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POLLUTANTS EMISSION PROBLEMS FROM THE COMBUSTION ENGINES OF OTHER APPLICATIONS THAN MOTOR CARS

Following motor car combustion engines, more and more significance is being attached to the pollutants emissions from the engines other than used in motor cars. The scale and variety of applications of such engines are considerable. At present these engines are less modern than those from motor cars, and requirements posed for them are not as restrictive with regards environmental protection, as in the case of motorism. This paper analyzes assessment procedures for the pollutant emissions from the combustion engines of other applications than in motor cars. Influence of the engine operating conditions on the pollutants emission has been evaluated.

Keywords*: construction machines, combustion engines, pollutants emission.*

1. Introduction

The requirements posed for the combustion engines by the environmental protection are at present becoming their quality factors. Particular importance is being attached to the emission of the pollutants harmful for humans and the environment. Following the achievements in limiting pollutants emission from the motor cars engines, there is growing interest in the improvement of the ecological characteristics of the engines in other applications than motorcars. This practically concerns all types of applications of combustion engines, amongst them: ships, aircraft, diesel locomotives, construction, agricultural and forestry machines, as well as gardening and utility devices [1, 2, 5, 9 – 14].

Knowledge of combustion engines ecological characteristics with respect to their pollutants emission is required for three basic reasons.

First reason is the necessity to qualify the combustion engines to be introduced to commercial trading and into operation, from their environmental impact characteristics point of view. To this end there are type approval procedures being used, enabling to establish compatibility of the product with the formal requirements [3, 5].

Second reason for testing combustion engines pollutants emissions is the necessity to know their environmental characteristics in the conditions equivalent to the real operating ones. This is necessary to evaluate the combustion engines environmental impact and in particular to record pollutants emission from various civilisation sources. Numerous counties, including Poland are obliged, upon international agreements, to record pollutants emissions, amongst them: European Program CORINAIR (Coordinated Information on the Environment in the European Community) [3, 5].

The third reason is connected with the ability to objectively evaluate methods to improve combustion engines characteristics regarding pollutants emission. It is necessary therefore to work out methods of testing pollutants emission from the combustion engines in the conditions reflecting the real operating ones. This enables to evaluate these engines characteristics in the specific conditions they work in. [1 – 3, 4, 6 – 7, 9, 11 – 14].

At present, there are well developed methods of testing motor cars combustion engines [3, 5]. These methods have been verified as a result of testing programs such extended, that it is possible to formulate conclusions of a statistic nature. In the case of the engines of applications other than in the motor cars, as well as in the motor cars, but very specific, (such as urban buses), the methods of car engine testing often turn out however to be ineffective. Which justifies the interest in the topic, being the subject of this paper.

2. Methods of testing pollutants emissions from the combustion engines of applications other than in motorcars.

Pollutants emission from the combustion engines is closely dependent on conditions these engines are in [3, 8]. Engines operating conditions can be characterised by the following processes: thermal state, revolutions and values characterising load, most often the torque [3, 4, 6, 8 – 14]. Pollutants emission from the combustion engines strongly depends on the static work states, defined by the torque value and engine revolutions [3, 4, 6, 10, 11], as well as on the dynamic states occurring in the engine operating conditions [3, 8]. For those reasons, there are combustion engines testing methods being developed with regards the pollutants emission, both static and dynamic.

Static tests are easier methods of testing combustion. Engines technical requirements with respect of testing equipment, used with the engine test bench, are lower in this case [5, 8, 11]. For those reasons, in the earlier period of testing, practically only static methods were being developed. These tests were used for motor car engines. The thirteen phase test has been developed according to Regulation 49 UN–EEC (Economic Commission for Europe), known as ECE R 49 [3, 5]. As time went by, using experiences from testing car engines, there have been static tests developed to test combustion engines of other applications. Static tests for combustion engines are defined by giving value of phase coordinates in various points on the plane: Engine revolutions against torque and proportions (weight ratios) of those phases in the whole test [3, 5, 9, 11 – 13]. Tests are carried out for the thermally stabilised state of the engine.

