

TORGAS CONDENSATE COMBUSTION IN THE SI ENGINE

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Abstract

The article presents results from IC engine tests on combustion of alcohol fuel with the addition of torgas condensate. Torgas is a by-product created from the torrefaction of Sida hermaphrodita. It was obtained from torrefaction carried out at a temperature of 400°C. Torgas was condensed in a tubular cooler. The basic fuel was butanol. This fuel was chosen, because regular hydrocarbon based fuels got delaminated while blended with torgas condensate. The condensate dissolves in alcohol therefore the choice was justified. In the mixture, the volume ratio of alcohol to condensate was 4:1. The combustion was carried out in a spark-ignition, single-cylinder engine with a cubic capacity of 650 cm³. The engine was able to vary its compression ratio. The engine worked at full load at maximum open throttle. The engine body was heated to a temperature of 95°C and this temperature was maintained throughout the testing period. The engine was running at 850 rpm. The first stage of the experiment included determination of the optimal ignition angle for butanol as a reference fuel and for a mixture of butanol and torgas condensate. The optimal spark angle was estimated based on the maximum indicated work. Three compression ratios, i.e.: CR=8.8, 10 and 11.2 were used. All tests were performed for a stoichiometric air fuel ratio. The obtained in-cylinder pressure diagrams for the reference fuel and the fuel with the addition of condensate were compared with each other. The rate of pressure increase inside the cylinder was calculated. For all tests, the following exhaust components were measured: CO₂, CO and HC.

Keywords: SI engine, butanol, bio-oil, torgas condensate, exhaust emission, torrefaction

1. Introduction

As known, in the torrefaction process, organic matter decomposes into solid and gaseous products. Torrefaction is anaerobic heating the substrate to temperature of approximately 300-400°C [11]. The solid fraction mainly contains carbon [12], while the majority of gas fraction is volatile hydrocarbon compounds [1, 10]. While cooling the torgas to ambient temperature, the gaseous products condense into liquid form known as torrefaction oil or torgas condensate [15]. The physical-chemical analysis, with aid of a chromatograph coupled with a mass spectrometer, of the condensate from torrefaction of Sida hermaphrodita showed that its composition included hydrocarbon compounds such as: oleamide (C₁₈H₃₅NO), acetic acid (CH₃COOH), propionic acid (C₃H₆O₂), furfural (C₅H₄O₂) and hydroxybutyric acid (C₄H₈O₃). The torrefied substrate contains about 10% water by mass, therefore, water is also considered as a significant substance in the condensate [12]. Then the condensate was subjected to the solubility test in various fuels [5]. An attempt was made to solubilise the torgas condensate with various potential fuels [6, 14]. Solubility ratio of 4:1 was maintained, where 20% of the mixture was the condensate. The following substances were selected: petroleum fuels, i.e. diesel oil and Pb95 unleaded gasoline and selected alcohol fuels: ethanol 60%, propanol and butanol [2, 13]. Additionally, a mixture of toluene and acetone was also used as a diluent to the condensate. In each of these substances, except from petroleum-derived fuels, the condensate dissolves satisfactory well and become stable after dilution [9]. In case of

applying petroleum-derived fuels, the condensate fraction from either diesel oil or gasoline was separated immediately [6]. The Authors' results of the test are shown in Figure 1. The pictures show that the condensate has higher density than petroleum fuels because it collects at the bottom [11].

