Utilization of waste glycerin to fuelling of spark ignition engines

Z Stelmasiak and D Pietras

Corresponding author. Akademia Techniczno-Humanistyczna, Katedra Silników Spalinowych i Pojazdów, 43-309 Bielsko-Biała, ul. Willowa 2
E-mail: zstelmasiak@ath.bielsko.pl

Abstract. The paper discusses a possibilities of usage a simple alcohols to fuelling of spark ignition engines. Methanol and blends of methanol with glycerin, being a waste product from production of bio-components to fuels based on rapeseed oil, have been used in course of the investigations. The main objective of the research was to determine possibilities of utilization of glycerin to blending of engine fuels. The investigations have been performed using the Fiat 1100 MPI engine. Parameters obtained with the engine powered by pure methanol and by methanol-glycerin mixtures with 10÷30% Vol content of glycerin were compared to parameters of the engine fuelled conventionally with the E95 gasoline. The investigations have shown increase of overall efficiency of the engine run on pure methanol with 2.5÷5.0%, and run on the mixture having 10% addition of glycerin with 2.0÷7.8%. Simultaneously, fuelling of the engine with the investigated alcohols results in reduced concentration of toxic components in exhaust gases like: CO, THC and NOx, as well as the greenhouse gas CO2.

1. Introduction
Necessity of usage of biofuels in Poland results from implementation of the Polish National Indicative Targets (NCW in short), imposing gradual increase in share of renewable fuels in total volume of the engine fuels [3, 4, 17]. According to decree of the Polish Council of Ministers on the NCW of the 20.07.2013, energetic share of biofuels in the year 2018 should reach the level of 8.5%, Figure 1. This requires numerous changes in agricultural production, new technologies of production of biofuels and changed fuelling systems of the engines [1, 2, 11, 17].

Figure 1. Anticipated share of biofuels in Poland, according to the Polish National Indicative Targets [17].
Achievement of the NCW targets can be attained by fuelling of some percentage of engines with pure biofuels or blends of biofuels with gasoline and Diesel oil [5, 6, 8, 9, 18]. Maximal content of biofuels in mixtures with petroleum fuels depends on a possibility of blending and creation of stable, homogeneous mixtures (in changing ambient conditions and long time intervals), as well as on the octane number (RON) and the cetane number (LC) of the bio-additives [13, 14, 17]. For this reason, simple alcohols are added to gasoline: methanol and ethanol mainly, or esters of the alcohols: ethyl-tert-butyl ester and methyl-tert-butyl ester. In turn, in fuels to Diesel engines are used esters of unsaturated fatty acids; in Polish conditions produced from rapeseed oil. The by-product in production of these esters is glycerin in quantity of about 100 kg per 1 tonne of processed rapeseed oil [12]. Considering average yearly consumption of Diesel oil, quantity of waste glycerin can be assumed as 100 thousand tons per year. The glycerin can be used in pharmaceutical, agricultural and food industries, but consumption capacity of these industries is much lower. Due to this, surplus in production of glycerin generates a big logistic issue, and some other methods of utilization of glycerin should be explored.

Additionally, another important issue, which should be also taken into considerations, is impact of combustion of alcohols on the natural environment, inclusive of greenhouse effect. The simple alcohols can be produced from a biomass, reproducible source of energy, possible to obtain in large quantities. In nature the biomass undergoes natural decomposition, resulting in production of carbon dioxide (CO\textsubscript{2}) and methane (CH\textsubscript{4}) – the both gases are classified among so called greenhouse gases. However, due to natural processes of decomposition of the biomass, emission of CO\textsubscript{2} and CH\textsubscript{4} in such case is not counted among harmful emissions. Utilization of the biomass and transforming it into alcohols, and next combustion of such alcohols in the engines results in emission of CO\textsubscript{2} to atmosphere, which in process of photosynthesis is used to production of a new biomass. In result, usage of the biomass can be considered, in aspect of CO\textsubscript{2}, as zero-emission one, which additionally reduces natural emission of CH\textsubscript{4} from processes of biodegradation.

Carbon dioxide and water are the effects of combustion of methyl and ethyl alcohols and glycerin, while this process occurs according to the following summary reactions:

\[
CH_3OH + \frac{3}{2}O_2 \rightarrow CO_2 + 2H_2O \quad (1)
\]
\[
C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O \quad (2)
\]
\[
C,H_5(OH)_3 + \frac{7}{2}O_2 \rightarrow 3CO_2 + 4H_2O \quad (3)
\]

Mass fraction of carbon atoms in molecule of alcohol is lower, comparing to traditional fuels, and amounts respectively to 0.375 for methyl alcohol, 0.520 for ethyl alcohol, and 0.391 for glycerin, while in case of gasoline and Diesel oil this ratio amounts approximately to 0.845 ÷ 0.855. It results in lower emission of CO\textsubscript{2} comparing to combustion of gasoline.

