

ANALYSIS OF THE ENGINE RUN CONDITIONS FOR THE WASTE COLLECTION VEHICLE AND A CONCEPT OF FUELLING IT WITH BIOGAS AND BIOMETHANE

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Abstract

The article contains an analysis of the load of the engines that drive city vehicles for waste collection. These vehicles operate in specific conditions and perform unconventional tasks. For this reason, the engines run in conditions of part load at low speed. Access to places where biogas is produced and the specific engine load led the Authors to propose a new concept of fuelling of the engine, which is presented in the article. To drive a waste collection vehicle for the Authors propose to use a spark ignition engine fuelled with dried biogas, which was purified from sulphur compounds and biomethane. In case of lack of biomethane, natural gas could be used. The two fuels are supplied to the engine in proportions depending on the load, but because of the specificity of the analyzed vehicles tasks it is expected that a significant share of time the engine will be fuelled by biogas or biogas slightly mixed with biomethane or natural gas. A prototype engine fuelled with two fuels will be based on a diesel engine, which will be modified. Especially pistons and fuel system will be changed. The ignition system with high discharge energy will be also prepared. The proposed concept of the engine intended to be applied to the waste collection vehicle is a result of analysis of engine run conditions for this type of operation. In particular, the idea combines the running conditions of the engine and the access of the vehicle to the place where renewable fuel is produced.

Keywords: *biogas, biomethane, engine run conditions, alternative fuels, waste collection vehicle*

1. Introduction

The requirements imposed on IC engines for trucks include not only the reduction of toxic emissions, increasing their efficiency and reduction of operating costs [1]. Increasingly, the idea of balanced share of fuels, including renewable fuels, in the structure of energy sources is introduced. The truck engines can be fuelled with the type of fuel, which is suitable for the specific conditions of operation of the vehicle [2]. A good example of specific operating conditions is urban transport conditions. A vehicle for urban transport, which should ensure low operating costs, primarily must comply with restrictions on emissions and noise. Urban operating conditions, among other things due to the limited mileage of the vehicle, give the possibility to use the energy contained in fuels such as biogas formed in the municipal landfills or in sewage treatment plants. Above all this applies to the vehicles for waste collecting, which come to the landfill every day. In order to fulfil the expectations related to urban truck features the Authors who have an experience gained in

adaptation of the bus engine to fuelling with natural gas [3, 4], propose an engine that would be fuelled with cheap, renewable fuel and meets the vehicle requirements of emission and low noise. The Authors propose the spark ignition engine fuelled with mixtures of dried and purified from sulphur compounds biogas and methane obtained from biogas (biomethane) or in case of its lack with natural gas.

2. Gas engines for trucks

Manufacturers of IC engines for trucks more often propose the units, which can be fuelled with compressed natural gas (CNG), liquefied natural gas (LNG) or methane from purified biogas (biomethane). These are both proposals of spark ignition engines and increasingly implemented dual fuel systems for compressed ignition engines fuelled with natural gas or biogas and diesel fuel. Among them, there are some advanced constructions such as ILS G Cummins spark ignition engine and Scania OC9 G04 (G05) engine. Dual fuel engine for the truck fuelled with biomethane and ester of vegetable oil is tested on the road by Volvo in FH12 model of the truck. The engine meets Euro 5 emissions standards. Volvo constructors assume that the share of energy in the gas fuel, which is supplied to the engine, is 70% and the target is to increase this share to 80% [5]. It is interesting to analyse the concepts of fuelling of spark ignition engines with gas fuel.

2.1. Cummins ILS G

Cummins ILS G engine is fuelled with a stoichiometric mixture in the whole range of engine operation. A very important feature is the high share of the engine exhaust gas recirculation in the air-fuel mixture. It was intended by the designers to replace the excess air appearing in the lean combustion by exhaust gases from recirculation. Recirculated exhaust gases are cooled in a highly efficient cooling system. The engine torque characteristics resemble the course of the torque of diesel engines on torque vs. speed characteristic. The engine can be fuelled with compressed or liquefied natural gas and biogas (in practice, with gas containing 98-99% of methane). The engine complies with U.S. EPA and CARB emission standards as well as European EURO 5 and EEV standards. It is possible because the engine is equipped with a very efficient, three-way catalyst exhaust. Cummins ISL G engines are offered as 250, 260, 280, 300 or 320 hp unit [6].

