An experimental study of the fuel consumption and opacity of the exhaust gas at work of diesel generator

Krasimir Ambarev[1,*] and *Valyo* Nikolov

Technical University – Sofia, Plovdiv Branch, Department of Transport and Aircraft Equipment and Technologies, Bulgaria

Abstract. In the article are presented and analysed the obtained results of the experimental study of the fuel consumption and opacity of the exhaust gas of a diesel engine with a generator at various external electrical loads. The systems for measuring of the fuel consumption and opacity of the exhaust gas of the diesel engine driving an electric AC generator are described. The weight of fuel is measured in its operation and the computer processing the obtained results with the created software in MATLAB. The basic technical data of the diesel engine, the electric AC generator, the load system, the system for measuring of the fuel consumption, the system for measuring of the opacity of the exhaust gas, and the computer processing of the obtained results for the fuel consumption with the created software in MATLAB and the opacity of the exhaust gas are presented. Measurements of the fuel consumption and opacity of the exhaust gas have been made on the combined operation of the diesel engine with the generator of established regimes with different electrical loads. The presented experimental graphical diagrams for the fuel consumption and opacity of the exhaust gas at different electrical loads were analysed.

1 Introduction

The economical indicators of internal combustion engines (ICE) is essential for the formation of the operating costs of different machines, aggregates and equipment. By measuring the hourly fuel consumption rate of the engine and its effective power, it is possible to calculate the effective specific fuel consumption of the tested engine under different modes of operation and to determine its consumption efficiency. [1-4]

Increased environmental pollution worldwide is linked to the adoption of ever stricter rules on harmful components in exhaust gases emitted from newly produced ICEs. In the case of diesel engines, of importance is the release of carbon particles in the exhaust gases in their operation as they are proven to be carcinogenic.

2 System for measuring the fuel consumption and the opacity

2.1 Fuel consumption

There are two methods for determining the hourly fuel consumption of an internal combustion engine – weight method and volume method. In this case, the weight method is used. By means of a load cell the total power of the weight of the tank, the frame and the fuel in the tank are measured.

The used load cell has a built-in amplifier and is produced by the company "ZEMIC Transducers" Model "H3-C3-25kg-3B", S-type, C3 precision class (Fig. 1). Its operating range is 0-25 kg. For its operation, a nominal supply voltage of 10 VDC (15 VDC maximum) is required.

Fig. 1. Load Cell ZEMIC H3-C3-25kg-3B.

The output voltage for the load cell at full load (25 kg) specified in the documentation is 2,002 mV/V. The load cell is hung on a console and stand with rubber vibro-insulators (Fig. 2). Based on the difference in measured weight for a predetermined period of time, the hourly fuel consumption rate is calculated.

The power supply of the load cell is DC and is from a Laboratory Stabilized Power Supply Unit "Mastech HY3005D-2".

The transformation of the analogue signal from the load cell into digital is done by the 16-bit analogue-to-digital converter (ADC) of the company National Instruments – USB-6343.

* Corresponding author: kambarev@tu-plovdiv.bg

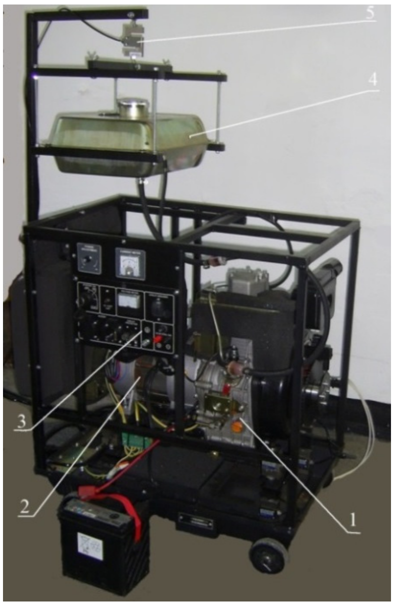

Fig. 2 General appearance of the experimental setting [3]: 1 – diesel engine; 2 – generator; 3 – control panel; 4 – fuel tank; 5 – dynamometer.