Methanol and ethanol, due to their excellent properties, high octane number, high heat of vaporization and high combustion rate mainly, can be successfully used both to spark ignition engines (as pure fuels or additives to traditional fuels) and to Diesel engines, as additives burnt simultaneously with Diesel oil. Methanol and ethanol have been used for more than eighty years to production of fuels to aviation and sports engines. So far, the glycerin, due to its high viscosity, lower calorific value, and infinitesimal production volumes, hasn’t been used to fuelling of engines. However, big market supply of glycerin, connected with production of biofuels, has resulted in interest of many research centres, what can be evidenced by growing number of publications printed recently in scientific literature [7, 9, 10, 12].

The paper presents results of research work on effects of methanol and methanol-glycerin mixtures on parameters of automotive spark ignition engine of the Fiat 1100 MPI type. Utilization of waste glycerin should facilitate achievement of the NCW targets and increase pool of biofuels produced from domestic feedstock.
2. The engine and the engine test bend
The tests were performed on four cylinder, spark ignition engine with multipoint fuel injection of the Fiat 1100 MPI type. Technical data of the engine are presented in the Table 1.

| Type of the engine                  | Fiat 1100 MPI |
|-------------------------------------|---------------|
| Bore x stroke                       | 70 x 72 mm    |
| Swept capacity                      | 1108 cm³      |
| Compression ratio                   | 9.6           |
| Max output power/rotations          | 40 kW/5000 rpm|
| Max torque/rotations                | 88 Nm/3000 rpm|

On the engine test bend it has been installed a duplex feeding system for fuelling with gasoline and alcohol. Each from these two systems was equipped with individual fuel pump, pressure stabilization system and system to measurement of fuel consumption. The fuelling system enabled controlling of transient fuel consumption, what considerably facilitated selection of engine adjustment when the fuels were changed. Size of injected doses of the fuel was selected depending on type of the fuel, engine load and rotation speed. View of the engine test bed is shown in the Fig. 2.

The engine test bed has incorporated a system to automatic acquisition of measured data to the Excel data sheet. Recorded values were used directly from computer files in programs to processing of the measured data.

3. Results of the investigations
Before start of the tests on the engine dyno it has been performed attempts to mix technical glycerin with Diesel oil, with gasoline, and with methyl alcohol. Assessment of a possibility of the mixing was performed by observation of the mixtures after about 15 minutes from intensive mixing and after about two months of immovable storage. In the Figure 3 is presented a view of the mixtures after about two months from time of the mixing.

Glycerin in ambient conditions is not mixable both with gasoline and Diesel oil. Process of the mixing doesn’t depend on content of glycerin; shares of the glycerin within interval of 5±50% Vol were used in course of the investigations. Anyhow, after intensive mixing it can be seen a segregation of the compounds, and glycerin as a heavier compound, in result of gravitation starts to accumulate on bottom of vessel, Figure 3a. After short time, about 15±20 minutes, it has been observed complete segregation of glycerin, gasoline and Diesel oil fractions.
Glycerin is easily soluble in methanol and ethanol, regardless of percentage share of glycerin in the mixture. After gentle shaking are created homogenous mixtures, maintaining its stable form for a long time, Fig. 3b. From engine applications point of view such situation is beneficial because none operational problems could occur in case of fuelling of engines with mixtures of various alcohols.

On the base of mixing tests of glycerin with different fuels, three mixtures of alcohol and glycerin having specified below volumetric composition have been selected to further comparative tests:

- Met-Gl 10% - 90%\textsubscript{vol} methanol + 10%\textsubscript{vol} technical glycerin,
- Met-Gl 20% - 80%\textsubscript{vol} methanol + 20%\textsubscript{vol} technical glycerin,
- Met-Gl 30% - 70%\textsubscript{vol} methanol + 30%\textsubscript{vol} technical glycerin.

In course of the tests it has been used 5 different fuels: commercial gasoline as a reference fuel, marked in the diagrams as E95, technical methanol marked as Met 100%, and three methanol-glycerin mixtures marked as 10%, 20% and 30% respectively, whereas the percentages denote volumetric content of glycerin in the mixtures. Properties of implemented fuels are specified in the Table 2.

| Fuel                  | Gasoline E95 | Methanol | Met-Gl 10% | Met-Gl 20% | Met-Gl 30% |
|-----------------------|--------------|----------|------------|------------|------------|
| Density [kg/dm\textsuperscript{3}] | 0.74         | 0.796    | 0.842      | 0.889      | 0.935      |
| Calorific value [MJ/kg]| 42.5         | 19.5     | 15.9       | 16.2       | 16.6       |
| Octane number         | 95           | 115      | -          | -          | -          |
Usage of methanol to fuelling of spark ignition engine results in growth of overall efficiency of the engine, Fig. 4. Improvement of the efficiency is reported in complete range of engine loads and for all tested rotational speeds. Especially significant changes of the overall efficiency were observed for a higher engine loads. Higher combustion rate of methanol is the reason for the observed changes, what was confirmed by earlier studies [6, 13].

**Figure 4.** Comparison of overall efficiency of the engine run on gasoline E95, methanol Met 100% and gasoline-methanol mixtures with different content of glycerin: efficiencies of gasoline-methanol mixtures are marked with dashed lines.

10% additive of glycerin in methanol results in further increase of the overall efficiency seen in complete range of change of engine loads and rotational speeds, Figure 4. More big contents of glycerin, 20% and 30%, resulted in reduction of the overall efficiency, and as consequence, the overall efficiency is lower than in case of fuelling with gasoline. Especially significant changes in the overall efficiency were observed in case of 30% additive of glycerin.

Absolute change of the overall efficiency in measuring points was determined as difference in efficiency of the engine run on methanol and mixtures with 10% glycerin, and gasoline, at the same engine load and rotational speed:
\[ \Delta \eta_o = \eta_{\text{Met100\%}} - \eta_{E95} \]  
\[ \Delta \eta_o = \eta_{\text{Met-G10\%}} - \eta_{E95} \]

where:  
\( \Delta \eta_o \) – change of overall efficiency of the engine [%],  
\( \eta_{\text{Met100\%}} \) – efficiency of the engine run on pure methanol [%],  
\( \eta_{\text{Met-G10\%}} \) – efficiency of the engine run on mixture of methanol and glycerin [%],  
\( \eta_{E95} \) – efficiency of the engine run on gasoline [%].

Course of values of absolute change of the efficiency in case of the engine run on alcohols is shown in the Fig. 5. Engine run on pure methanol results in increase of the overall efficiency at rotational speed of 2000 rpm within range of 2.5÷5.0% of the absolute values, depending on engine load, comparing to the engine run on gasoline. Similar growths of the efficiency were also obtained for higher rotational speeds. Differences in the overall efficiency are growing together with increase of engine load. It is worth to be emphasized that even at minimal engine loads it has been obtained increase of the efficiency with more than 2% in spite of reduced temperature of the charge, what is connected with higher heat of vaporization of methanol and worsened conditions of combustion.

Usage of methanol mixture with 10% additive of glycerin resulted in further increase of the overall efficiency. For the engine speed of 2000 rpm, differences in the efficiency, comparing to gasoline fuelling, amount to 2.0÷7.8% of the absolute values. The highest differences are seen in range of medium engine loads and decrease at maximal loads. For higher rotational speeds it has been observed a little bit lower differences of the efficiency, comparing to gasoline fuelling. It is worth to underline that 10% additive of glycerin to methanol resulted in increase of the overall efficiency, comparing to fuelling with pure methanol, in complete range of change of engine load and rotational speed, Figure 4.

![Figure 5. Absolute change of overall efficiency of the engine run on methanol Met 100% and methanol-glycerin mixture with 10% content of glycerin: rotational speed 2000 rpm.](image.png)

Effect of alcohol fuels on overall efficiency of the engine can be also evaluated by relative change of the efficiency, described from the following formula:

\[ \delta \eta_o = \frac{\eta_{\text{Met100\%}} - \eta_{E95}}{\eta_{E95}} \times 100\% \]

Course of absolute value of change of the overall efficiency in function of engine load presented in the Figure 6 is pointing at considerable improvement of engine efficiency in area of medium and maximal engine load, especially for the mixture with 10% additive of glycerin. Relative changes of the efficiency above 10% should contribute to reduction of operational consumption of energy and improvement of ecological features of the engine (significant reduction of carbon dioxide emission). Analysis of the Fig.
6 is also pointing at considerable increase of the efficiency in area of lower engine loads. Relative changes of the efficiency in such operational conditions amount to 12÷20% in case of the methanol, and to 15÷28% in case of mixture with glycerin. Such changes can have an effect on operational fuel consumption, because percentage of engine operation at low loads is considerable, especially in conditions of heavy traffic urban driving.

![Figure 6. Relative change of overall efficiency of the engine run on methanol Met 100% and methanol-glycerin mixture with 10% content of glycerine.](image)

Quantitative changes of the efficiency caused by 10% additive of glycerin in relation to the efficiency in case of methanol are presented in the Figure 7. For the rotational speed 2000 rpm it have been obtained increase of the overall efficiency, comparing to the run on pure methanol, in range of 1.0÷4.0% of the absolute values. For higher rotational speeds, changes in the efficiency were lower and amounted to 0.5÷1.5%, what also needs to be classified as a beneficial phenomenon.

![Figure 7. Absolute change of overall efficiency of the engine run on methanol-glycerin mixture with 10% content of glycerin with respect to the engine run on pure methanol](image)

Use of alcohols to fuelling of the engine has also significant effect on emission of toxic components of exhaust gases, what can be testified by change of concentration of carbon oxide CO, summary hydrocarbons THC and nitrogen oxides NOx shown in the Figure 8. Usage of both methanol and its mixture with 10% addition of glycerin results in reduction of carbon oxide and hydrocarbons concentration in exhaust gases of the engine, observed in complete range of changes of engine load and rotational speed, Fig. 8a and 8b. Especially important is reduction of THC: in case of methanol 2÷3 fold
and in case of mixture with glycerin 1.2÷2.0 fold. However, it should be noticed that additive of up-to 10\% of glycerin results in tendency to lower emissions of CO and higher emission of THC, comparing to the engine run on pure methanol.

Combustion of methanol results in reduction of concentration of nitrogen oxides in exhaust gases, Figure 8c. Root cause of such phenomenon is lower temperature of flame and shorter combustion time of methanol-air mixtures [6]. Especially significant differences are present in area of high engine loads, when the biggest quantities of nitrogen oxides are generated. The changes described here are especially significant due to difficulties in reduction of nitrogen oxides in reduction type catalytic converters. Simultaneously it should be noted that 10\% additive of glycerin, in case of medium and maximal engine loads, leads to increase of NO\(_x\) emission, comparing to fuelling with pure methanol. This issue needs additional investigations in range of dynamics of combustion process.

**Figure 8.** Changes in concentration of toxic components of exhaust gases of the engine run on Met 100\% and methanol-glycerin mixture with 10\% content of glycerin

Bigger contents of methanol (20\% and 30\% additives) result in increased concentration of carbon oxide and summary hydrocarbons, and reduced concentrations of nitrogen oxides in exhaust gases, Fig. 9a÷9c. Direction of change of these components in exhaust gases points at worsening of combustion parameters of the charge, what is connected with worsening of conditions of atomization and vaporization of the mixture due to higher viscosity of glycerin comparing to methanol. It can be also confirmed by fact of reduction of overall efficiency of the engine, described earlier.
Higher additions of glycerin result in reduction of temperature of exhaust gases behind the exhaust valve, what also can be indicative of worsening of combustion conditions of flammable mixture at high contents of glycerin, Figure 9d.

It seems that distinctive worsening of overall efficiency of the engine and increased emission of carbon oxide and hydrocarbons restrict possibility of adding glycerin in quantities lower than 10%, calculated volumetrically. However, in light of required regulations in area of the Polish National Indicative Targets such addition should be considered as significant, what should substantially increase possibility of obtaining of national bio-components to fuels.

Figure 9. Changes in concentration of exhaust gas components, CO, THC and NO\textsubscript{x}, and temperature \( T_{sp} \) of exhaust gas in function of engine load for various content of glycerin: engine rotational speed 3000 rpm.

4. Summary

Based on performed investigations it is possible to draw the following conclusions of a general nature:

- Use of simple alcohols to fuelling of spark ignitron engines leads to improvement of operational economy and ecological properties.
- In case of the engine powered by pure methanol it has been obtained increase of overall efficiency of the engine, comparing to gasoline fuelling, in range of 2.5÷5.0% of relative values and about 12÷20% of absolute values. 10% additive of glycerin resulted in further increase of overall efficiency of the engine. Absolute increases of the efficiency in comparison to gasoline fueling
amounted to 2.0÷7.8%, while relative ones increased with 15÷28%. The highest increase of the efficiency was obtained in area of average and maximal engine loads.

- Distinct improvement of the overall efficiency observed in area of all investigated engine loads and rotational speeds can contribute to reduction of operational consumption of energy, especially in urban conditions with heavy traffic. It can lead to considerable reduction of emission of greenhouse gases (CO₂) because share of carbon atoms in molecule of glycerin and methanol is lower comparing to gasoline and amounts respectively to 0.375 for methanol and 0.391 for glycerin, while in case of average gasoline amounts to 0.855.

- Usage both of methanol and its mixture with 10% additive of glycerin results in reduction of concentration of carbon oxide and hydrocarbons in complete range of changes of engine load and rotational speed. Especially important is reduction of THC: for methanol 2÷3 fold, and for mixture with glycerin 1.2÷2.0 fold.

- Combustion of methanol results in decreased concentration of nitrogen oxides in exhaust gases. Especially big differences are seen in area of high engine loads, when the biggest quantities of nitrogen oxides are generated. Due to difficulties in reduction of nitrogen oxides in reduction type catalytic converters, the changes described here are very important. Addition of small quantities of glycerin can lead, in area of medium and high engine loads, to increased emission of NOₓ comparing to fuelling with pure methanol.

- Advantageous effects of addition of glycerin to methanol, in terms of improvement of overall efficiency of the engine and reduction of concentration of toxic components of exhaust gases, suggests that glycerin can be used in quantities below 10% to production of mixtures with methanol and ethanol, destined to spark ignition engines. This allows usage of waste glycerin from production of bioesters from rapeseed oil, what significantly can increase pool of Polish national bio-components to engine fuels.

References

[1]. Baczewski K and Kołdoński T 2005 Paliwa do silników o zapłonie iskrowym. WKiŁ, W-wa
[2]. Borychowski M 2012 Produkcja i zużycie biopaliw płynnych w Polsce i na świecie – szanse, zagrożenia, kontrowersje. Roczniki Ekonomiczne Kujawsko–Pomorskiej Szkoły Wyższej w Bydgoszczy nr 5, s. 39-59.
[3]. Biuletyn Urzędu regulacji Energetyki nr 2/2010.
[4]. Gmyrek J 2010 Bioetanol w realizacji NCW w PKN ORLEN S.A. Konferencja „FUELS ZOOM – BIOETANOL” Kraków 27-28 kwietnia 2010 r.
[5]. Kowalewicz A 2004 Emission Characteristics of Compression Ignition Engines Fuelled with RME/DF and Ethanol. Journal of KONES vol. 11/2004 No 1-2 2004.
[6]. Kowalewicz A and Pajączek Z 2004 Eco – Diesel engine with additional injection of ethanol, Archives Combustionis vol. 23/2003 No. 3-4
[7]. Lábaj J, Barta D and Lenhard R 2008 CFD simulation of glycerol combustion in diesel engine. Archives Combustionis vol. 23/2003 No. 3-4
[8]. Larisch J and Stelmasiak Z 2013 Dual Fuelling SI Engine by Mixing Alcohol and Gasoline. Combustion Engines No. 3/2013.
[9]. McNeil J, Day P and Sirovski F 2012 Glycerine from biodiesel: The perfect diesel fuel. Process Safety and Environmental Protection - ELSEVIER. Vol 90 Tom Part B No 3.
[10]. McNeil J 2011 Efficient Combustion of Glycerol and Other Low Cetane Fuels in the Diesel Engine. The Institution of Diesel and Gas Turbine Engineers publication Power Eng.
[11]. Pańczyszyn T 2010 Forum rośliń energetycznych. Produkcja biopaliw płynnych – potencjał surowcowy. Poznań 12.02.2010.
[12]. Rychlik A and Kibalczyc Ł. 2015 Zastosowanie gliceryny do zasilania tłokowych silników wysokoprężnych dużej mocy Combustion Engines No 3/2015.
[13]. Semikow J 2012 Studium dwupaliwowego zasilania silnika o zapłonie iskrowym benzyną i alkoholem. Praca doktorska ATH Bielsko-Biała.
[14]. Stelmasiak Z, Larisch J, Semikow J 2009 Some aspects of dual fuelling SI engine with gasoline and alcohol 12th EAEC European Congress Bratislava EAEC 2009 June 29-July 1
[15]. Stelmasiak Z, Semikow J 2010 The possibilities of improvement of spark ignition engine efficiency trough dual fuelling of methanol and gasoline Combustion Engines, No 3/2010, pp. 59-67
[16]. Stelmasiak Z 2011 A New Concept of Dual Fuelled SI Engines Run on Gasoline and Alcohol, *The Archives of Transport, nr 2/2011*, pp. 73-85
[17]. Stelmasiak Z 2014 Applications of alcohols to dual-fuel feeding the spark-ignition and self-ignition engines. *Polish Maritime Research nr 3/2014*, s. 86-94.
[18]. Westcott P. C 2007 Ethanol Expansion in the United States: How Will the Agricultural Sector Adjust?. *Economic Research Service*. 