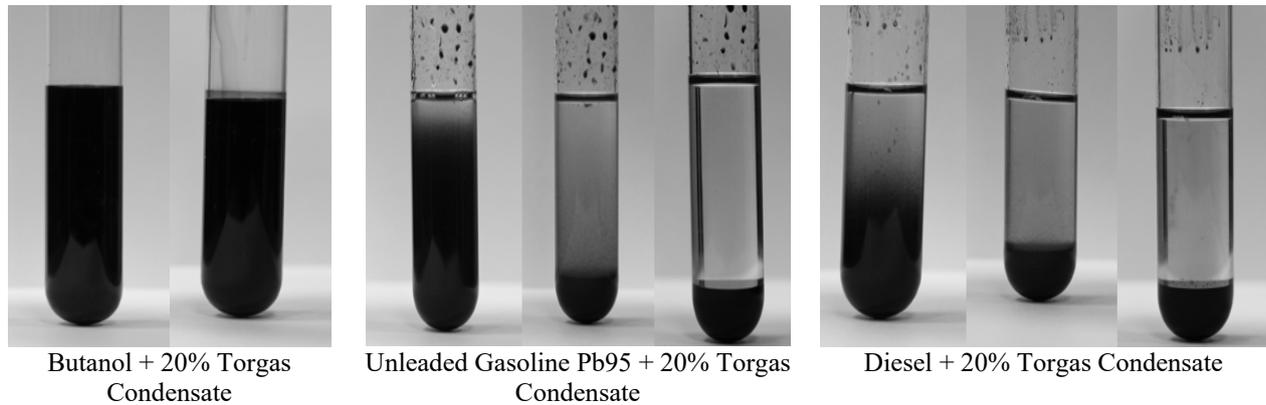


Fig. 1. Torgas condensate mixed with selected fuels

2. Description of the research stand

The main devices of the test stand are the engine and measurement equipment, as shown in Figure 2. The piezoelectric sensor from Kistler was used to measure the pressure inside the cylinder. Next, the signal was processed by the Kistler's charge amplifier. An encoder built into the camshaft was used to measure the rotation angle of both the camshaft and the crankshaft. Texas Instrument equipment and the SAWIR program were used for data acquisition. The program SAWIR was created at the Institute of Thermal Machinery by M. Gruca. It enables registration and online analysis of p-v diagrams in real time. To set the selected ignition angle, an electronic pulse generation system controlled by signals from the encoder was used. The same electronic system was also used to control the injector. In case of butanol, the injection duration was about 25 ms and for butanol with addition of the torgas condensate, it was longer and equalled to 33 ms. The injection duration was set to maintain stoichiometric composition of the mixture. The Bosch exhaust gas analyser was used to analyse the composition of flue gas.

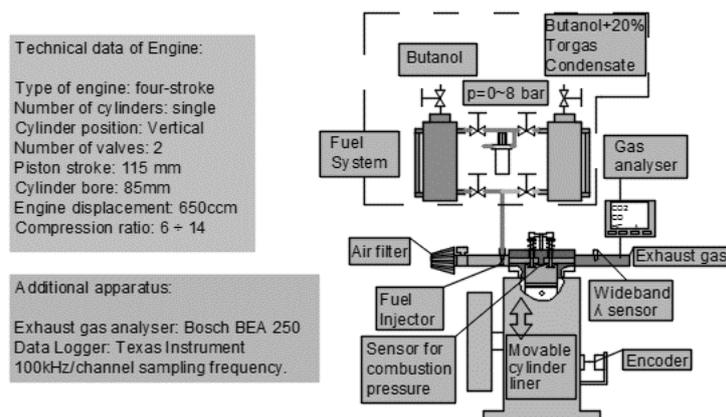


Fig. 2. Test bed with the engine with variable compression ratio

3. Results and discussion

The experiment consists of several steps. The first one includes determining the most effective ignition angle (optimization works to get Maximum Brake Torque) for a butanol and mixture of butanol with torgas condensate. The optimal ignition angle calculated from actual data for pure butanol was 10 deg BTDC. Indicated work (also known as indicated mean effective pressure - IMEP) amounted to 798 kJ/m³, which is the average from 100 combustion events. For a mixture of

butanol with the addition of torgas condensate, the maximum indicated work is 778 kJ/m^3 ; it was also averaged from 100 combustion events, at the optimal ignition angle of 15 deg BTDC. For other ignition angles, the indicated work is lower. This correlation is shown in figure 3. For further measurements, the fixed ignition angle of the mixture is set to 15 deg BTDC.

