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COMPARISON STUDY OF TWO DIESEL HYDRAULIC LOCOMOTIVE ENGINES REGARDING THE ENVIRONMENTAL POLLUTION

R.-M. BALOGH*, N. LONTIS, I. IONEL, L. DUNGAN

University'Politehnica' of Timisoara, 1 Mihai Viteazu Blvd., 300 222 Timisoara, Romania
E-mail: *baloghramon@gmail.com*; *ionel_monica@hotmail.com*

Abstract. The process of modernisation of the diesel hydraulic locomotive, i. e. the changing of the Sulzer engine, old over 50 years as concept, was necessary. Thus, the replacement with a Caterpillar 3508 B engine and a heat exchanger with three circuits was necessary to fit into account the evolution of technique and the pollution standards.

Keywords: gases flow, locomotive pollution, experimental noxious measurements, environmental impact.

AIMS AND BACKGROUND

The paper aims to provide a comparison in terms of flue gases and noxious emissions from diesel hydraulic locomotive 920 kW (LDH 125) and diesel hydraulic locomotive 1000 kW.

In the EU considerable efforts have being made to implement clean transport technologies and to apply the concept of sustainable mobility issues such as: (i) use of vehicles with lower fuel consumption; (ii) implementation of new propulsion technologies to reduce emissions and pollutants; (iii) encourage and promote public rail and community transportation, especially electric; (iv) ensure comfort and safety of traffic, and (v) restructuring vehicles developing and upgrading urban and interurban vehicles.

Romania, due to its geographical location, is an area of intersection of Pan-European Transport Corridors IV and IX rail and roads linking northern and southern-west with the East European continent. According to the present situation, our country is in a difficult position to follow the EU conditions regarding transportation. Thus, the overall objective of the national transport strategy is to ensure extensive transport infrastructure, simultaneously with a modern and sustainable progress in conjunction with the sustainable development of the economy and quality of life[1,2].

* For correspondence.

One of the first steps taken towards achieving this objective is the modernisation of existing rolling stock. The paper compares outputs of 2 locomotives (one old fashioned and the latest of improved features).

DESCRIPTION OF THE 920 KW DIESEL HYDRAULIC LOCOMOTIVE

The diesel hydraulic 920kW locomotive (Fig. 1) is a middle rail transportation locomotive and a product of Romanian technology. The mechanical energy produced by the diesel engine is converted into kinetic energy in the hydraulic turbo transmission in the primary phase, and again the mechanical energy in the secondary phase. The items used are 2 type Fottinger torque converters. The hydraulic turbo-transmission is in this case assimilated with a gearbox with an infinite number of steps[3].

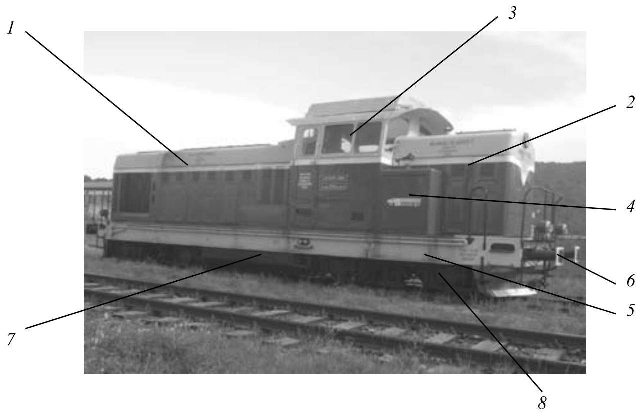

Fig. 1. Components of locomotive LDH 125 of 920 kW (Ref. 4)
1 – large hood for the locomotive diesel engine 6 SA 28 B; *2* – low hood for the locomotive of the train hauled aggregate heating system; *3* – locomotive cab for the two control panels; *4* – compressor; *5* – longitudinal locomotive which supports the top of the locomotive and the link with the device running; *6* – collision and binding machines; *7* – main tank locomotive; *8* – location for the apparatus to run the locomotive

DESCRIPTION OF THE 1000 KW DIESEL HYDRAULIC LOCOMOTIVE

The diesel hydraulic 1000 kW locomotive (Fig. 2) is a middlerail transportation locomotive produced in Romania in cooperation with companies specialised in railway vehicles motorisation (Caterpillar).