For automatic calculation of weight fuel consumption, software was created in the MATLAB. The Data Acquisition Toolbox is used. The algorithm for calculating the mass fuel consumption at a predetermined duration of operation includes measuring the voltage at the output of the load cell, calculating the voltage difference in V at the beginning – U_b and at the end – U_e of the measurement period t, s, conversion of the resulting voltage difference into weight of fuel consumed and calculation of the hourly fuel consumption rate - G_h. For this purpose the following dependencies are used:

$$G_h = 3600/t\ [1000\ (U_b - U_e)\ /precision_{Load\ Cell}],\ \text{kg/h}; \quad (1)$$

$$G_e = G_h\ /U\ I,\ \text{kg/kVAh}, \quad (2)$$

where G_e is a brake specific fuel consumption, U=230 V, I - size of current through the electrical load, A.

The measurements use one of the analogue inputs of the ADC to which the load cell outputs are differentially connected. The used analog input has a working range of ± 0,2 V. The real-time measurement data is recorded and stored in a file with a “mat” extension allowing for further use and processing.

For the accuracy of the 16-bit ADC measurement, with a voltage range of ± 0,2 V and the voltage of the load cell of the flowmeter – 12 VDC, the following is obtained:

$$precision_{A/D\ converter} = voltage\ range/2^{\ number\ of\ bits} = \quad (3)$$

$$=0{,}4\ \text{V} / 2^{16} = 0{,}006104\ \text{mV}.$$

The precision of the load cell is as follows:

$$precision_{Load\ Cell} = Output\ sensitivity \times Voltage/Capacity = \quad (4)$$

$$= 24\ \text{mV} / 25\ \text{kg} = 0{,}96\ \text{mV/kg}.$$

Then the precision of the measurement results is:

$$Precision = 0{,}006104\ \text{mV} / 0{,}96\ \text{mV/kg} = 6{,}36\ \text{g}. \quad (5)$$

Software for recording and visualization of the results obtained from the measurement, is developed in the MATLAB.

The connection between the NI 6343 and the computer is via a USB interface.

2.2 Opacity of the exhaust gas

Two methods are used for measurement of the opacity in the operation of diesel ICE – direct and indirect. The direct method involves the use of special filters, and for indirect measurement of the content of visible carbon black particles in the processed gasses, legislation was introduced absorption photometry method (Hartridge Method).

The opacimeter functioning principle rests on the fact that, depending on concentration, emission exhaust allows less light to penetrate than air would. This principle is put into practice in the opacimeter, called absorption photometry. The emission exhaust is collected in an elongated chamber with a transmitter and receiver located at the respective ends.

The transmitter consists of a LED which transmits a wave length of 567 nm. This wave length is coordinated with the absorption capacity of the emission exhaust. A photo electric cell receives the impinging light on the opposite side of the chamber (Fig. 3).

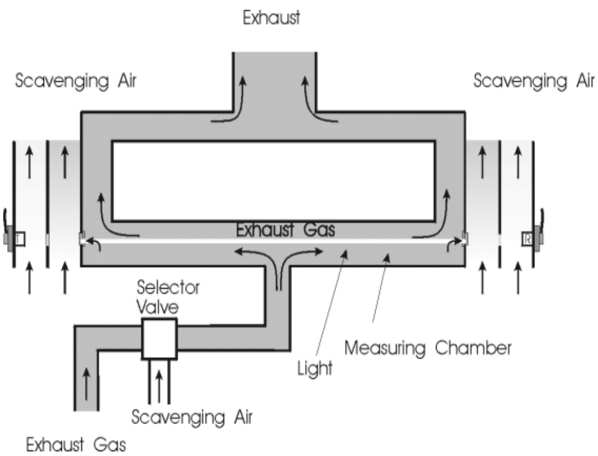

Fig. 3. The measuring principle

The indicator is the opacity in % - R_n (Hardtridge). The measurement is in percentage, where the percentage darkening of the optical environment is indicated by the absorption coefficient k or by percentage.

Fig. 4. Emission Tester MAHA MDO2-LON

For a smoke measurement is used opacimeter MAHA MDO2-LON (Fig. 4). Measurement principle is absorptionsphotometrie. Wavelength of the spotlight is 567 nm, measurement chamber length is 430 mm, External/ Internal diameter of test chamber is 28 mm/25 mm, warm-up time of the measurement chamber is approximately 180 s, on-board voltage is 12 V/24 V.

2.3 Experimental system

The fuel consumption measurement system is mounted on an experimental system [3] consisting of a diesel engine, a loading device – AC generator (Fig. 2).

The experimental system was developed on the basis of an AC generator manufactured by KIPOR (China), model "KDE 6500T", which is a single-cylinder, air cooled diesel engine – KIPOR KM 186F, having the following technical parameters and indicators: cylinder diameter D = 86 mm; stroke of the piston S = 72 mm; displacement volume V_h = 0,418 dm^3; compression ratio ε = 19; rated power N_e = 5,7 kW at speed n = 3000 min^{-1}. The KIPOR KM 186F engine mounted on the KIPOR KDE 6500T alternating current unit and for the purpose the study, it has been supplied with additional systems and sensors as described in [5].

For loading of the electric generator and the connected to it diesel engine an external electrical load is used, which consists of seven heaters connected in parallel in two electrical circuits. The adjustment of the electrical current through the electric load is achieved by two power regulators.

Fuel consumption measurements are performed at a stabilized rotation speed n = 3000 min^{-1}, as the motor drives an AC generator with a frequency of the generated voltage f = 50 Hz.

To ensure comparability of the results obtained at a different value of the electric load, it is necessary to measure the fuel consumption at:

- equal adjustment (according to the manufacturer's prescriptions) of: the gas distribution mechanism (kinetic circuit loops) and the engine fuel system (initial angle of injection and injecting pressure $p_{вп}$);
- the same thermal state (engine oil temperature in the crankcase of the engine);
- equal atmospheric conditions (capture of indicator diagrams in one day).

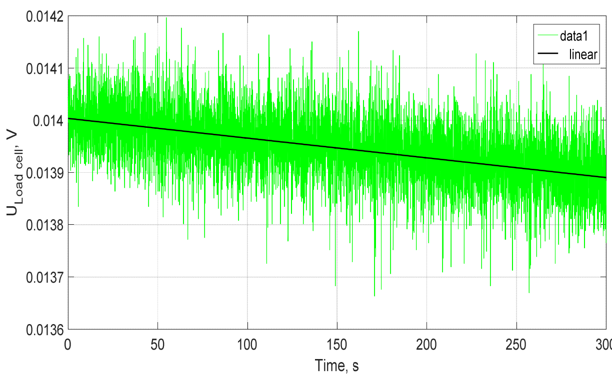

Fig. 5. Measured output voltage of load cell depending on the time.

A visualization of the results of the voltage measurements at the output of the load cell at a value 20 A of the electrical load is shown in Fig. 5. As the engine operating mode is constant for each measurement, the fuel consumption is constant and the change in weight of the fuel recorded by the load cell can be represented with straight lines. In Fig. 5 is represented also the line, which is the averaged value of the measured voltage. The voltage measurement period of the load cell output for the different currents through the electric load is such that the measurement error is up to 5%.

The program allow you to choose the time during which fuel consumption is recorded, the recording and averaging of the weight values in function of time and the calculation of the fuel consumption.

3 Experimental study

3.1 Fuel consumption

The research consists of the measurement of the fuel consumption during operation of the diesel engine at established electric current modes with I = 0, 5, 10, 15, 20 A at 3000 min^{-1}. The obtained results are graphically presented in Figures 6 and 7. The lowest hourly fuel consumption is 0,310 kg/h at idling.

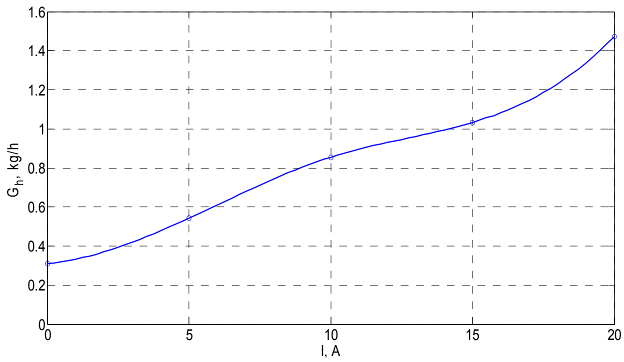

Fig. 6. Measured fuel consumption Gh, kg/h.

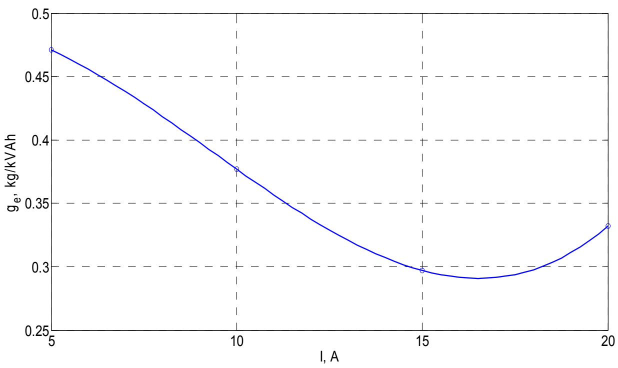

Fig. 7. Specific fuel consumption of the diesel aggregate g_e^{DA}, kg/kVAh.

The results show that the lowest value of the effective specific fuel consumption of the diesel aggregate g_e^{DA} = 0,297 kg/kVAh is obtained in the mode of current through the electric load I = 15A. The highest value of g_e^{DA} = 0,471 kg/kVAh is at I = 5 A.

3.2 Opacity of the exhaust gas

The research of the opacity consists of measuring the light absorption coefficient k and opacity in % during diesel engine operation at established electrical current modes $I = 0, 5, 10, 15, 20$ A at 3000 min^{-1}.

Figures 8 and 9 shows the average opacity values in % and the light absorption coefficient k for t = 20 s from three consecutive measurements and various values of the electric current.

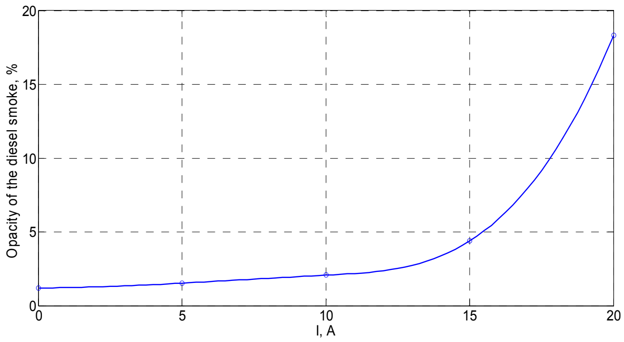

Fig. 8. Measured opacity of the exhaust gas in % for 20 s.

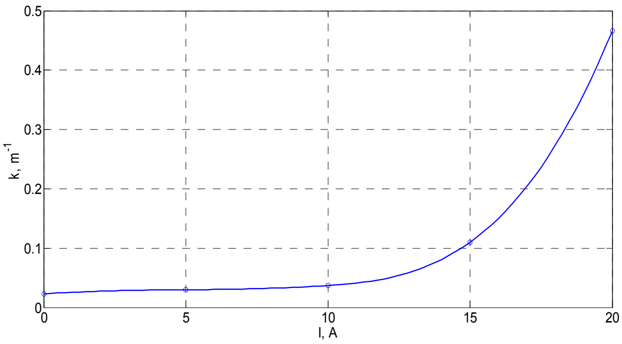

Fig. 9. Measured opacity of the exhaust gas in k, m^{-1} for 20 s.

The research was conducted in a laboratory of the Department of Transport and Aircraft Equipment and Technologies at the Technical University – Sofia, branch Plovdiv.

4 Conclusion

With the created fuel consumption measurement system, the hourly fuel consumption of the diesel engine has been measured at different electric load values, and the effect of the electric load on the economy of the diesel engine has been investigated. Also the light absorption coefficient k and the opacity in % at different values of the electric load were measured.

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