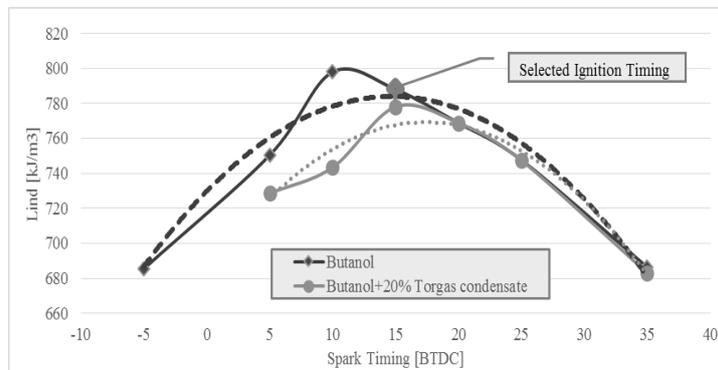


Fig. 3. Average indicated work calculated from 100 measurements vs. spark timing

Figure 4 additionally presents the motored pressure for the engine working without firing events. The engine was fuelled with either butanol or butanol with addition of the condensate, the compression ratio was $CR = 8.8$. The highest peak combustion pressure occurred while burning pure butanol. The addition of condensate caused reduction in the maximum cylinder pressure from 4.24 MPa to 3.23 MPa. This was due to large amount of water in the condensate

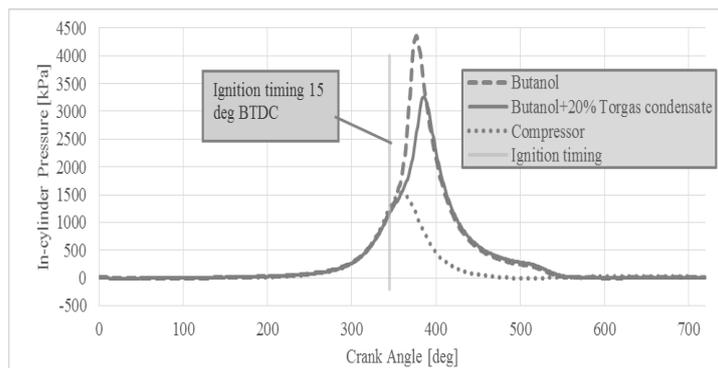


Fig. 4. In-Cylinder Pressure history at $CR=8.8$

Figure 5 shows the pressure rise vs. crankshaft rotation. On the basis of this chart, one can see that addition of condensate to butanol causes delay in combustion, however the combustion itself is less rumble.

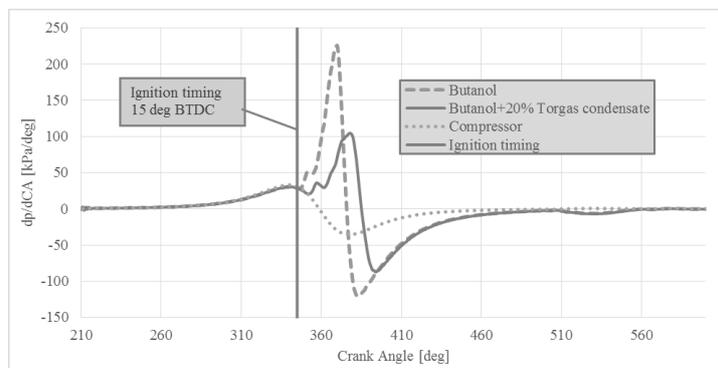


Fig. 5. Pressure rise ratio vs. crank angle

In the next part of the tests, the compression ratio was increased from 8.8 to 10. The test was performed for the same fuels: the reference fuel and the mixture of butanol with the addition of 20% torgas condensate. Increase in the compression ratio did not cause knocking. The maximum in-cylinder combustion pressure for the mixture of butanol and condensate increased from 3.23 MPa to 3.60 MPa. A further increase in the compression ratio to CR=11.2 also did not cause knocking for the reference fuel as well as for the fuel with the addition of torgas condensate. The maximum pressure for butanol is 5.07 MPa, and for butanol with condensate is 3.78 MPa. During the tests, toxic emissions were measured using the exhaust gas analyser [3, 4, 7, 8]. Additionally, CO₂ was also measured as depicted in Figure 6a. In combustion of butanol with torgas condensate, the CO₂ emission decreased. This was caused by incomplete combustion, as a result CO emission increased, as shown in Figure 6b. In the combustion of butanol with condensate, CO₂ emissions ranged from 13.11% vol to 13.6% vol. The CO emission is from 1.68% vol to 2.3% vol. It is higher than for the combustion of pure butanol. The emission of hydrocarbons for various ignition angles is presented in Figure 7.

