude and equal to 0.8 for areas north of 60 North latitude. For other areas, k_t=1.0;

k_v is the coefficient of influence from the motion speed of a diesel locomotive; shunting operations imply low motion speeds, so we take k_v=1.2.

5. Relationship between the duration of a shunting diesel locomotive operation at each position of the driver's controller and the types of shunter operations

It is known that shunting operations are characterized by prolonged downtime of a diesel locomotive at idling, the frequency of change in the positions of the driver's controller, work at the low positions of the controller, a large number of accelerations and braking. In general, these processes are stochastic in nature. When performing shunting movements, diesel locomotives exploit transition modes. When analyzing shunting operations, one can highlight several specific types of operations that have similar characteristics: a hill-related work, dispatch work, shunting operations at a station and along a railroad section.

Most shunting locomotives currently employ the fuel consumption control system "BIS-R", which is a distributed microprocessor system to controlling fuel consumption by shunting diesel locomotives. It registers fuel consumption, power, the duration of operation at each position of the driver's controller over 10 days with a step of 2 minutes.

Our analysis of data from the system "BIS-R" has made it possible to determine the average operation duration of a shunting diesel locomotive at the i-th position of the controller depending on the type of shunting operations performed. Results from this analysis are shown in Fig. 1.

Fig. 1 clearly demonstrates the uneven distribution of the operation duration of a shunting diesel locomotive at individual positions of the driver's controller depending on the type of a shunting operation. Such a character of distribution affects the respective amounts of polluting substances emitted into the atmosphere (Table 1).

The results from calculations, based on formula (10), of the average operating specific emissions of pollutants emitted into the atmosphere by a shunting locomotive, depending on the type of a shunting operation, are shown in Fig. 2.

Analysis of the acquired data indicates that the longer the operation of a shunting locomotive at high positions of the controller, the greater the amount of pollutants released into the atmosphere. This mostly refers to the hill-related operations and dispatch operations.

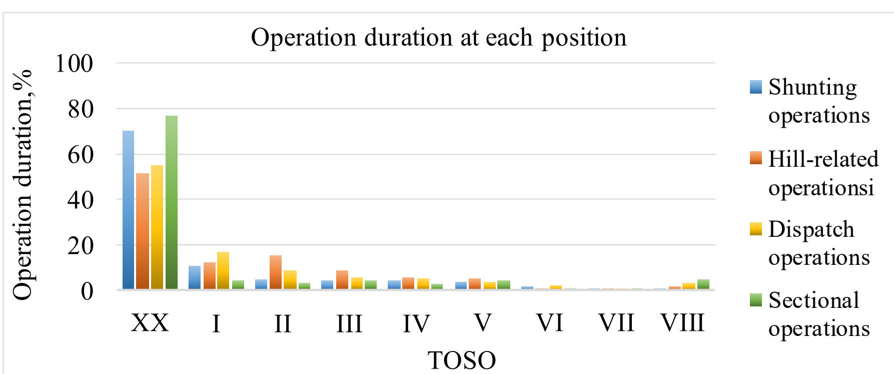

Fig. 1. Time share of a shunting diesel locomotive operation depending on the type of shunting operations

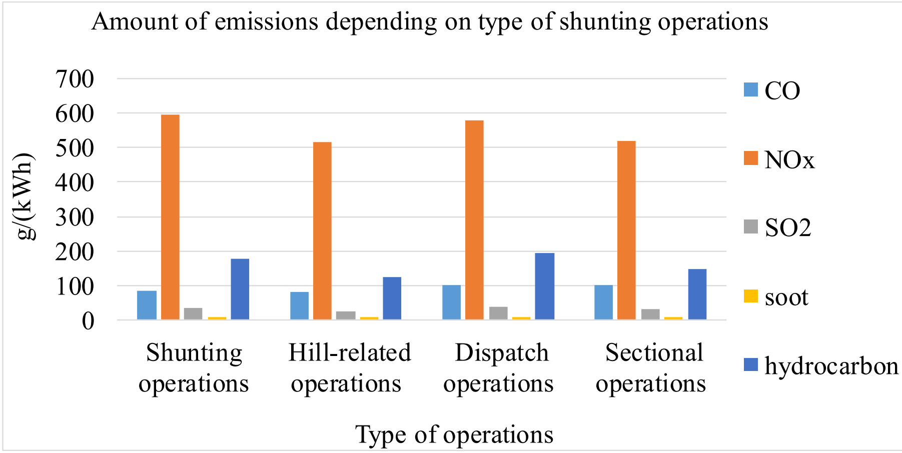

Fig. 2. Total value of specific emissions of polluting substances depending on the type of a shunting operation

6. Determining the amount of harmful emissions by a shunting diesel locomotive equipped with an energy accumulator in a power circuit

When applying an energy accumulator within a power circuit in a shunting diesel locomotive, there is an opportunity accumulate energy from electrodynamic braking and from the accumulator's charge at idling to subsequently use it for traction (9).

Energy of the electrodynamic braking may be determined from formula [13]:

$$P_{br}=\frac{v_i^{'2}-\frac{1}{\eta_e}\left(\frac{\sum R_b CU^2}{CF^2}\right)}{7.2b}, \qquad (11)$$

where η_e is the efficiency of the accumulator; b is the coefficient that accounts for the mass and inertia of the rolling stock; CF is the loading characteristic; n is the number of traction engines; I_b is the braking current, A.

$$b=\frac{3.6n}{(1+\gamma)Q\eta_v}10^{-3}, \qquad (12)$$

where η_v is the mechanical transmission efficiency.

The motion speed of shunting rolling stock at any point is determined from formula:

$$v_i=v_{i-1}+a\Delta t, \qquad (13)$$

where a is the acceleration (deceleration) of a train under the action of an accelerating (decelerating) force in m/s^2; Δt is the step of integration; in calculations shall be made equal to c; v_{i-1} is the motion velocity at the preceding step, m/s.

The magnitude of acceleration (deceleration) for a train is calculated based on the differential equation of train motion [17]:

$$a=\frac{\left(F-w_q^{''}-w_l^{'}\right)}{Q}-\left(S-L_2\right)\frac{(Qg)}{(1+\gamma)}+\frac{L_b}{g}+m_l, \qquad (14)$$

where F is the specific traction force of a locomotive, N;

$w_q^{''}$ is the total specific resistance to the movement of rolling stock, N/kg;

$w_l^{'}$ is the total specific resistance to the movement of a locomotive, N/kg;

L_2 is the length of an ascending path, m;

L_2 is the slip portion length, m;

S is the total length, m;

γ is the coefficient that takes into consideration the inertia of rolling stock;

Q is the mass of rolling stock, kg.

The decelerating current related to the motion speed of a train:

$$I_b=\frac{v_i\cdot CF}{\sum R_b}, \qquad (15)$$

where $\sum R_b$ is the total resistance of the circuit engine and accumulator, Ohm.

A change in the amount of average operating specific harmful emissions when using the energy accumulator is calculated from formula

$$\Delta=M_{ce1}-M_{ce2}, \qquad (16)$$

where M_{ce1} is the average operating specific emissions of pollutants without an energy accumulator (10), g/(kWh); M_{ce2} is the average operating specific emissions of pollutants with an energy accumulator, g/(kWh).

Fig. 3 shows a diagram of the dependence of a decrease in the amount of average operating specific emissions of polluting substances by a shunting locomotive with an energy accumulator on the type of a shunting operation, calculated from formula (16).

The respective percentage for the decrease in the average operating specific emissions with an energy accumulator is calculated from formula:

$$\Delta\%=\left(\frac{M_{ce2}-M_{ce1}}{M_{ce1}}\right)\cdot 100\,\%. \qquad (17)$$

The obtained percentage values for a decrease in the average operating specific emissions by a diesel locomotive with an energy accumulator are given in Table 3.

Analysis of data from Table 3 reveals that the percentage of decrease in the average operating specific emissions of pollutants into the atmosphere by a shunting locomotive with an energy accumulator in the power circuit is not the same for different types of shunting operations. This is due to the different amount of the energy accumulated by the energy accumulator, which depends on the nature of the shunting operations. Thus, a shunting operation on a hill produces maximum indicators for a decrease in the average operating specific emissions, because such an operation implies a large number of cyclic accelerations and braking.

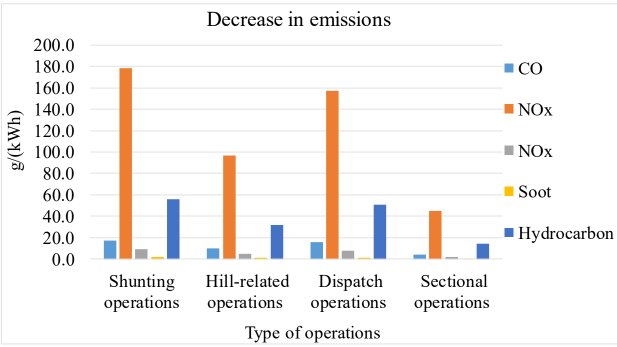

Fig. 3. Dependences of a decrease in the amount of average operating specific emissions of polluting substances by a shunting locomotive with an energy accumulator on the type of shunting operation

Table 3

Percentage of a decrease in the average operating specific emissions, %

Title of pollutant	Hill-related operations	Dispatch operations	Shunting operations	Sectional operations
CO	21 %	12 %	16 %	4 %
NO_x	30 %	19 %	27 %	9 %
SO_2	26 %	19 %	20 %	7 %
Soot	23 %	14 %	19 %	6 %
Hydrocar-bons	32 %	25 %	26 %	10 %

7. Discussion of the research results

When using the energy accumulator at a shunting diesel locomotive, part of the energy from electrodynamic braking during motion of shunting rolling stock and the energy from a diesel-generator installation of the diesel locomotive at idling is stored in the energy accumulator, to be further used for traction. This decreases the amount of energy that must be received from a diesel-generator installation to enable the locomotive traction. That reduces the amount of average operating specific emissions of pollutants into the atmosphere from the diesel engine of a shunting locomotive.

Our research has made it possible to establish a difference in the total operation duration of a shunting diesel locomotive at a separate position of the driver's controller under conditions for execution of different types of shunting operations. The diagram of distribution of this duration depending on the position of the controller and the type of a shunting operation performed by a diesel locomotive is shown in Fig. 1.

To assess the effectiveness of application of the energy accumulator within a power circuit at a shunting diesel locomotive, we have proposed the new approach to calculating the amount of harmful emissions by the diesel engine of a locomotive into the atmosphere, taking into consideration the mode of the locomotive operation, specifically a position of the driver's controller and the type of the shunting operation performed.

This approach to calculations has allowed us to discover the relationship between the volume of the energy accumulated by the energy accumulator and the amount of emissions of pollutants into the atmosphere by shunting locomotives. Fig. 2 shows total values for the amount of specific emissions of pollutants depending on the type of a shunting operation, calculated depending on the operation duration at each position of the driver's controller.

It should be noted that the current research was carried out under conditions for the execution of shunting operations that are carried out at a railroad station and adjacent tracks. The work did not consider the main-line operations of diesel locomotives, at which the amount of stored energy depends primarily on the profile of the railroad track.

The further advancement of the current research implies identifying opportunities to reduce the emissions of pollutants into the atmosphere by various types of shunting diesel locomotives depending on the parameters of the applied hybrid power plants and the energy accumulators under different modes of shunting operations.

The proposed approach could make it possible to establish rational characteristics for the energy accumulator at a shunting locomotive so that it executes specific types of shunting operations.

8. Conclusions

1. It has been confirmed that the amount of emissions of pollutants into the atmosphere from the diesel engine at a shunting locomotive depends on the position of the driver's controller at which it operates. A position of the driver's controller directly affects the used power of the diesel generator, which is why operations at high positions of the controller produce larger amounts of specific emissions of pollutants.

2. To assess the effectiveness of application of an energy accumulator within a power circuit of a shunting diesel locomotive, the new approach has been proposed to calculating the amount of harmful emissions from the diesel engine in a locomotive into the atmosphere, taking into consideration the operation mode of a locomotive, specifically a position of the driver's controller and the type of the shunting operation performed.

3. Based on the results from processing data acquired from the system BIS-R, we have determined the average operation duration of a shunting diesel locomotive at each position of the driver's controller. We have established differences in the total duration operation at each position of the driver's controller for each type of shunting operation.

4. The results of our calculations indicate that using the energy accumulator within a power chain in a shunting diesel locomotive reduces specific volumes of emissions into the atmosphere: carbon oxide CO – by 4...21 %, nitric oxide NO_x – by 9...30 %, sulfur dioxide SO_2 – by 7...26 %, soot – by 6...23 %, hydrocarbons – by 10...32 %, depending on the type of the shunting operation performed.

References

1. Walsh, M. P. (2011). Mobile Source Related Air Pollution: Effects on Health and the Environment. Encyclopedia of Environmental Health, 803–809. doi: https://doi.org/10.1016/b978-0-444-52272-6.00184-7
2. Buekers, J., Van Holderbeke, M., Bierkens, J., Int Panis, L. (2014). Health and environmental benefits related to electric vehicle introduction in EU countries. Transportation Research Part D: Transport and Environment, 33, 26–38. doi: https://doi.org/10.1016/j.trd.2014.09.002
3. Dzikuć, M., Adamczyk, J. (2014). The ecological and economic aspects of a low emission limitation: a case study for Poland. The International Journal of Life Cycle Assessment, 20 (2), 217–225. doi: https://doi.org/10.1007/s11367-014-0819-x
4. Düring, I., Bächlin, W., Ketzel, M., Baum, A., Friedrich, U., Wurzler, S. (2011). A new simplified NO/NO_2 conversion model under consideration of direct NO_2-emissions. Meteorologische Zeitschrift, 20 (1), 67–73. doi: https://doi.org/10.1127/0941-2948/2011/0491
5. Honcharov, O. M., Kinter, S. O., Tereshchak, Yu. V. (2014). Analysis of Prerequisites of Modernization of Shunting Locomotives of the Lviv Railroad Hybrid Power Station. Zaliznychnyi transport Ukrainy, 6, 19–25.
6. Kahramanian, A. O., Rukavishnykov, P. V. (2010). Doslidzhennia vplyvu osnovnykh faktoriv ekspluatatsiyi dyzeliv teplovoziv na vykydy zabrudniuiuchykh rechovyn. Zbirnyk naukovykh prats DonIZT, 21, 160–169.
7. Tighe, C. J., Twigg, M. V., Hayhurst, A. N., Dennis, J. S. (2012). The kinetics of oxidation of Diesel soots by NO2. Combustion and Flame, 159 (1), 77–90. doi: https://doi.org/10.1016/j.combustflame.2011.06.009
8. Sarvi, A., Lyyränen, J., Jokiniemi, J., Zevenhoven, R. (2011). Particulate emissions from large-scale medium-speed diesel engines: 1. Particle size distribution. Fuel Processing Technology, 92 (10), 1855–1861. doi: https://doi.org/10.1016/j.fuproc.2011.04.031
9. Lee, T., Park, J., Kwon, S., Lee, J., Kim, J. (2013). Variability in operation-based NOx emission factors with different test routes, and its effects on the real-driving emissions of light diesel vehicles. Science of The Total Environment, 461-462, 377–385. doi: https://doi.org/10.1016/j.scitotenv.2013.05.015
10. Reşitoğlu, İ. A., Altinişik, K., Keskin, A. (2014). The pollutant emissions from diesel-engine vehicles and exhaust aftertreatment systems. Clean Technologies and Environmental Policy, 17 (1), 15–27. doi: https://doi.org/10.1007/s10098-014-0793-9
11. Falendysh, A., Hatchenko, V., Kletska, O. (2017). The analysis of approaches to the calculation of emissions from the exhaust gases of diesel locomotives. Visnyk im. V. Dalia, 3 (233), 228–233.
12. HSTU 32.001-94. Vykydy zabrudniuiuchykh rechovyn z vidpratsovanymy hazamy teplovoznykh dyzeliv. Normy ta metody vyznachennia. Chynnyi vid 01.01.1995 r.
13. Yarovoy, R., Chernetska-Biletska, N. (2019). Method of immatious modeling of electrodynamic braking processes. Visnyk im. V. Dalia, 3 (251), 216–219.
14. Kudryavcev, A. P., Chichin, A. V., Sakaev, E. K. (1999). Sredstva ekologicheskogo kontrolya. Lokomotiv, 3, 26–28.
15. Smaylis, V. I. (1991). Sovremennoe sostoyanie i novye problemy ekologii dizelestroeniya. Dvigatelestroenie, 1, 3–6.
16. Malov, R. P., Evgunov, P. M., Pankov, Yu. N., Sheynin, M. G. (1991). Tehniko-ekologicheskie harakteristiki teplovozov. Moscow: TR. VNIIZHT, 35–40.
17. Kosov, Ye. Ye., Azarenko, V. A., Korniev, A. N., Komarnytskyi, M. M. (2008). Vplyv efektyvnosti nakopychuvacha enerhii na palyvnu ekonomichnist lokomotyva. Lokomotiv, 3, 44–45.
18. Bolzhelarskyi, Ya. V., Honcharov, O. M. (2007). Dosvid i problemy normuvannia palyva na manevrovu robotu v umovakh Lvivskoi zaliznytsi. Zaliznychnyi transport Ukrainy, 2, 71–72.
19. Liudvinavičius, L. Lingaitis, L. P. (2010). New locomotive energy management systems. Maintenance and reliability, 1, 35–41.
20. Barrade, P. (2001). Series connexion of Supercapacitors: comparative study of solutions for the active equalization of the voltage, École de Technologie Supérieure (ETS). Montréal.
21. Boyes, J. D., Clark, N. H. (2000). Technologies for energy storage. Flywheels and super conducting magnetic energy storage. 2000 Power Engineering Society Summer Meeting (Cat. No.00CH37134). doi: https://doi.org/10.1109/pess.2000.868760
22. Poór, I., Varga, M., Németh, G., Rónai, A., Nemes, P. (2012). Az Mk48 403 Mozdony Hibridhajtású Fejlesztése, Vasútgépészet, 4, 9–14.
23. Schofield, N., Yap, H. T., Bingham, C. M. (2005). Hybrid Energy Sources for Electric and Fuel Cell Vehicle Propulsion. 2005 IEEE Vehicle Power and Propulsion Conference. doi: https://doi.org/10.1109/vppc.2005.1554530
24. Steiner, M., Scholten, J. (2005). Energy storage on board of railway vehicles. 2005 European Conference on Power Electronics and Applications. doi: https://doi.org/10.1109/epe.2005.219410