2.2. Scania OC9 G04 (G05)

Scania has a long experience in the manufacture of gas engines. In 1999 the company introduced a spark ignition OSC11 03 260 hp engine. Scania's latest engine designed for gas fuelling is OC9 engine produced as 270 hp version (G04) and 305 hp version (G05). This engine, unlike ILS G Cummins engine, is fuelled with very lean mixtures, for which the excess air ratio reaches the value of $\lambda = 1.6 - 1.7$. This composition is close to the border of the flammability limit of methane-air mixture ($\lambda = 2.1$). Fuelling of the engine with such a lean mixtures is supported by a high compression ratio $\varepsilon = 12$, which also contributes to the high thermal efficiency of the engine. For Scania OC9 G04 (G05) engine high efficient oxidizing catalytic converter was selected. The engine meets Euro 5 and EEV emission standards. Like the Cummins ILS G gas engine Scania OC9 G04 (G05) engine the shape of the torque curve on the torque vs. speed characteristic is close to the course of diesel engine torque, which is crucial for the operation of the engine of the truck.

3. Analysis of the run conditions of the engine for the waste collection vehicle

On the base of the data read from some engine control units of Scania vehicles for waste collection, it is possible to analyse the engine operation in an urban conditions. Analysed vehicles were equipped with different types of diesel engines from 230 hp up to 380 hp. Obtained maps of

the engine load enable to understand the specificity of the engine run of that vehicle type (Fig. 1). For comparison in Fig. 2 shows the maps of load of the engines in long distance vehicles. The load of the engine shown in Fig. 1 and Fig. 2 should be understood as a percentage of the maximum torque developed by the engine at given engine speed.