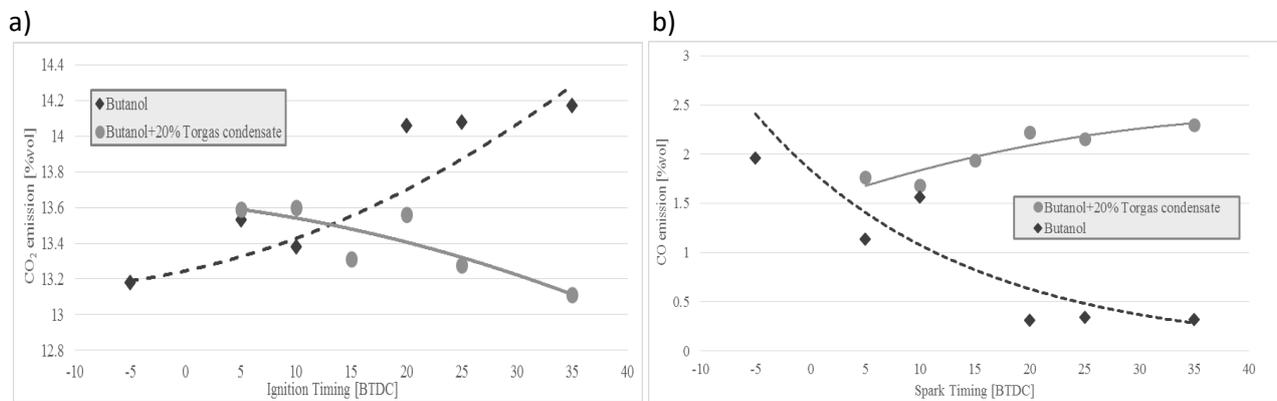


Fig. 6. CO₂ emission vs. ignition timing (a), CO emission vs. ignition timing (b)

In case of combustion of pure butanol, the spark timing was sensitive parameter causing high changes in HC emission. At optimal ignition angle, the HC emission for butanol with torgas condensate did change remarkably with change in spark timing.

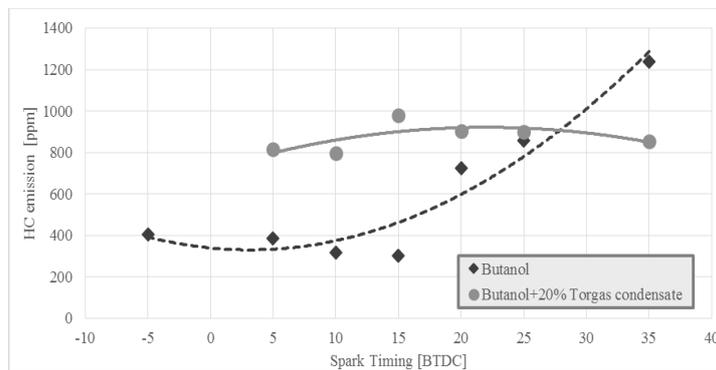


Fig. 7. HC emission vs. variable ignition timing

Plot in figure 8a shows the CO₂ emission for three compression ratios. For each case, CO₂ emission is higher for butanol with the addition of torgas condensate than for pure butanol. Conversely, in the case of CO emissions (Figure 8b), slightly higher proportions of CO in the exhaust gas is obtained for pure butanol than for butanol with the addition of torgas condensate.

