COMPARATIVE STUDY OF FUEL INJECTION AT COMMON RAIL SYSTEM USING DIFFERENT TYPES OF FUEL

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Abstract

In recent years the use of alternative fuels based, among other things, on vegetable oil is causing increasing concern, which is also observed in our country. Such fuels have different physical and chemical properties (especially viscosity) with reference to the standard diesel fuel. Therefore it is important to know the effect of the additive of biocomponents on fuel injection process, in particular of its parameters, which play an important role in the combustion process and formation of pollutions in exhaust gases. In the paper is presented the test results of selected parameters of the injection process executing by four different electromagnetically controlled injectors using diesel fuel without the biocomponents and mixtures of such fuel with esters of rapeseed oil (FAME). Investigations were carried out on a specially prepared test stand which enables the measurement of fuel delivery and fuel returning from the injector together with its density and temperature. Additionally, beside mentioned parameters, there were recorded high-speed courses of pressure in the high-pressure pipe behind the rail and before the injector. Next, using a system of AVL Visioscope, the fuel injection into the visualization chamber filled with fuel was recorded. It determined the basic parameters of the fuel spray. The aim of this study was to determine the impact of fuel type on the injection process executed by the injectors with different constructional parameters.

Keywords: *common rail, fuel injection, alternative fuels*

1. Introduction

The development of diesel engines with direct injection, where mainly Common Rail systems are used is generally conditioned by the increasing ecological requirements. These considerations also decide about increasing the interest in alternative fuels. The use of alternative fuels to power internal combustion engine with Common Rail fuel injection system, taking into account its flexibility in shaping the injection timing, gives chance to further reduce the negative impact of the increasing number of cars driven by combustion engine on the environment. However, the use of alternative fuels, which properties differ from the properties of conventional fuels, requires proper adjustment of the injection system to the internal combustion engine to keep correct power and ecological performances of the engine. Different values of the energy parameters of alternative fuels, as well as their viscosities and densities require a corresponding adjustment of the injection duration to deliver the equivalent energy with simultaneously keeping the required level of emissions of toxic components in exhaust gases [4, 5]. Moreover, different fuel viscosity may influence on injector working due to the electro-hydraulic character of its work, where are used precise, calibrated holes of small dimensions to control the flow of fuel to achieve correct pressure distribution acting on the needle lift, and thus on entire injection process. Changing the fuel viscosity can cause changes in the flow rate through individual calibrated holes, and the pressure distribution above and below the needle may be different than assumed, what can affect on the changes in the injection process and thus changes the fuel delivery.

This article presents a comparative study of injection process carried out by four types of electromagnetic injectors used in engines with different capacities. During investigation there was used diesel oil without biocomponents and fuel which was a blend of diesel oil and rapeseed oil esters.

2. Test stand and investigations methodology

The aim of this comparative study was to determine the effect of the used fuel for injection process carried out by electromagnetic injectors used in Common Rail systems of various types. This impact was determined by measuring such parameters as:
- delivery of injected fuel,
- overflow quantity of fuel returning from the injector,
- spray forming and spray tip penetration,
- fluctuation of pressure in injection system (in injection pipe).

The study was carried out for four different injectors controlled electromagnetically:
- five-holes – from engine Fiat 1.3 MultiJet, marked 0 445 110 083 (W083),
- five-holes – from engine Peugeot 2.0 HDI, marked 0 445 110 044 (W044),
- six-holes – from engine Mercedes 2.3 CDI, marked 0 445 110 189 (W189),
- five-holes – marked 0 445 110 083 with needle lift sensor (Wpom).

The study was executed in a variety of operating conditions of injection system, i.e. for the 1 and 3 ms injection duration, the pressures in the system amounting to 75, 100 and 125 MPa and for pump speed amounting to 1000 rpm. The study was conducted in the implementation of single phase of injection. The tests were executed for following fuels:
- diesel oil without biocomponents (ON100),
- blend of 80% diesel oil and 20% rapeseed oil methyl ester (B20).

The basic parameters of tested fuels were determined using samples taken from the injection system. It is shown in Tab.1. Lubricity of the two fuels was similar. The obtained value of scuffing load force was about 900 N for both analyzed fuels [3].

Tab. 1. The basic parameters of tested fuels [2]

Parameter name	Diesel oil without biocomponents (ON100)	Blend of 80 % diesel oil and 20 % rapeseed oil methyl ester (B20)
Density at temperature of 20°C [kg/m^3]	829.6	840.4
Dynamic viscosity at temperature of 20°C [mPas]	8.4	11.0
Gross calorific value [kJ/kg]	46008	44852
Net calorific value [kJ/kg]	43043	41956

In order to execute investigations using different types of fuels there was built a special test stand, allowing working with the use of selected fuels. Normally, in tests bench for injection system, special test oils are used. The producer does not allow using of other types of fuels, particularly fuels containing biocomponents.

The test stand was built basing on test bench EPS-815 Bosch, which was used to drive high-pressure pump. To power the rail of pressure, there was used three-piston high pressure pump, marked 0 445 010 046. It is a pump in the standard version type of CR/CP1S3/R65/10-16S with pressure regulator (valve DRV). In this pump, there is applied detachable electromagnetic plunger (using the valve EAV). In the system there was used high-pressure rail from four-cylinder engine marked with code 0 445 214 004. It is also equipped with a pressure regulator. Fuel from the tank was pumped to high-pressure pump with an electric fuel pump located in the fuel tank. The volume of the entire hydraulic system was about 12 dm^3. The test stand is shown on Fig. 1.

To measure the flow of injected fuel and the amount of overflow, flow meters with Coriolis sensors type of MicroMotion made by Emerson Co. were used. The flow meters also allow for the measurement of density and temperature of the flowing fuel. The components of the injection system were powered with battery (this way is used in vehicles) and additional power supply. It allowed keeping a constant voltage in the system to avoid the impact of its fluctuations on the injection process [6]. Operation of the fuel injection system was realized by worked out controller. Parameters of control signal, such as: the switching time, the frequency, the pulse-width modulation in hold up phase was kept constant in order to reduce their impact on the injection process [7, 8].

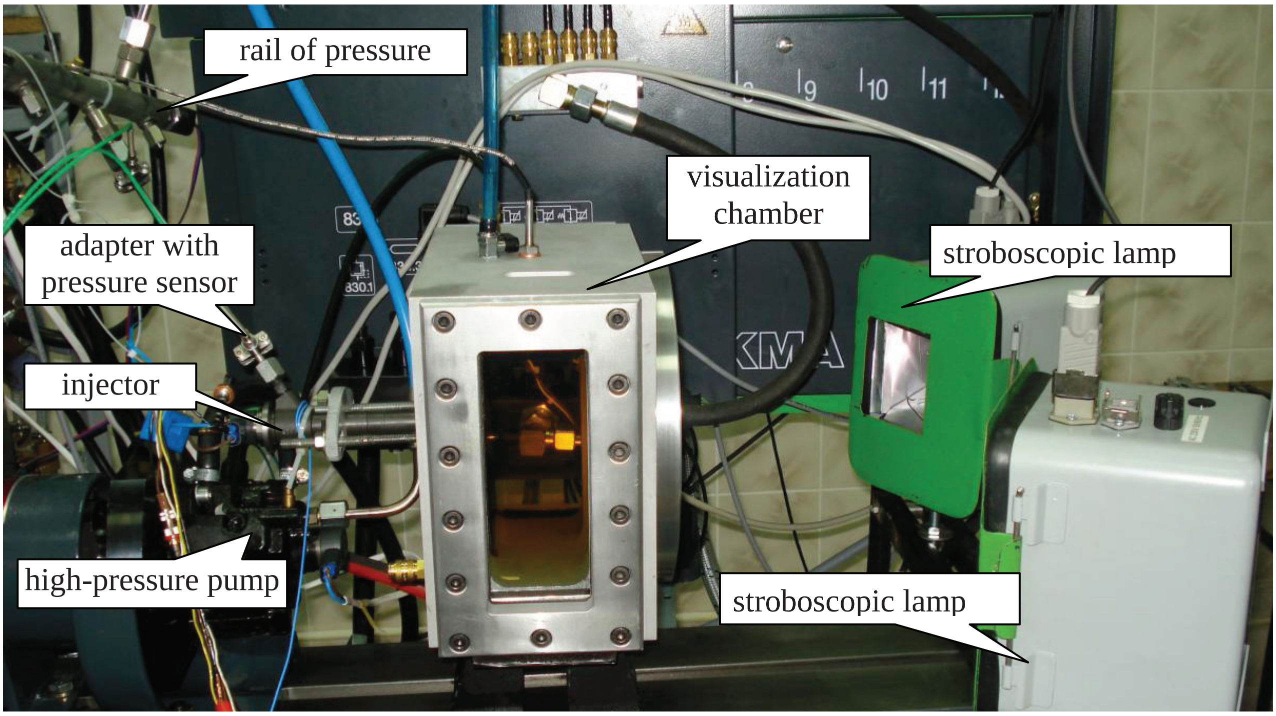

Fig. 1. Test stand with visualization chamber and stroboscopic lighting system

The test stand was equipped with a special worked out visualization chamber with stroboscopic lighting system. It allowed recording a spray forming of injected fuel. The system included two stroboscopic lights with adjustable flash.

The process of spray forming was recorded with visualization system type of AVL Visioscope with angle resolution amounting to 0.1 deg of pump shaft revolution (OWP). The injection to visualization chamber filled with tested fuel was realized.

For recording of high-speed courses, such as pressures in injection system and electric signals, there were used an acquisition data system basing on measurement card of National Instruments characterized by sampling rate amounting to 1 MHz. A broader description of test stand is presented in paper [1].

3. Analysis of test results

On Fig. 2 and 3 there are shown fuel delivery Q_w injected by tested injectors into the visualisation chamber filled with fuel. The fuel delivery is presented as a function of pressure in the system p_{rail}. A dependence is made for both tested fuels and for injection durations t_{inj} amounting to 1 and 3 ms. As we can see, the individual injectors in a different way react to the change of fuel parameters. For short injection duration (1 ms), the greatest change of fuel delivery depending on type of fuel for five-holes injectors W044 and W083 is observed. The biggest differences in fuel delivery are for injector W044 – at the injection duration of 1 ms and rail pressure amounting to p_{rail} = 125 MPa. But it should be noted that the mentioned injector is characterized by significant scatter of fuel delivery using fuel B20. The injector WPom is characterized by the smallest reaction to the different parameters of fuel B20. All five-holes injectors inject more fuel ON100 with relation to B20, irrespective of the value of the pressure in the injection system. However, six-holes injector W189, which injects more fuel than other injectors at given work conditions of injection system, injects more fuel B20 with increasing the pressure (Fig. 2).

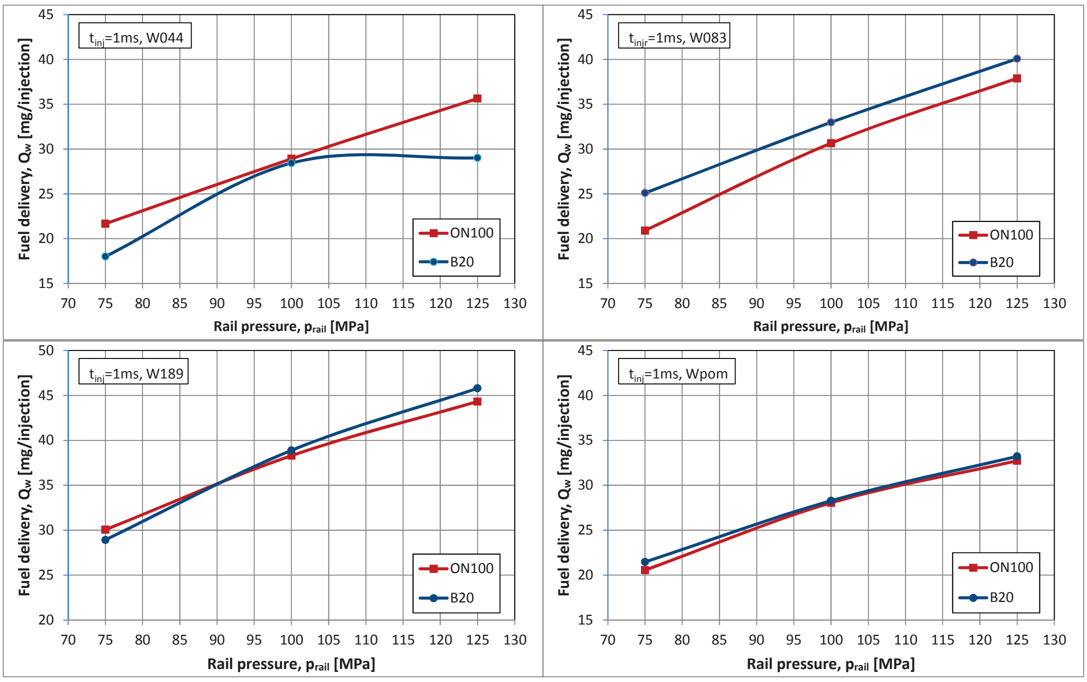

Fig. 2. Fuel delivery Qw injected by tested injectors with analyzed fuels at injection duration tinj=1 ms and various values of pressure in injection system prail (rotational speed n=1000 rpm)

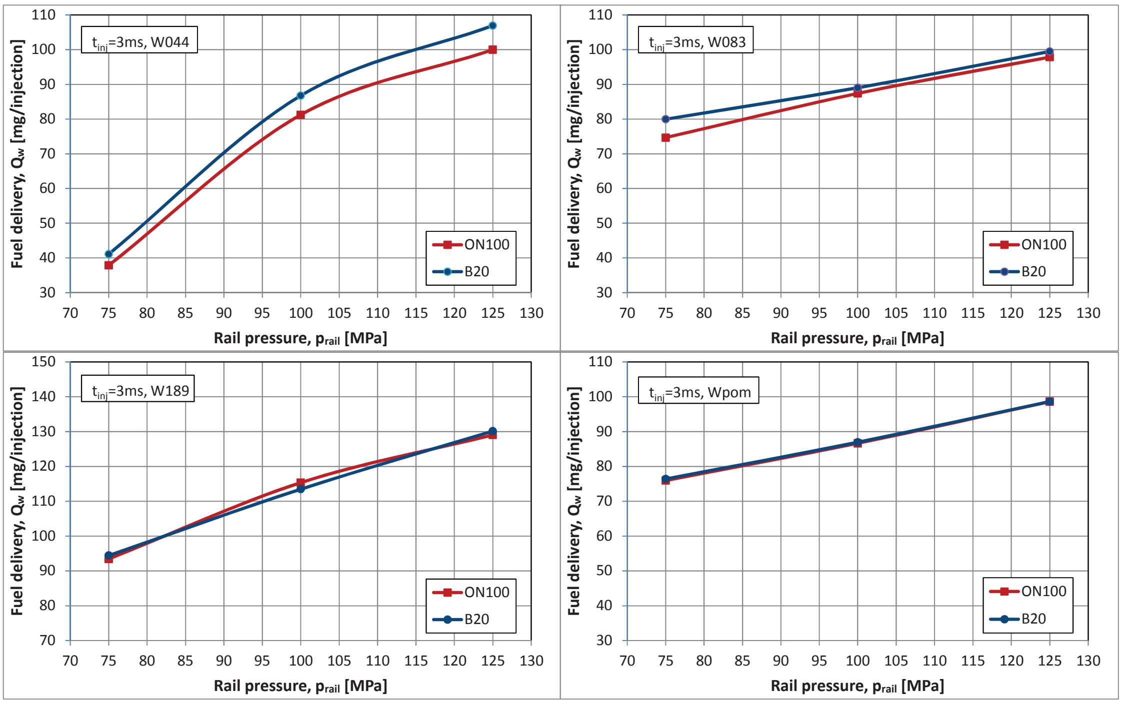

Fig. 3. Fuel delivery Qw injected by tested injectors and analyzed fuels at injection duration tinj=3 ms and various values of pressure in injection system prail (rotational speed n=1000 rpm)

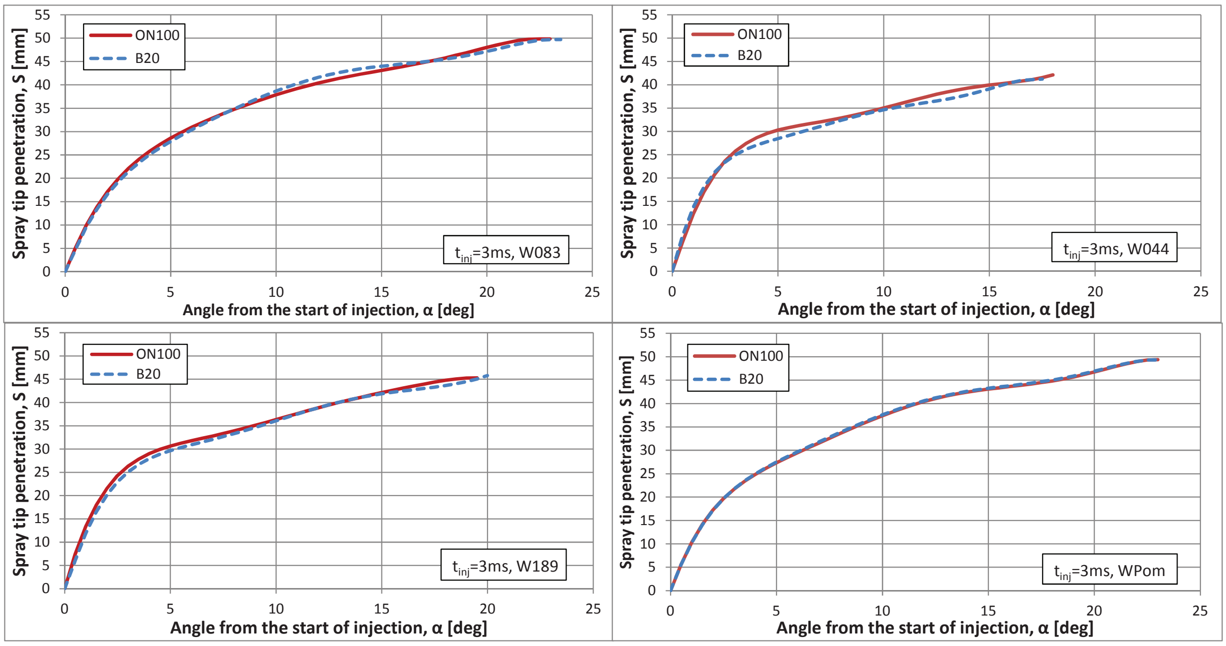

Fig. 4. *Spray tip penetration S for tested injectors and analyzed fuels depending on rotate angle α of high-pressure pump at rail pressure p_{rail}=100 MPa (rotational speed n = 1000 rpm, injection duration t_{inj} = 3 ms)*

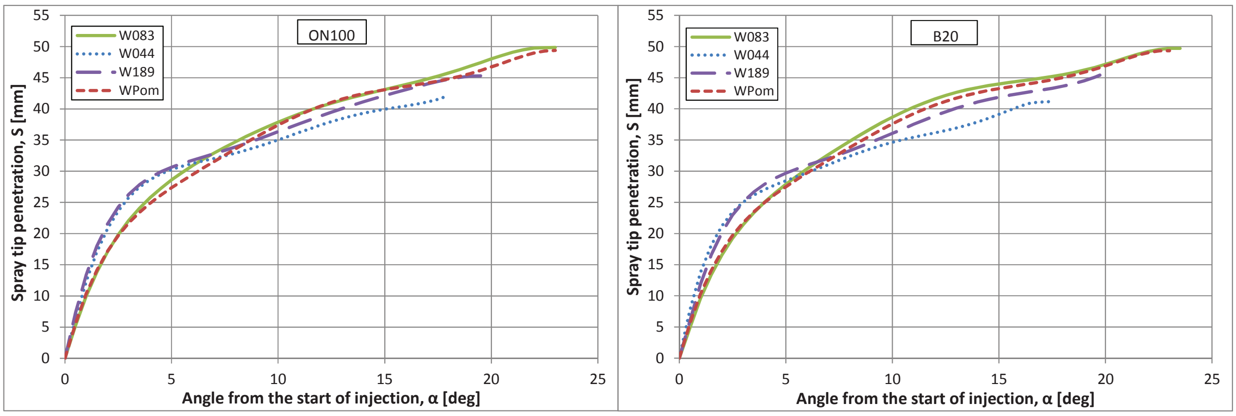

Fig. 5. *Comparison of spray tip penetration S for tested injectors depending on rotate angle α of high-pressure pump at rail pressure p_{rail}=100 MPa for both analyzed fuels (rotational speed n = 1000 rpm, injection duration t_{inj} = 3 ms)*

On Fig. 4 there are shown the courses of average spray tip penetration as a function of the angle of rotation of the high-pressure pump. As the initial angle was always assumed the start of the injection specified with maximum available accuracy amounting to 0.1 deg. However, the spray tip penetration was determined for each spray separately with resolution 0.5 deg and then average value was calculated. As we can see, the spray tip penetration for selected type of injector only insignificantly depends on kind of fuel, and the appearing differences may result from measurement error. Comparable spray tip penetration can be explained by the fact that the greater density of fuel B20 is compensated by a higher viscosity. Generally, at higher density can be expected larger mass of droplets, what can cause the longer spray tip penetration. However, at established test method – injection into the chamber filled with fuel – higher viscosity of ambient condition for fuel B20 can reduce the spray tip penetration.

Figure 5 shows the comparison of average spray tip penetration for all tested injectors as a function of angle rotation of high-pressure pump. As we can see, in this case the differences in the courses for spray tip penetration are much larger. It should be pay attention that the differences in curves are larger and the spray tip penetration in the initial phase is larger for injectors W044 and W189.

Both of these two injectors are characterized by having smaller spray tip penetration and shorter injection duration as well. Also, we can see that for range of the rotation angle amounting to 6-8 deg from the start of injection, the spray tip penetration obtained by each injector is very similar. Above this value of the angle, injector W044 differ significantly from the others forming a shorter spray tip penetration and having the shortest injection duration for both tested fuels at the same time.

4. Conclusions

Basing on study of injection process we can conclude, that depending on type of injectors, the impact of fuel type is different. The fuel delivery at the same conditions for all injectors supplied by various kind of fuel can differ from other even several percent. The results collected during investigations concerning the spray tip penetration and consisting of injection into the chamber filled with test fuel – according to established test methodology show, that average spray tip penetration for test fuels are similar. It can be caused by the, fact that the fuel with higher density at the same time has larger viscosity. So, larger mass of droplets at higher density can cause the longer spray tip penetration but larger viscosity of ambient fuel really reduces the spray tip penetration. In order to confirm this thesis, the investigations should be prepared for fuels with various values of viscosity and density – according to scheme: similar values of viscosity and various densities and vice versa.

The established test method for injection process, especially for spray tip penetration, allows conducting a comparative investigations using a various kinds of injector design and fuels with various parameters.

References

[1] Balawender, K., Lejda, K, Ustrzycki, A., *Stanowisko badawcze wtryskowych układów Common Rail zasilanych paliwami różnego typu*, Visnik Natsional'nogo transportnogo Univyersityetoo, No 23/2011, Kiev 2011.

[2] Jaworski,A, Kuszewski, H, Ustrzycki, A., *Wpływ biododatków na parametry energetyczne paliw stosowanych w spalinowych napędach środków transportu*, Visnik Natsional'nogo transportnogo Univyersityetoo, No 23/2011, Kiev 2011.

[3] Kuszewski, H, Jaworski, A, Ustrzycki, A., *Badania smarności wybranych paliw zastępczych stosowanych w transporcie samochodowym*, Visnik Natsional'nogo transportnogo Univyersityetoo, No 23/2011, Kiev 2011.

[4] Kuszewski, H., Lejda, K., Ustrzycki, A., *Determinanty dokładności dawkowania paliwa w systemie zasobnikowego układu zasilania Common Rail*, Czasopismo Techniczne - Mechanika, Wydawnictwo Politechniki Krakowskiej, Z. 8-M/2008, Z. 12 (105), s. 161-172, Kraków 2008.

[5] Kuszewski, H., Lejda, K., Ustrzycki, A., *Study of the injection process in the common rail system in aspect of fuel energy parameters*, Combustion Engines, No. 3/SC203/2011.

[6] Lejda, K., Ustrzycki, A., *Effect of supply voltage on the dosage of fuel in injection system the Common Rail type*, Journal of Polish CIMAC, Vol. 4, No. 2, 2009.

[7] Ustrzycki, A., *Wpływ parametrów sygnału sterującego wtryskiwaczem elektromagnetycznym na dawkowanie paliwa w zasobnikowym układzie wtryskowym*, Naookovo-tyehnichniy zbirnik, No 20 `2009, Visnik Natsional'nogo Transportnogo Univyersityetoo, Kiev 2010.

[8] Ustrzycki, A., Balawender, K., Ogiba, T., *Wpływ częstotliwości sygnału sterującego wtryskiwaczem na dawkowanie paliwa w układzie zasilania typu Common Rail*, Systemy i środki transportu samochodowego, Nr 1, Oficyna Wyd. Politechniki Rzeszowskiej, Rzeszów 2010.