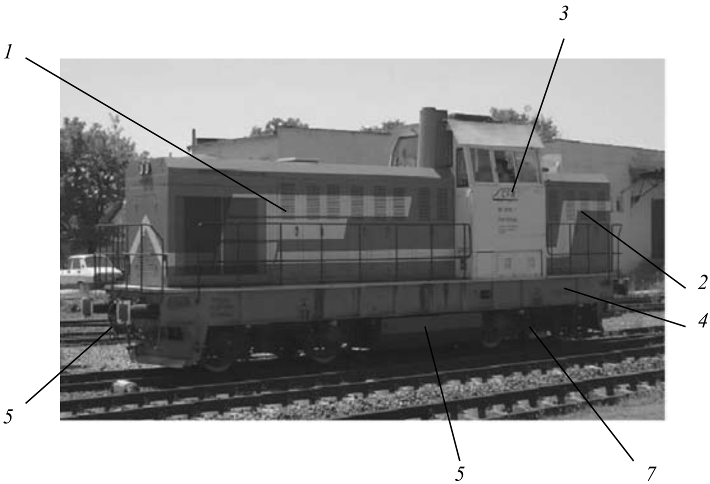

Fig. 2. Components of locomotive LDH 125 of 1000 kW (Ref. 4)
1 – large hood for the locomotive diesel engine Caterpillar 3508 B; *2* – small hood for the locomotive where the train heating generator towed; *3* – locomotive cab where there are two control panels; *4* – longitudinal; *5* – collision and binding machines; *6* – main tank locomotive; *7* – device running of the locomotive

One of the main objectives of the EU is the reduction of the emissions and pollutants produced by transport. Following this scope the paper aims to present a comparison in terms of the exhaust gases and compressed pollutants emitted by diesel engines that power the diesel hydraulic locomotives: the old and the new one, modernised.

Dispersion of pollutants in the atmosphere is a natural phenomenon, difficult to assess and with unpredictable effects. The quality of air is vital for life on earth. One of the main polluting sources is the means of transport. Emissions from internal combustion engines are harmful both by emitted concentrations and amounts. Being emitted at ground level, in the imminent approach of human habitat, their influence on air quality is much more effective and dangerous.

Compounds that are formed in the exhaust gases contribute to air pollution both globally and locally, directly or indirectly, causing chemical chain reactions in the atmosphere. Very dangerous are the CO_2 emissions as contributors to the climate change according to their global warm effect. On the whole planet, increasing the concentration of gases and particles producing climate change will have unpredictable consequences on the environment, climate and quality of life in the next near time periods[5].

Over the years, the diesel hydraulic locomotive of 920 kW underwent several modernisations. In the first stage, the modernisation was oriented versus the team working conditions of maintenance personnel and improvements to the equipment inside the cab were brought. Following upgrades were made:

1. The inside of the cabin has been refurnished and changed up to 90 %, also equipped with protective, diagnostics and signalling equipment and traction controller with adaptive program.

2. The steam aggregate (used to heat the train) was replaced with a generator for electrical heating for passenger trains, usually one used diesel type BF06M Deutz 1015 HP single-phase synchronous electric generator.

3. As most significant step, leading to the total change of locomotive, both inside and outside (Fig. 1), the modernisation involves several steps[1].

The replacing of the Sulzer 6 SA 28 B engine with a Caterpillar 3508 B motor that has better performance regarding the consumption, emissions and reliability in service was the most important. Also the TH 2 hydraulic transmission was changed to be adapted to the new speed (100 km/h). Compressor without lubrication with teflon-coated pistons, hydrostatic trained were installed. The hydrostatic system was also introduced with a modern replacement facility, delivered by the company BEHR – Germany. Controller mounting and brake control of the diesel locomotive and train brakes became standard retrofitting. Also mounted blocks for automatic brake control and brake control block for direct braking were mounted. The electrical installation at 24 V was introduced. Finally the construction of a new cab suspension stiffer and hoods of a new modular system were installed. The changes inside the cab driver, by redesigning the station management and automation cabinet in line with new equipment, offered better comfort, side windows installation with products from AEROFINA – Bucharest as well as the installation of electrically for operating window wipers and the installation of air conditioning equipment, refrigerator, and ergonomic chairs were installed[1].