Dynamic tests are defined by the revolutions – torque curve. To conduct them, there is engine test bench equipment needed, which enables loading the engine in the dynamic conditions. Additionally, the dynamic tests often include states of negative torque, reflecting braking with the engine, which requires propelling the engine. This poses additional demands for a bench brake and its control system. For those reasons dynamic engine tests have been developed within the last few years: first dynamic tests were carried out in the United States in 1985. (HDDTT – Heavy Duty Diesel Transient Test and HDGTT – Heavy Duty Gasoline Transient Test) [3, 5, 11]. In Europe, first dynamic test of combustion engines was introduced in 2000. (ETC – European Transient Cycle), but it has been used for type approval processes only since 2005. [11]. For the engines of construction machines, first dynamic tests were developed only at the end of XX century by US EPA – United States Environment Protection Agency) [14]. The universal dynamic test have also been proposed for testing non–road machines, called NRTC (Non–road Transient Cycle). This test was also accepted by the European Union and introduced into testing procedures after 2005 [11].

Combustion engines' tests are defined in relative coordinates, related to values on the engine characteristics.

Relative speed is [4, 6, 11 – 13]:

$$n_w = \frac{n - n_{bj}}{n_N - n_{bj}} \qquad (1)$$

where: n – speed, n_{bj} – minimal idling speed, n_N – nominal speed.

Relative torque for the engine n speed is being related to the torque on the engine characteristics for the same revs. [4, 6, 11 – 13]:

$$M_{ew} = \frac{M_e(n)}{M_{ez}(n)} \qquad (2)$$

where: $M_e(n)$ – torque for the n speed, $M_{ez}(n)$ – torque on the engine characteristics for the n speed.

Relative useful power for the n speed. is defined as a ratio [11 – 13]:

$$N_{ew} = \frac{N_e(n)}{N_{ez}(n)} \qquad (3)$$

where: $N_e(n)$ – useful power for the n speed, $N_{ez}(n)$ – useful power on the engine characteristics for the n speed.

Figure 1 shows ECE R 49 static test complying with Regulation 49.02 UN ECE. In the static tests presented on the diagrams, the areas of the circles are proportional to the share of each phase in the test.

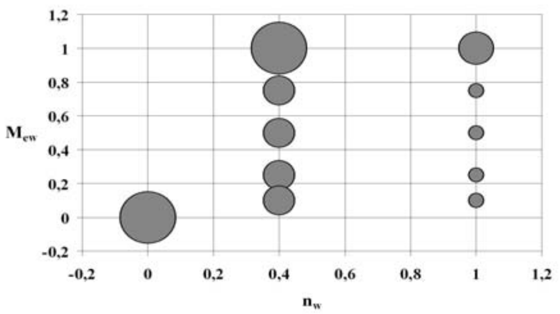

Fig. 1. Test ECE R 49

Test ECE R 49, being for years a standard one for testing pollutants emission from the motor car self ignition engines as well as engines powered by gas fuels, has become, (according to the ISO 8178–4 Standard), a basis for the synthesis of the static tests for the engines of other applications than motorcars [3, 5, 8, 11 – 13]. Points of this test define, so called universal test, marked as B test – Figure 2.

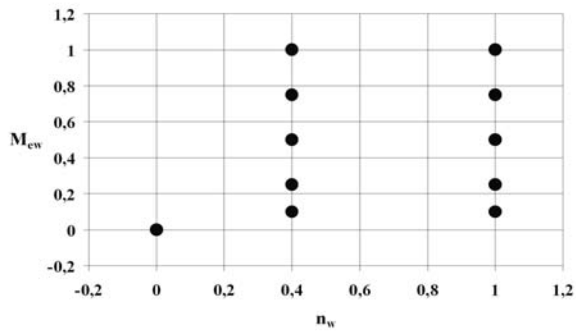

Fig. 2. Type B universal test according to ISO 8178–4 standard

In the universal test, the coordinates of measuring points are taken [3, 5, 8, 12, 13]:

- idling with minimal revolutions;
- nominal relative revolutions with loads of relative torque : 0,1; 0,25; 0,5; 0,75 and 1;
- intermediate relative revolutions with loads of relative torque : 0,1; 0,25; 0,5; 0,75 and 1; while the intermediate revolutions – n_p meets conditions:

$$\begin{aligned} & n_P = n_M, \text{ when } n_M \in (0{,}6 \div 0{,}75)\, n_N \\ \text{or } & n_P = 0{,}6\, n_N, \text{ if } n_M < 0{,}6 \\ \text{or } & n_P = 0{,}75\, n_N, \text{ if } n_M > 0{,}75 \end{aligned} \qquad (4)$$

Figures 3 and 4 show examples of static tests acc. to ISO 8178–4 standard. C1 test is designed for off road vehicles and self propelled off road machines powered by by self ignition engines. This test uses points from the universal test. E3 test is adapted for ships powered by highly loaded engines. Due to specifics of the ships main power plants operating conditions, the points of E3 test do not coincide (agree) with the universal test points, but are placed on the engine propeller characteristics.

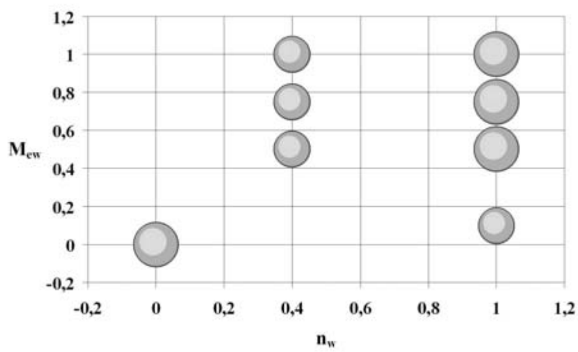

Fig. 3. C1 type test for off road vehicles and self propelled off road machines powered by self ignition engines

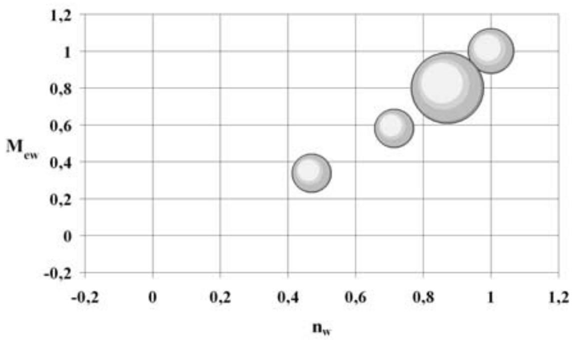

Fig. 4. E3 type test for ships powered by highly loaded engines

Dynamic tests are defined as time functions of relative revolutions and relative torque [3, 11, 14].

Figure 5 shows dynamic test – Agricultural Tractor Cycle (ATR) for testing agricultural tractor engines, developed in US EPA (Environment Protection Agency) [11, 14].

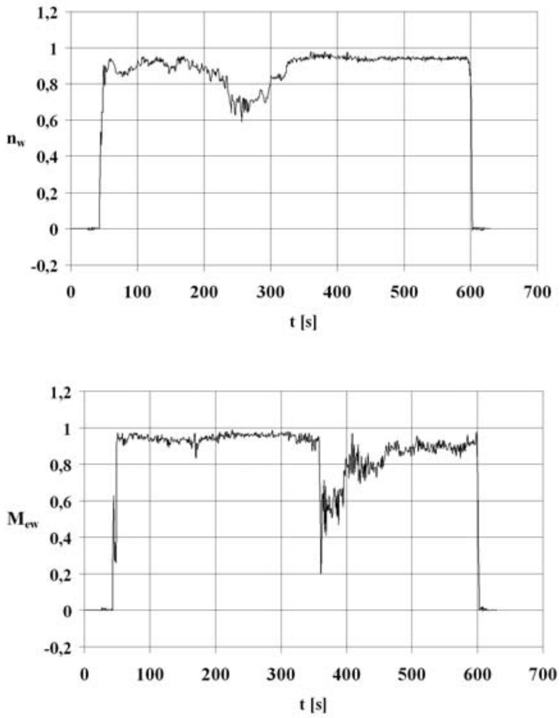

Fig. 5. Test Agricultural Tractor Cycle (ATR)

Figure 6 shows universal dynamic test – NRTC, for testing engines of none road machines.

Criterial values of assessing pollutants emission from the engines of the applications other than motorcars are specific brake pollutants emissions – "*e*", averaged in the tests [3, 5, 11 – 13]. Pollutants emission from the combustion engine is described by its mass – *m*. Specific brake pollutants emission is defined as a pollutants emission derivative of useful work – L_e [3, 5]:

$$e = \frac{dm}{dL_e} \tag{5}$$

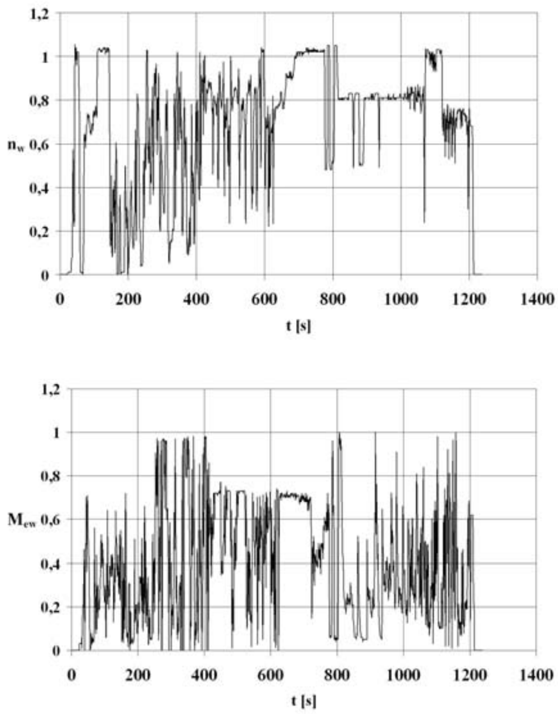

Fig. 6. NRTC test

Usually specific brake pollutants emission is obtained as an emission intensity derivative – *E* of useful power – N_e [3, 5]:

$$e = \frac{dE}{dN_e} \tag{6}$$

where: pollutant emission intensity is emission derivative of time – *t* [3, 5]:

$$E = \frac{dm}{dt} \tag{7}$$

Average specific brake pollutant emission, in the static tests, is defined using each test phase – u as [3, 5, 11]:

$$e = \frac{\sum_{i=1}^{K} E_i \cdot u_i}{\sum_{i=1}^{K} N_{ei} \cdot u_i} \tag{8}$$

where: *K* – number of test phases.

In the dynamic tests, average specific brake pollutants emission is calculated as [3, 5, 11]:

$$e = \frac{\int_0^{t_T} E \; dt}{\int_0^{t_T} N_e \; dt} \frac{1}{2} \tag{9}$$

where: t_T – test duration.

It has been accepted that the specific brake pollutants emission value is expressed in traditional measuring units, inconsistent with SI system, namely, grams per kilowatt, times an hour, written

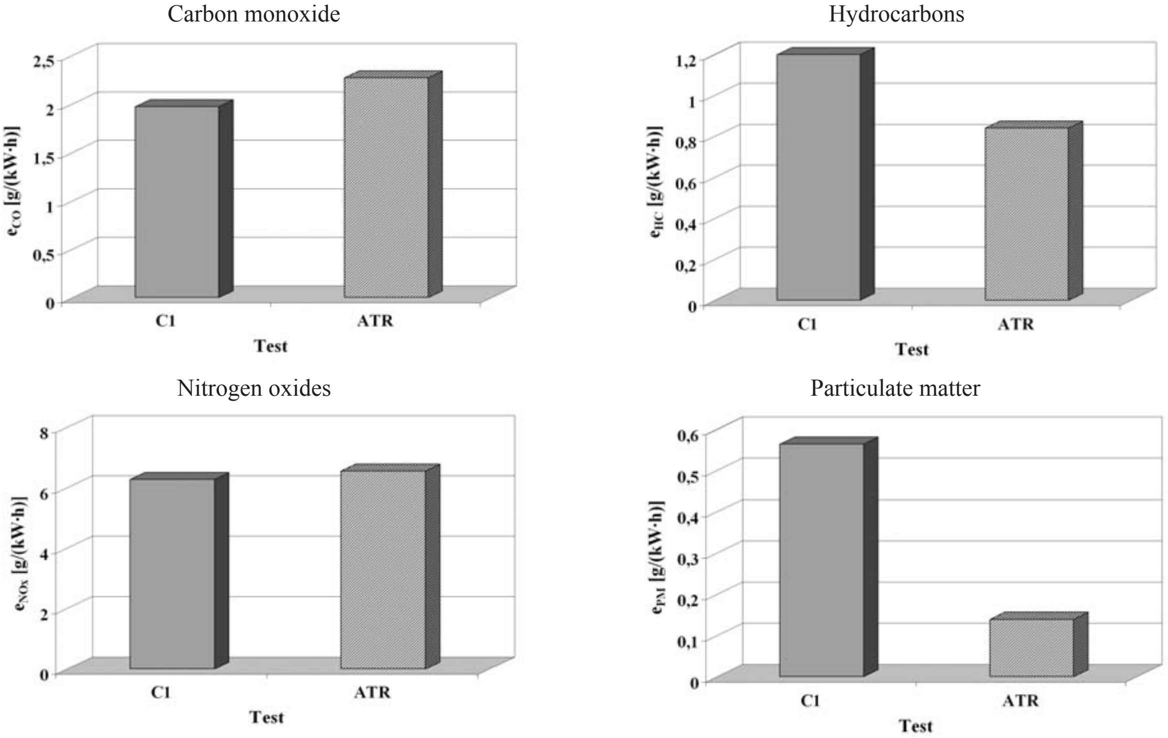

Fig. 7. Specific brake pollutants emissions in the tests: static C1 and dynamic ATR

correctly as – „g/(kW·h)", while in the legal acts and specialist literature, it usually appears in an incorrect form as – „g/kWh" [3, 5].

3. Results of pollutants emission simulation studies in the research tests

It has been accepted that pollutants emission simulation studies in research tests use mathematical model of a self ignition engine in a form of a vector function of pollutants intensity [7, 11]

$$\mathbf{c} = \mathbf{f}\left(n, M_e\right) \tag{10}$$

Vector "*c*" contains intensities of each pollutant in the exhaust gasses

$$c = \left[c_{CO}, c_{HC}, c_{NOx}, c_{PM}\right]^T \tag{11}$$

where: c_{CO} – carbon monoxide volumetric intensity in the exhaust gasses, c_{HC} – hydrocarbons volumetric intensity in the exhaust gasses, c_{NOx} – nitrogen oxides volumetric intensity in the exhaust gasses, c_{PM} – hydrocarbons mass intensity in the exhaust gasses.

Identification of the model parameters has been done as a result of empirical tests in the static conditions, according to the Box–Bekhen plan [11].

Procedures used to test agricultural tractors have been selected here as an example research tests: static C1 test acc. to ISO 8178 as well as dynamic – ATR. Values from the model (10) have been accepted for pollutants emission intensity simulation in both static and dynamic conditions.

Figure 5 shows specific brake pollutants emissions in the tests: static C1 and dynamic ATR.

Although tests C1 and ATR are envisaged for the same category of combustion engines, the results obtained differ significantly. This confirms great sensitivity of the pollutants emission to the engine static operating conditions. In the case of taking into account the differences in the pollutants emission form the engine in the dynamic conditions; even more distinct differences are to be expected [8].

4. Summary

The pollutants emissions matters from the combustion engines of various applications are becoming – like in the case of motor car applications – a priority subject, determining development of various machines and devices power plants. Existing testing methods refer usually to the type approval procedures and can – in case of engine applications, different than typical motor cars operation – be little effective to objectively evaluate the engine characteristics. This stems, first of all, from significant sensitivity of the ecological characteristics of engines to their operating conditions, with regards both static and dynamic states in their working environments. For those reasons, it is necessary – first of all to evaluate environmental impact – to test engine working conditions in the machines and devices, not limiting it to the qualifying test methods.

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