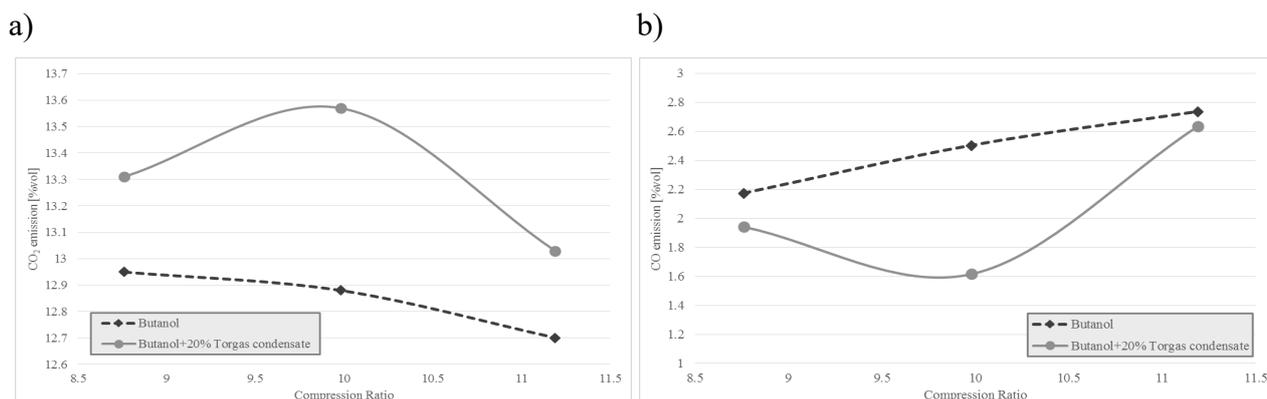


Fig. 8. CO₂ emission vs. compression ratio (a), CO emission vs. compression ratio (b)

In case of hydrocarbon emission, the combustion of butanol with addition of the condensate emitted even 5 times more HC to the ambient air (for the compression ratio 10) than for pure butanol as depicted in figure 9.

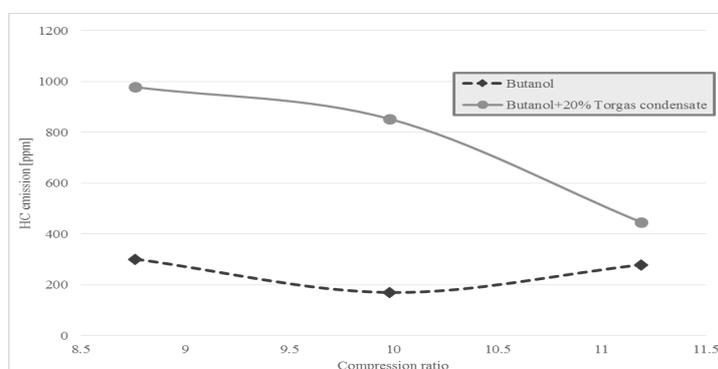


Fig. 9. HC emission vs. variable compression ratio

4. Conclusions

Torgas condensate does not mix with petroleum fuels; it splits immediately, so it cannot be used as an additive to such fuels. The condensate satisfactorily dissolves in alcohol fuels and can be added to such a fuel, e.g. E100. Combustion of torgas condensate in a spark-ignition internal combustion engine is one of the methods of using the produced substance during torrefaction.

Adding 20% condensate to butanol by volume causes lowering the pressure in the cylinder and makes the combustion process slower. This is related to the large amount of water contained in the condensate. The optimal ignition angle for the mixture is more advanced of 5 CA deg with respect to the butanol - reference fuel. An increase in the compression ratio to 11.2 did not cause knocking.

Emission of CO₂ to the atmosphere for a mixture of butanol and torgas condensate at optimal ignition angle is similar to pure butanol. The CO content in the exhaust gas, regardless of the ignition angle for the butanol mixture with the condensate, is always higher compared to pure butanol. HC emission at the optimal ignition timing is higher for butanol-blended condensate than for pure butanol.

4. Acknowledgments

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References

- [1] Ambrosewicz-Walacik, M., Walacik, M., *Waste tires as a source of valuable chemicals*, Journal of KONES Powertrain and Transport, Vol. 23, pp. 25-29, 2016.
- [2] Basu, D., Phulli, S., Kotebavi, V., *Performance analysis of a VCR SI engine using petrol alcohol blends*, *Power and Energy Systems: Towards Sustainable Energy*, Conference paper, 2014.
- [3] Chwist, M., