Impact of the injection dose of exhaust gases, on work parameters of combustion engine

W Marek¹ and K Śliwiński¹

¹Cracow University of Technology, Institute of Automobiles and Combustion Engines, al. Jana Pawła II 37, 31-864 Krakow, Poland
E-mail: wmarek@pk.edu.pl

Abstract. This article is another one from the series in which were presented research results indicated the possible areas of application of the pneumatic injection using hot combustion gases proposed by Professor Jarnuszkiewicz. This publication present the results of the control system of exhaust gas recirculation. The main aim of this research was to determine the effect of exhaust gas recirculation to the operating parameters of the internal combustion engine on the basis of laboratory measurements. All measurements were performed at a constant engine speed. These conditions correspond to the operation of the motor operating an electrical generator. The study was conducted on the four-stroke two-cylinder engine with spark ignition. The study were specifically tested on the air injection system and therefore the selection of the rotational speed was not bound, as in conventional versions of operating parameters of the electrical machine. During the measurement there were applied criterion which used power control corresponding to the requirements of load power, at minimal values of engine speed. Recirculation value determined by the following recurrent position control valve of the injection doses inflator gas for pneumatic injection system. They were studied and recorded, the impact of dose of gases recirculation to the operating and ecological engine parameters such as power, torque, specific fuel consumption, efficiency, air fuel ratio, exhaust gas temperature and nitrogen oxides and hydrocarbons.

1. Introduction
Combustion engines are used not only as driving source for various vehicles but also as industrial machine drive. These engines found application in various branches of industry e.g. building, power industry, mining, gastronomy etc. Combustion engines work successfully all over the world in various latitudes and climatic conditions, practically in every field of economy and are characterized by high reliability. In dependence on destination of the engines driven mechanism and its working conditions, the engine may be fuelled with liquid or gaseous fuel. Working in these conditions combustion engines, may be used as the main driving source, additional source (used in case of failure of the main source or in chided temporally in order to obtain on assumed power aim) or may work in cogeneration with another source e.g. electric engine or heat pump. Two or more individual processes compounded, each of them aiming at producing one useful product, is called a compound process. Association of some thermal processes aims shortening the thermodynamic changes process what leads to reduction
of power losses. Application of compound processes leads to reduction of exploitation costs and
decrease in cumulated power consumption, hence in consequence reduction of harmful (toxic) waste
products. The main part of the consumed energy is used for production of the main product. Municipal
power plants and professional ones of high power are the basic cogeneration systems. However,
present costs of power production force creation of newer alternative sources of power production.
Small systems are created based upon reciprocate engines or gas turbines – so called CHP systems.
Power of these systems oscillates from some kilowatts to a dozen or so megawatts. They permit
application of compound production in small arrangements everywhere where demand for heat and
electric power is rather low. Development of this type of systems is connected with high costs of
electric and heat energy from the existing network. Application of small compound system gives the
possibility of effective use of chemical energy of the fuel where high demand for heat and electric
energy occurs, and investing in a big thermal electric power plants is not economical or impossible out
of technical reasons. At the same time should be satisfied with the government and interest groups to
diversify sources of energy supply [1]. It seems appropriate to propose small cogeneration systems
that provide heat with the greatest possible efficiency using a variety of gaseous and liquid fuels.
Conversion efficiency is considered as a factor in the optimization process. Small four-stroke internal
combustion engines with spark ignition, is distinguished from other internal combustion engines
relatively low total efficiency of about 25%. However, they are perfect as a base for multifuel engines
[2]. If we assume that the production of electricity at maximum efficiency, will be not the primary task
of a cogeneration system, it is possible to create a new application cogeneration system with multifuel
engine, designed for optimized heat production from various fuels, with a significantly reduced (to
larger engines) emissions of toxic exhaust gases components. This publication is a next of cycle [3] [4]
[5], in which will be presented the results of studies indicating areas of possible uses, proposed by
Professor Jarnuszkiewicz concept of the pneumatic injection by means of hot exhaust gases. In this
publication will be presented, the results of research the regulation system of exhaust gases
recirculation, in an internal four-stroke combustion engine for the control of conversion a chemical
energy of fuel, to an engine work

2. Purpose and methodology of research
The main aim of the research was to determine by laboratory measurements, the impact of exhaust
gases recirculation, on working parameters of the combustion engine. All measurements on engine test
bench, was carried out at a constant engine speed. These conditions correspond to the operation of the
engine in the power generator. The study tested the specificity of the pneumatic injection system, and
therefore the selection of the rotational speed was not bound, as in typical solutions, by the operating
parameters of the electrical machine. The criterion was a task - use an exhaust gases recirculation
adjustment of power, corresponding to the energy demands of the load, with minimum values of
rotation of the crankshaft of the engine. Under these conditions, the converters of mechanical energy
into electrical energy, are used in the form of inverters. Among the control parameters of the test
engine, which had to be matched to the type of examined fuel were primarily:
- ignition timing,
- coefficient of excess air,
- recirculation value of exhaust injection dose.
These parameters have a very significant impact on the process of combustion in the cylinder, which
then results primarily, for the value of generated energy parameters. Especially in the case of exhaust
gases recirculation, these parameters directly influence on the location in time, and duration of the
combustion process. For this reason, for the examined fuel, and for each operating point of the engine
load, these control parameters were individually set. Was studied and recorded, the impact of the
examined fuel on the engine parameters such as torque and power, the specific fuel consumption, the
total efficiency, the coefficient of air excess and the exhaust gas temperature.
3. Test bed investigation of the SI engine

Research of engine, were carried out on a special test bed in the Laboratory of Combustion Engines, Cracow University of Technology, whose essential elements are as follows:

– two-cylinder, four-stroke spark ignition engine,
– engine brake generator MEZ,
– AVL fuel mass flow meter, AVL Type 4210,
– the measuring systems for determining: exhaust gas temperature, ambient pressure and humidity of the intake air by the engine, the excess air ratio.

As a research object was prepared a two-cylinder four-stroke spark-ignition engine 126 000 A1, equipped in the pneumatic-fuel injection system using the hot exhaust gases, according to the concept of Professor Jarnuszkiewicz, which in the factory configuration, was carburettor equipped.

In this configuration, the engine was characterized by the following working indicators [6]: rated power on petrol 17.7 kW/4500 l/min., the maximum torque of 42 Nm/ 3000 l/min, the minimum specific fuel consumption of 300 g/kWh. Embodiment of this supply system of such an engine, require the design and building a pneumatic injection system and the supply fuel system, which the configuration similar to a conventional, low pressure injection supply system [2] [7]. Pneumatic injection system has been designed based on the concept of Professor Jarnuszkiewicz, described in an article on his achievements, in connection with the jubilee of Conference Konmot 2016 [3]. The functional model of designed and mounted on engine, prototype system of pneumatic injection, was shown in Figure 1.

To control: the value of fuel dose and phase of its dosing, the angle of ignition timing, degree of throttle opening and the composition of the combustible mixture (excess air ratio), and also the value of dose of exhaust gases to blowing the dose of fuel, was designed and used a special engine controller. Value of recirculation was determined by next reproducible positions of the control valve, an injection dose of the blowing gases into the pneumatic injection system. As the fuel was used engine petrol. Due to the prototype nature of fuel supply, and combustion system, the power control range was limited to medium loads.

![Figure 1. The view of the functional model of the pneumatic injection using hot exhaust gases for liquid fuels.](image)

4. Results and analysis of investigations

Exhaust gas recirculation is generally used to modify the combustion process to reduce the intensity of the formation of nitrogen oxides. In the pneumatic injection system, using exhaust gases, naturally we are dealing with a kind of internal exhaust gas recirculation, by the accompanying of fuel injection, exhaust gases blown dose. Dose of the value of exhaust gas at a constant engine speed, depends mainly on the value of the free cross section of flow conduit of pneumatic fuel injection. The study used nine valve positions and the corresponding of them, value of the cross-section flow, from a completely free flow (point 0) to a position with a minimum cross-section (point 8), which provide yet
correct fuel injection. The results are shown in the following figures. The fuel delivery strategy, implemented an assumption of power adjustment corresponding to the energy demands of the load, with minimum values of rotation of the crankshaft of the engine. For this case, it was 6 kW. Regardless of the degree of recirculation, the dosage was practically on the same level – figure 2.

![Figure 2](image.png)

**Figure 2.** The fuel consumption, for the required level of engine load.

Also the load on the engine remained at a similar to required level, only at a very low value of recirculation, a load was increasing to 7 kW. This was related with favourable conditions for the process of heat evolution in cylinder – Figure 3.

![Figure 3](image.png)

**Figure 3.** The value of engine load.

Inspection results to determine the excess air ratio, have reflected the characteristic gradual depletion of combustible mixture (from rich to lean), as far as reducing the value of recirculation – Figure 4.
This is due to the gradual reduction of the dose of exhaust gas supplied to the cylinder in the intake phase of the fresh air charge.

![Figure 4. The checking value of the excess air ratio.](image1)

The observed an increase in load of engine at a very low value of recirculation, and at a fixed dose of fuel, was resulted in a positive increase in the total efficiency – figure 5.

![Figure 5. Comparison of the total efficiency.](image2)

The previously mentioned conditions was also observed in the case of a gradual increase in exhaust gas temperature. As to decrease the value of the recirculation rate and the increase in the value of air excess, the process of heat release occurred efficiently, at higher combustion temperatures - Figure 6. The variation of the concentration of nitrogen oxides is strongly associated with the value of the load. The increase in load accompanying drastically reduced recirculation, caused a significant increase in the concentration of NOx – Figure 7.
On the other hand, the variation of the concentration of hydrocarbons, is strongly associated with the value of recirculation. The decrease in the value of recirculation has a positive effect on the process of heat release and on working cycle’s repeatability. This is a typical observation, reduce the concentration of hydrocarbons, as a consequence the reduction of the degree of recirculation.
5. **Summary**

The investigation results of impact of the injection dose of exhaust gases, on working parameters of combustion engine 126 000 A1 powered by petrol, allow to formulate the following most important conclusions:

1. The study revealed a significant effect of recirculation exhaust gas injection dose, on all working parameters of an engine, fitted in the pneumatic injection system using the hot exhaust gases,

2. In the case of variability in the concentrations of hydrocarbons and nitrogen oxides in the exhaust gas, their course is typical for the impact of value of recirculation, on the working process of the internal combustion engines,

3. Disclosed is also, a significant impact of the volatility of the recirculation value, on the volatility of air excess ratio. This phenomenon is very important, because it concerns a system of direct injection into the cylinder. We found that, although the value of charge of fresh air in the cylinder also depends on the exhaust gas injection dose. This is related probably to the fact, that the present injection system of the four-stroke engine, is performed at the start of the charging phase of the cylinder.

4. Choosing a strategy for controlling the dosage of fuel, in relation to the injecting exhaust gas dose, should strive for a compromise between maximizing the values of engine energy parameters and minimization of environmental performance.

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