Agronomy Research **13**(5), 1227–1233, 2015

Adding biobutanol to diesel fuel and impact on fuel blend parametres

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Abstract. One of the main arguments for the use of biofuels is environmental reason. Biofuels release significantly lower quantities of greenhouse gases (GHG) during the combustion opposed to conventional fossil fuels. Fatty acid methyl esters are commercially blended with diesel and bioethanol with gasoline. Biobutanol and bioethanol are using the same sources. Biobutanol can be used as a biofuel in internal combustion engines in the same manner as bioethanol. Application of biobutanol in diesel is rather marginal, but is definitely preferable in diesel engines in comparison with bioethanol. There are plenty of options to use biobutanol in diesel engines. The simplest are blends with diesel. Number of parameters can used to compare biobutanol with standard diesel. Fuel parameters are changing with the amount of butanol added. Maximum amount of butanol in diesel in order to prevent negative effects was assessed.

Key words: biofuel, cetane number, density, viscosity, cold filter plugging point.

INTRODUCTION

The issue of biofuels is still at an early stage in terms of their technological development. As ‘first generation’ biofuel is most often declared bioethanol produced from starch or sugar, biodiesel produced from vegetable oils (rapeseed, soy etc.) and animal fats without chemical modification or by a process of transesterification on fatty acid methyl esters (FAME, from rapeseed oil RME). Technologies are sophisticated and above all commercially available.

Among ‘second-generation’ biofuels are classified ethanol produced from lignocellulosic biomass part, BTL fuels produced by thermo–chemical processing of biomass into liquid synthetic fuels and also hydrogen produced from renewable energy sources.

It is an extremely complex and highly capital–intensive technology. Currently it is not possible to make a final assessment of the related processes in terms of energy and environmental balance and economics of production (De Wit & Faai, 2010; Carriquiry et al., 2011; Demirbas, 2011; Kumbar & Dostál, 2014).

Biobutanol (n–butanol, butan–1–ol) is an alternative to bioethanol, which is currently commercially produced and used as a component of motor gasoline or as E85 (Hönig et al., 2014).

Both bioethanol and biobutanol are produced from the same raw materials by ethanol fermentation of simple sugars, which is called ABE (Aceton–Butanol–Ethanol) process under the action of *Clostridium Acetobutylicum* (Campos et al., 2002; Gnansounou, 2010).

Raw materials for ABE fermentation are distinguished:

Starchy (potatoes, corn, wheat, rice).

Sugary (sugar beet molasses, whey).

Lignocellulosic (straw, wood).

The second generation biofuels produce currently both positive and negative emotions (especially ethanol but also butanol). Different materials containing saccharidic cellulose, e.g. straw or waste paper waste and energy crops are main source of raw materials for manufacturing of biofuels. Cellulose must be released from lignocellulosic matrix and its subsequent cleavage to glucose units is done either chemically or enzymatically being more costly opposed to conventional saccharidic sources (Groot et al., 1992; Melzoch et al., 2010; Sims et al., 2010; Nigam & Singh, 2011).

Biobutanol has up to 31% higher energy content and contributes to nearly 95% of the energy of biofuels oppose to bioethanol with 75%. Biobutanol as fuel is safer due to lower vapour pressure than bioethanol. Biobutanol unlike bioethanol not absorbs water and freezes at -89°C. The transport of biobutanol by pipeline systems, oppose to bioethanol, has no risk of corrosion and water separation. Biobutanol is well biodegradable and poses no threat to the environment being substance of natural origin.

Biobutanol advantage is that can be added in higher concentrations in gasoline and hypothetically can be added in higher amounts to diesel unlike bioethanol (Hazar & Aydin, 2010; Hönig et al., 2014).

Blends of hydrocarbon fuel and biobutanol are caused by the different chemical nature (Table 1). The main problem is the low reactivity (cetane number), which must be increased by special additives (Costagliola et al., 2013; Mařík et al., 2014).

Table 1. Comparison of the basic parameters of diesel, gasoline, bioethanol and biobutanol (Mužíková et al., 2010; Pospíšil et al., 2014)

Parameter	Diesel	Gasoline	Bioethanol	Biobutanol
Density at 15°C (kg m^{-3})	820–845	720–775	789	813
Cetane number	> 51	–	7	17
Octane number (research metod)	–	91 – 100	108	94
Calorific value (MJ dm^{-3})	36	31	21	27
Calorific value of mass (MJ kg^{-1})	42.6	43.6	28.9	33.1
Oxygen content (% wt.)	–	< 2.7	34.7	21.6
Boiling point (°C)	163–357	30 – 215	78	118
Melting point (°C)	–	–	-114.4	-88.6

There is a number of options to use alcohols in fuels (Pirs & Gailis, 2013). For example, E95 fuel consisting of 95% bioethanol and 5% of additives promotes lubricity and reactivity. It is also possible to use a bi–fuel system with separate tanks. It consists in injecting alcohol into the combustion chamber simultaneously with the separate injector for diesel.

Application of alcohol in diesel fuel in Europe is increasingly considered and experimentally tested (Aydogan, 2015; Zhu et al., 2014). Biobutanol in diesel engine was tested but not in terms of the properties of fuel (Lebedavas et al., 2010; Kumar et al., 2013). Research suggests, that butanol is a preferable alternative to bioethanol also in diesel engines.

Ethanol also meets the fuel standard marked E–diesel (containing about 7–15% vol. of ethanol) and O2Diesel™ (consisting of 7.7% vol. of ethanol). The simplest solution, however, seems to add directly biobutanol into diesel. Technical adjustments are not only expensive, but do not allow return back to pure diesel combustion in diesel engines. This paper is aimed at assessing the impact of diesel parameters of biobutanol according to standard EN 590. The resulting blended fuels must comply with this standard for unmodified diesel engines.

MATERIALS AND METHODS

For laboratory tests was used diesel compliant to EN 590 without fatty acid methyl esters. Tested n–butanol had p.a. quality (LachNer, Ltd).

Model blends of diesel fuel were tested by methods compliant to standard EN 590.

Distillation test by EN 3405,

Density at 15°C by EN ISO 3675.

Kinematic viscosity at 40°C by EN ISO 3104.

CFPP – Cold filter plugging point by EN 116.

Cetane number by EN ISO 5165.

Cetane index by EN ISO 4264.

Flash point by EN 22719.

Value of viscosity and flash point was assessed by three analyses. Final value was calculated as the average of the three measurements. Three measurements of separate samples for assessment of distillation curve, where difference of temperature was below 1°C. The value of second sample was taken for further processing. Other values were measured directly without any statistical processing according to standard EN 590.

RESULTS AND DISCUSSION

Determination of distillation curve is the dominant test, which is always necessary to assess the quality of the fuel. Figs 1 and 2 show, that butanol significantly affects the start of a distillation curve. Admixture of butanol in diesel fuel will cause the fine spray of fuel injection. The resulting droplets have a greater total surface area and a higher evaporation rate. In blends up to 30% vol. are also ensured heavier components contained in diesel, which vaporize gradually during the compression stroke, wherein the walls of the combustion chamber are cooled. After distilling off the butanol distillation curve continues the course of a typical diesel.

Distillation curve has a typical course for diesel fuel after distilling off the butanol (Fig. 1 and 2).

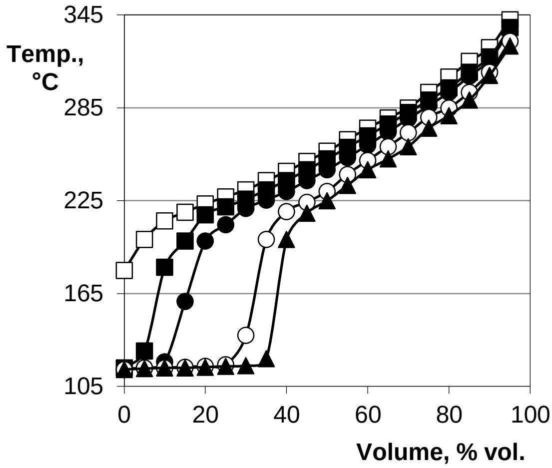

Figure 1. The distillation curve of diesel fuel containing n–butanol.
Distilled volume in % vol. is on horizontal axis, distillation temperature in ° C is on vertical axis y. Content of butanol is: □ 0% vol.; ■ 7.5%vol.; ● 15% vol.; ○ 30% vol.; ▲ 40% vol.

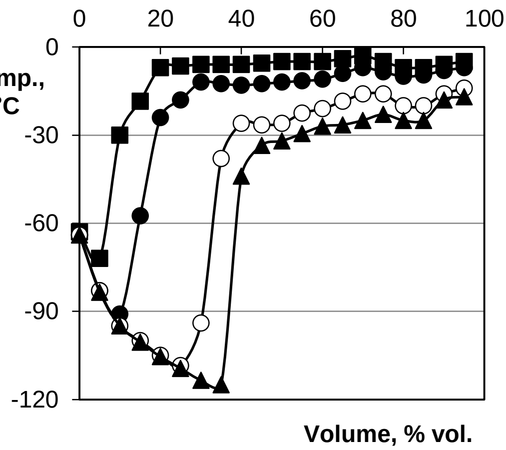

Figure 2. Changes in temperature distillation of diesel fuel containing n–butanol compared to diesel fuel base.
Distilled volume in % vol. is on horizontal axis and represents pure diesel fuel, change in distillation temperature in °C is on vertical axis y. Content of butanol is: ■ 7.5%vol.; ● 15% vol.; ○ 30% vol.; ▲ 40% vol.

Cetane number is ignition characteristic of diesel fuel and characterises the fuel's suitability for the engine. When the cetane number is too low, the fuel ignites in the cylinder too late, if at all. When the cetane number is too high, the burning starts too early. The consequences of this are power decrease, high fuel consumption and high possibility to break the engine.

Cetane number of butanol is very low compared to diesel fuel. EN ISO 5165 allows to measure up to 19.3 cetane units. Therefore, extrapolated data for 70% vol. and 80% vol. in Fig. 3 are calculated as it was not possible to verify them experimentally.

Test of cetane number is quite difficult. Therefore, the cetane index was introduced as characteristic of ignition. Cetane index was calculated from the density and points of distillation curve according to EN ISO 4264.

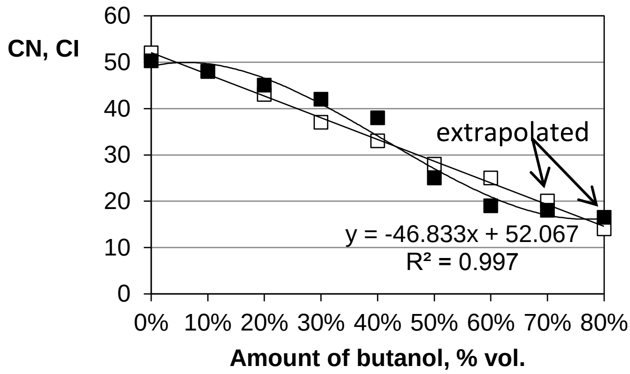

Figure 3. Effect of n–butanol in diesel fuel blend on the cetane number and cetane index: cetane number □; cetane index ■.

As seen in Fig. 4, the presence of butanol in the fuel does not decrease density significantly. Decrease of density corresponds with differences of densities of diesel and butanol. In the case of kinematic viscosity at 40°C a different course of decline has appeared. It is assumed that the more pronounced curvature of viscosity is caused by hydrocarbon chain. Viscosity also limits maximum of butanol in diesel fuel. Low viscosity may cause damages of moving parts of the fuel system.

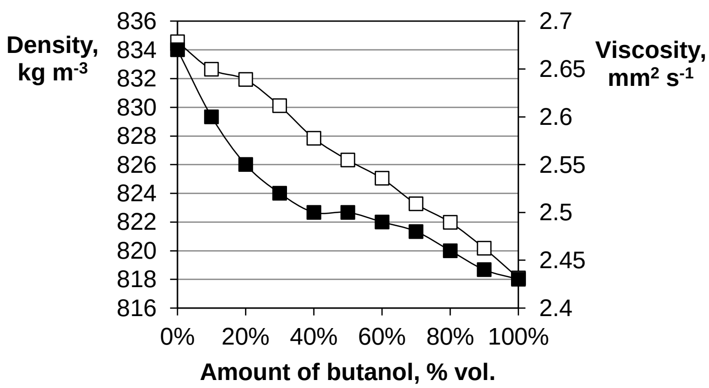

Figure 4. Effect of n–butanol in diesel fuel blend on the density at 15°C and kinematic viscosity at 40°C: density □; kinematic viscosity ■.

Fig. 5 shows the positive parameters of cold properties of diesel fuel. Even a small amount of butanol significantly reduces CFPP value. It is also important that at very low temperatures the fuel blend doesn't split to two layers, which is typical for ethanol blends.

Also the flashpoint significantly changes with increased butanol content in fuel blend. Fig. 5 shows that from about 5% of butanol in diesel fuel is already second class combustible. This value is not changing to 100% of n–butanol.

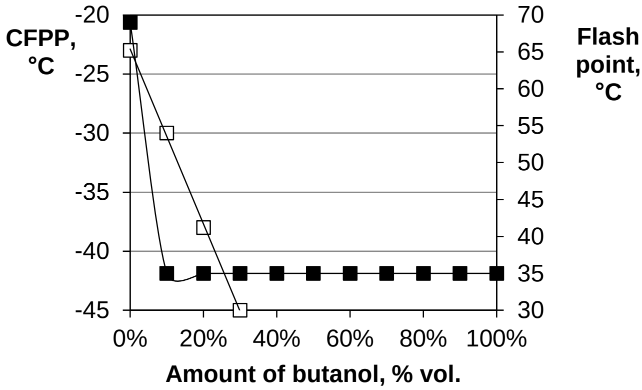

Figure 5. Effect of n–butanol in diesel fuel blend on the CFPP and flash point: CFPP □; flash point ■.

It is not recommended to add over 30% vol. of butanol to diesel fuel blend according to standard requirements (EN 590) and analysed values. Higher content of butanol would decrease power of diesel blend, increase consumption and cause irregular engine operation. Also, the density and kinematic viscosity would be below the standard, which could cause problems with the lubricity of the fuel. The wear would damage moving parts and ability to use the machine.

CONCLUSIONS

The paper evaluates impact of butanol in diesel blend for engines, which are not adjusted to non–standard fuels. The analyses suggest that blends of butanol with diesel fuel are in accordance with requirements of standard EN 590. Quantity of butanol in diesel blend is limited according to criteria observed. Absence of significant deterioration of the fuel is apparent, except for reducing the flash point of about 35°C if butanol is blend with diesel fuel. The decreased cetane number is necessary to compensate by commercial additives. Observed non–linear reduction in the density and kinematic viscosity of the reduced lubricity requires standardisation. When using n–butanol (biobutanol) as component of diesel fuel there were not observed problems with the stability of mixed fuels even at very low temperatures. These problems are characteristic for blends containing bioethanol. Adding butanol into diesel fuel has a positive effect on the low temperature characteristics and CFPP of fuel.

ACKNOWLEDGMENTS. The paper was created with the grant support project CIGA CULS Prague 20153001 – Utilization of butanol in internal combustion engines of generators.

REREFRENCES

Aydogan, H. 2015. Prediction of diesel engine performance, emissions and cylinder pressure obtained using Bioethanol-biodiesel-diesel fuel blends through an artificial neural network. *Journal of Energy in Southern Africa* **26**(2), 74–84.

Campos, E.J., Qureshi, N. & Blashek, H.P. 2002. Production of acetone Butanol ethanol from degermed corn using Clostridium beijerinckii BA 101. *Applied Biochemistry and Microbiology*, 553–556.

Carriquiry, M.A., Du, X. & Timilsina, G.R. 2011. Second generation biofuels: Economics and policies. *Energy Policy* **39**, 4222–4234.

Costagliola, M.A., De Simio, L., Iannaccone, S., Prati, M.V. 2013. Combustion efficiency and engine out emissions of a S.I. engine fueled with alcohol/gasoline blends. *Applied Energy* **111**, 1162–1171.

De Wit, M. & Faai, A. 2010. European biomass resource potential and costs. *Biomass Bioenergy* **34**, 188–202.

Demirbas, A. 2011. Competitive liquid biofuels from biomass. *Applied Energy* **88**, 17–28.

Gnansounou, E. 2010. Production and use of lignocellulosic bioethanol in Europe: Current situation and perspectives. *Bioresource Technology* **101**, 4842–4850.

Groot, W.J., Lans, R.G.J.M. & Luyben, K.Ch.A.M. 1992. Technologies for Butanol Recovery Integrated with Fermentations, *Process Biochemistry* **27**, 61–75.

Hazar, H., & Aydin, H. 2010. Performance and emission evaluation of a CI engine fueled with preheated raw rapeseed oil (RRO)-diesel blends. *Applied Energy* **87**, 786–790.

Hönig, V., Kotek, M. & Mařík, J. 2014. Use of butanol as a fuel for internal combustion engines. *Agronomy Research* **12**(2), 333–340.

Kumar, S., Cho, J.H., Park, J. & Moon, I. 2013. Advances in diesel–alcohol blends and their effects on the performance and emissions of diesel engines. *Renewable and Sustainable Energy Reviews* **22**, 46–72.

Kumbar, V. & Dostál, P. 2014. Temperature dependence density and kinematic viscosity of petrol, bioethanol and their blends. *Pakistan Journal of Agricultural Sciences* **51**(1), 175–179.

Lebedavas, S., Lebedava, G., Sendzikiene, E. & Makareviciene, V. 2010. Investigation of the Performance and Emission Characteristics of Biodiesel Fuel Containing Butanol under the Conditions of Diesel Engine Operation, *Energy & Fuels* **24**, 4503–4509.

Mařík, J., Pexa, M., Kotek, M., Hönig, V. 2014. Comparison of the effect of gasoline - ethanol E85 - butanol on the performance and emission characteristics of the engine Saab 9-5 2.3 l turbo. *Agronomy Research* **12**(2), 359–366.

Melzoch, K., Patáková, P., Lipovský, J., Fořtová, J., Rychtera, M. & Čížková, H. 2010. Exploitation of food feedstock and waste for production of biobutanol, *Czech Journal of Food Science* **27**(4), 276–283.

Mužíková, Z., Pospíšil, M. & Šebor, G. 2010. The use of bioethanol as a fuel in the form of E85 fuel. *Chemické listy* **104**(7), 678–683 (in Czech).

Nigam, P.S. & Singh, A. 2011. Production of liquid biofuels from renewable resources. *Progress in Energy and Combustion Science* **37**, 52–68.

Pirs, V. & Gailis, M. 2013. Research in use of fuel conversion adapters in automobiles running on bioethanol and gasoline mixtures, *Agronomy Research* **11**(1), 205–214.

Pospíšil, M., Šiška, J. & Šebor, G.: BioButanol as fuel in transport, Biom [online]. [cit. 2014-17-01]. Available at www: biom.cz.

Sims, R.E.H., Mabee, W., Saddler, J.N. & Taylor, M. 2010. An overview of second generation biofuel technologies. *Bioresource Technology* **101**(6), 1570–1580.

Zhu, Y.C., Chen, Z. & Liu, J.P. 2014. Emission, efficiency, and influence in a diesel n-butanol dual-injection engine. *Energy Conversion and Management* **87**, 385–391.