DESCRIPTION OF EQUIPMENT

For measurement of pollutant emissions from the reciprocating combustion of engine was used a chemical method (the TESTO 350 M / XL gas analyser). Species that the analyser can measure are: SO_2, CO, O_2, NO_2, NO and NO_x. Additionally, it indicates some very important thermodynamic parameters such as air excess, temperature, pressure, gas velocity, concentration of CO_2, etc.

EXPERIMENTAL

MEASUREMENTS MADE ON DIESEL HYDRAULIC LOCOMOTIVES

Tables 1 and 2 present the results of the measurements case study 1 for pollutant emissions resulting from the operation of locomotive LDH 125 of 920 kW and case study 2 for locomotive LDH 125 of 1000 kW, measured under conditions specified in the technical use of the device.

Table 1. Experimental values for emission exhausted by a LDH 125 locomotive equipped with a 920 kW engine

No	Speed (rpm)	Fuel consumption (kg/min)	Gas temp. (ºC)	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_x (ppm)	SO_2 (ppm)	λ_{air}	Ambient temp. (ºC)	O_2 ref. (%)
1	380	0.20	133.2	19.40	131	1.17	105	110	0	13.15	25.1	3.0
2	420	0.55	203.6	15.25	91	4.22	505	530	0	3.65	26.0	3.0
3	460	0.70	250.8	14.26	101	4.94	643	675	0	3.12	26.4	3.0
4	480	0.85	283.8	13.89	128	5.21	684	719	0	2.96	26.8	3.0
5	510	1.01	313.3	13.08	174	5.81	754	791	0	2.65	27.0	3.0
6	560	1.31	364.8	11.85	304	6.71	815	856	0	2.30	27.2	3.0

Table 2. Experimental values for emission exhausted by a LDH 125 locomotive equipped with a 1000 kW engine

No	Speed (rpm)	Fuel consumption (kg/min)	Gas temp. (ºC)	O_2 (%)	CO (ppm)	CO_2 (%)	NO (ppm)	NO_x (ppm)	SO_2 (ppm)	λ_{air}	Ambient temp. (ºC)	O_2 ref. (%)
1	600	0.12	139	18.61	119	1.75	391	410	0	8.78	25	3.0
2	850	0.31	243	12.38	132	6.32	1166	1224	0	2.44	27	3.0
3	950	0.60	275	11.63	139	6.87	1179	1238	0	2.24	28	3.0
4	1030	0.75	319	10.65	169	7.59	1123	1179	0	2.03	27	3.0
5	1104	0.88	354	9.97	265	8.09	985	1039	0	1.90	27	3.0
6	1180	1.01	398	8.77	320	8.91	943	1011	0	1.84	27	3.0

RESULTS AND DISCUSSION

To highlight the emissions of the two locomotives, they were subjected on static test by loading each engine on five loading steps; the resulted data were plotted into diagrams (Figs 3–7) for the most important pollutants and parameters depending to the fuel consumption. By comparing the results from the both engines of the locomotives it results that the trends of the variation of the flue gas emissions are similar.