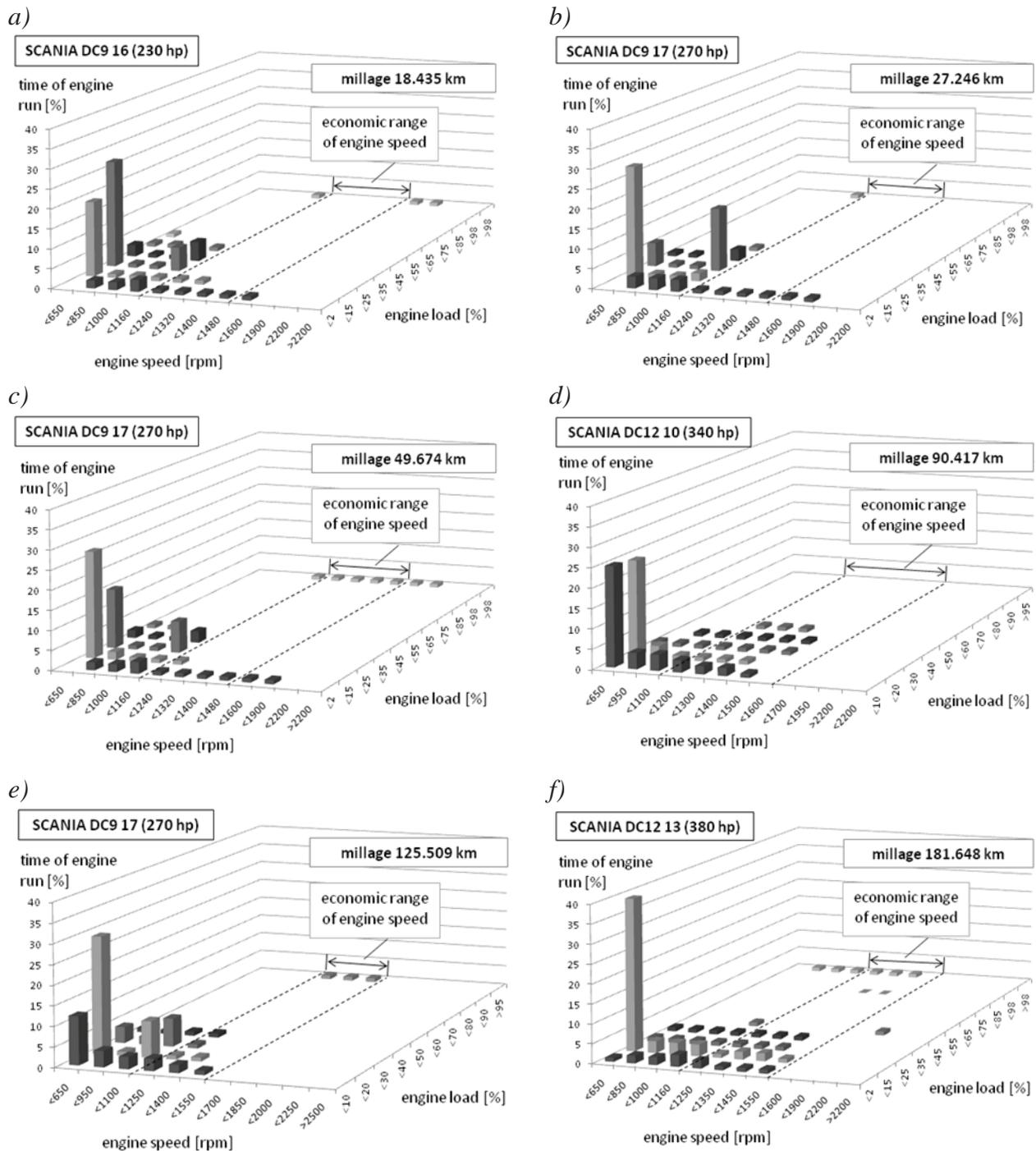


Fig. 1. Structure of the load and speed of engines for vehicles for refuse collection throughout their life

Analysis of the data leads to the following conclusions:

- a) the engines in refuse collection vehicle for a relatively short time running in the field of economic speed specified for the type of engine. The share of running time with the economic speed for analyzed engine (Fig. 1) ranged from 4% to 22%, respectively: a) 6% b) 4%, c) 9%

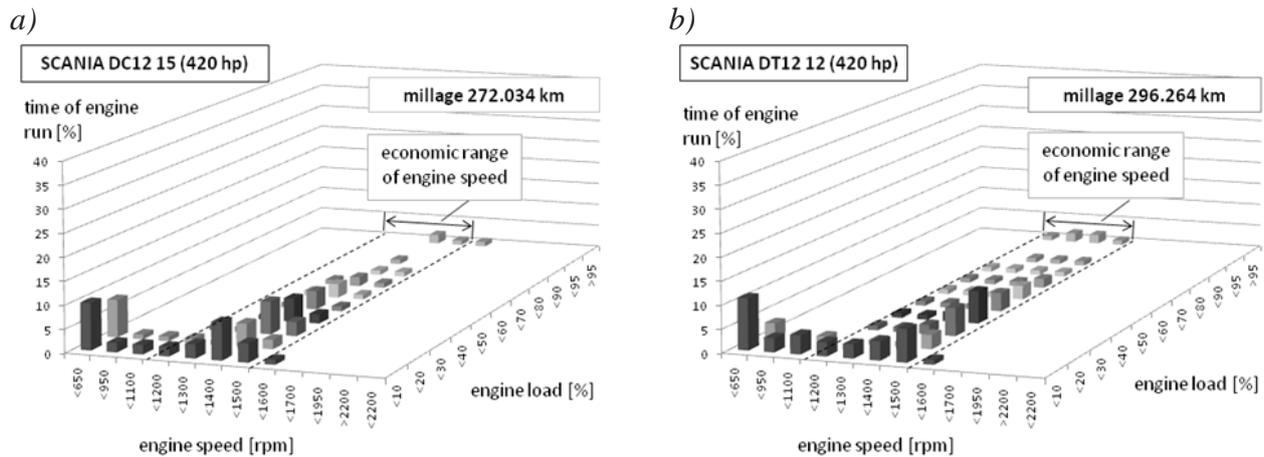


Fig. 2. Structure of the load and speed of engines for long distance vehicles throughout their life

- d) 22% e) 13 %, f) 20%. For the engines of long distance vehicle, this share was respectively a) 74% and b) 76% (Fig. 2),
- b) the share of time running at the rotation speed, which was, less than 650 rpm is very high for the engine of waste collection vehicle. It is: a) 51% b) 35% c) 45%, d) 50% e) 46% f) 42% (Fig. 1). It should be noted that the engines in this running area have been charged no more than 25%,
- c) the large share of running time with the speed which was less than 650 rpm was caused by stationary run of the engines to drive PTO at the time of loading and unloading of waste,
- d) the large engine loads, including a few percent of their running time are caused by the start of the laden vehicle,
- e) the nature of the engine load maps does not change with the millage of the vehicle.

4. The concept of fuelling of SI engine with dried and purified from sulphur compounds biogas and biomethane

The analysis of the structure of the engines load for the waste collection vehicles enable Authors to develop their own concept of fuelling of such a vehicle. For the concept for the following assumptions were made:

- the vehicle will be adapted to the possible use of renewable energy, and thus the power of the vehicle will be consistent with the idea of sustainable use of available, including renewable energy sources,
- daily mileage is about 300 km,
- the vehicle can be fuelled once a day,
- the cost of fuel should be as low as possible,
- the vehicle must meet the current standards limiting emission of toxic gases,
- the torque should not be less than 800 Nm of torque at low engine speeds (600-800 rpm) and should reach a value of approximately 1200 Nm at a speed from 1300 to 1500 rpm, giving the maximum power of 260 hp.

4.1. Gaseous fuels for fuelling of prototype waste collection vehicle

Acquisition of pure methane (biomethane) from biogas requires large amount of expensive cleaning of biogas and removal of all redundant components including carbon dioxide. Biogas, which is cleaned only with sulphur compounds and dried (containing carbon dioxide) with the content of methane in the range of 50-60 %, is several times cheaper. The concept involves the use

of two types of fuels: dried biogas cleaned only with sulphur compounds and biomethane. In case of lack of biomethane, natural gas could be used instead of it.

4.2. Fuelling of the engine according to the Author's concept

Because of adaptation of a standard diesel engine, a spark ignition engine fuelled with biogas and biomethane (or natural gas) will be prepared. It demands some construction changes such as change of piston construction (in order to decrease compression ratio and provide better conditions for combustion of homogeneous air-fuel mixtures) and application of a spark ignition system but first of all the conversion demands preparation of a new fuel system. Depending on the engine run conditions it will be fuelled only with purified from sulphur compounds and dried biogas (in terms of the run with low speed and low load) or a mixture of biogas and biomethane (under heavy load). This way of supplying the fuels requires tanks mounted on the vehicle for two types of gas. Cleaned and dried biogas containing carbon dioxide will be refuelled to six separate tanks but biomethane or natural gas used in case of lack of it to the other two tanks.

Increasing the share of gas with a high content of methane supplied to the engine will enable the especially designed system to control of fuel composition. Obtaining the required power in terms of higher engine load (which contribution is very small for total time of the engine run), will be possible by additional dose of biomethane (or natural gas) to the mixture consisting of air and biogas. Biomethane or natural gas will cause a smaller decrease of volumetric efficiency and above all has a much higher calorific value. As the analysis of engines run shows the share of engine run with maximum load is only a few percent. In these state, the engine can be fuelled only with biomethane or natural gas. Addition of natural gas or biomethane can also be used if the content of methane in the biogas will be very low. Such an low-cost engine fuelling with renewable fuels will give the possibility of obtaining the proper operation of the engine for total range of load and speed. The engine in the whole range of its run will be fuelled with the stoichiometric mixture thanks to application of sensor-controlled closed-loop control. Toxic components of exhaust gases will be reduced by the application of the three way exhaust catalytic converter specifically designed for the engines powered by methane. Carbon dioxide included in the biogas, which will be supplied to the engine to some extent, will act as EGR. For part load conditions, when the share of biogas in the biogas-air mixture will be large (approx. 1:9) due to the relatively low heating value of biogas, participation of carbon dioxide from biogas in a mixture can be about 4%. For the analyzed engines of the waste collection vehicles, the run with the engine speed, which was less than 650 rpm, was about 45% of the total run time, which means that the engine at that time can effectively burn biogas whose combustion process is relatively slow. This phenomenon also contributes to reduction of noise of the engine.

5. Conclusions

The proposed concept of the engine intended to be applied to the waste collection vehicle is a result of analysis of engine run conditions for this type of operation. In particular, the idea combines the running conditions of the engine and the access of the vehicle to the place where renewable fuel is produced. The idea gives the possibility of an efficient combustion of gas fuel in specific engine operating conditions. The proposed engine meets ecological and economical operation criteria for the engine of the vehicle, which operates in the city.

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