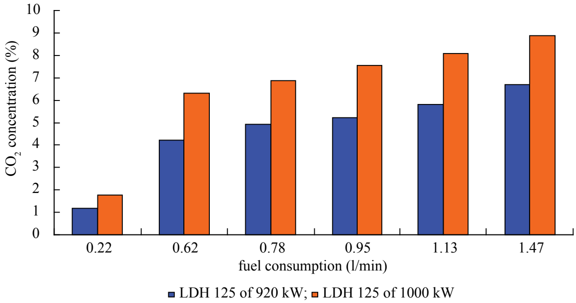

Fig. 3. CO_2 emissions of the 2 locomotives depending on fuel consumption

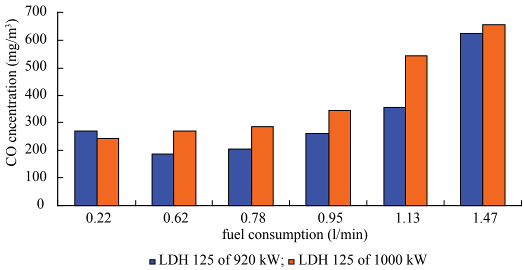

Fig. 4. CO concentration of the 2 locomotives depending on fuel consumption

The CO_2 exhaust is found to increase according to the fuel consumption (that is normal) as more fuel means more carbon to be oxidised. What is to be special to mention is concerning case study number 2: the emission is always higher in comparison to the basis (case study 1), but also important is the engine speed (rpm) in the second case. The CO emission has a similar variation except of the first step of load in case study 1 where the concentration is going down and then is growing as the speed engine and fuel consumption increase. The explanation for decreasing in the first step is that the engine on idle is working with $\lambda>1$ and in step 1 it gets close to 1 and from step 3 the λ is less than 1. In case study 2 the variation is growing from each loading step because of a better injection and regulation of λ on idle speed.

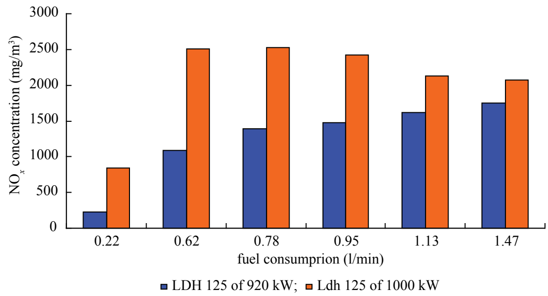

Fig. 5. NO_x emissions of the 2 locomotives depending on fuel consumption

The NO and NO_x variation is similar ($NO_x = NO + NO_2$) and depends on fuel consumption and its concentration, which is decreasing in case study 2. An explanation is offered through the mechanism of the thermal mechanism formation depending on temperature and fuel consumption/air ratio[2]. An important note is that for the 1000 kW diesel hydraulic locomotive, the noxious emissions (NO_x) decrease after reaching the speed corresponding to 1020 rpm and in the case of the 920 kW diesel hydraulic locomotives continues to increase with engine speed rotation. However, the values obtained in case study number 1 are much more reduced (even by 57% in first load step), in the first loading steps, and increase permanently in the following. The difference became smaller (up to 17% in the last loading steps), as the modernisation of the engine causes more reduced NO_x formation.

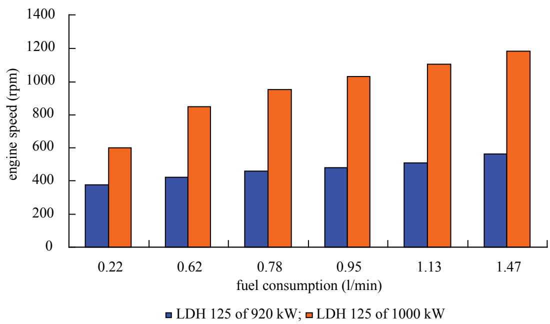

Fig. 6. Engine speed depending on fuel consumption

Regarding the gas temperature, the variations of the 2 engines are close, but the values for the engine speed (rpm) are very different. Both engine speed (rpm) and gas temperature are depending on fuel consumption, larger power means also bigger values.

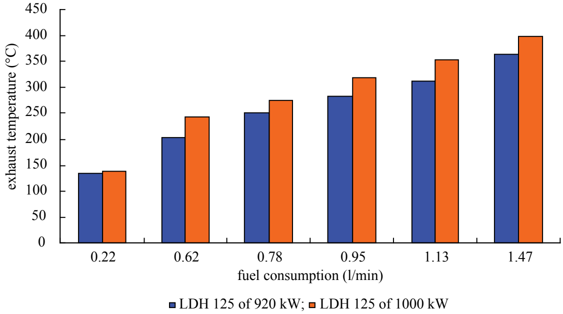

Fig. 7. Exhaust gas temperature depending on the fuel consumption

Even so one has to remark that for case number 1 the rotation speed is much more limited to the fuel consumption influence. An explanation may be the speed range, injection mechanism, injector type, injection pressure and another important aspect is that in the old engine the injection regulation is made by mechanical mechanism and in the new engine it is made electronically by ECU (engine control unit).

SOLUTIONS FOR LIMITATION OF POLLUTANT EMISSIONS

Methods for reducing solid and gaseous pollutant concentrations are divided into active ones aimed to act at their source by optimising combustion. The passive methods are aiming to retention and/or oxidation. The category of passive methods concerns post-treatment of burned gases, as well as particulate filters that are mounted and oxidation catalysts. The selection of the most suitable method for post-treatment depends on the particle composition analysis and of the fuel gases pollutant concentration. It is known that the particulate filters are very effective in neutralising the insoluble fraction of particles and filters are used in case of oxidation catalysts for neutralisation of soluble fraction[6].

Recently, passive methods of treatment (post-treatment) are more active. The flue gases are ongoing a catalytic reactions, in order to reduce the NO_x species. Systems are called passive NO_x reduction. NO_x reduction by active methods is a difficult operation, requiring significant changes in combustion. In the NO_x reduction, it is necessary to take into consideration minimum three compromises[7]:

– reduction of NO_x concentration in relation to fuel consumption;

– compromise of the NO_x reduction, compared to the ratio of CO_2/CO issued;

– compromise of the NO_x concentration reducing with respect to the emission of particles.

The states of art of passive methods are consisting of controlling through particle filters installed in the exhaust system. The most common devices are the ceramic filters. They are capable to capture 80% of particles from the burnt gas. Other methods for controlling the amount of particles is performed through catalytic regeneration. Also the after-burning system of the exhaust gases is known as active system. In this case a small amount of fuel is injected into the exhaust gas, thus providing the necessary catalyst-reducing agent. NO_x filter retention applies a new process for removing NO_x emission from the exhaust gases known as catalytic selective (SCR). NO_x reduction can be achieved and with plasma, as well, in case of higher sulphur content of the fuel as it is a major disadvantage in using catalytic treatment in this situation.

Selective non-catalytic reduction (SNCR) occurs in a temperature window that is between 850 and 1000°C. In terms of the reduction process, this window is relatively narrow[8].

CONCLUSIONS

The level of the pollution gases, especially NO_x, corresponds to stage II emission standards, but regarding to the new legislation for large diesel engines which are using fossil fuels, which has to be applied up to 2014, the NO_x concentration has to decrease under 7.4 g/kWh, the CO concentration under 3.5 g/kWh (Ref. 9). Thus, two main solutions may be adopted in the future.

(A) Selective non-catalytic reduction (SNCR) technique is one possibility but it requires a thorough knowledge of engine operation intended to reduce NO_x. It is often useful and thus it is necessary to mount an SNCR reduction system only after some preliminary studies on temperature measurements in flue gas zones affected by injection process and being performed at different thermal loads of equipment[7]. The position of the injection system can be adopted, in most cases in order to be split into several control areas, as the reagent must be injected, if possible, as close as possible to the region where combustion occurs in order to achieve the maximum reduction. SNCR technique can be applied using different reagents and under different physical states of aggregation, such as gaseous ammonia, liquid ammonia solution, urea in solid granules. The total, even if the reactions are extremely fast (of the order of 0.1 s), is dependent on the physical state of injected reagent. A liquid or solid reagent requires additional time permitting the vaporisation or sublimation of the emission.

In all cases the designing of the injection system has a great importance because: (1) it generates characteristics of the product injected and the flue gas that must be reduced; (2) the system must withstand the temperature levels, and (3) the system should not slow the technical performance of the primary mover[10,11], if it is cooled.

(B) Selective catalytic reduction (SCR) is the most efficient after-treatment method for NO_x reduction[12]. In SCR technology the nitrogen oxides are converted by a catalyst into nitrogen N_2 and water H_2O (Ref. 13). To take place the conversion reactions, a reducing gas is needed, which is usually a solution of urea (32.5%) and high purity water (distilled water) known as AdBlue. However, other solutions such as anhydrous ammonia or aqueous ammonia which are sprayed into the flow of smoke or exhaust gas and by absorbed are the catalyst[14] are known.

The problem of applying the system on vehicles appears from the fact that reducing agents are stored in a separate tank and system should be injected with a powerful injection into the exhaust.

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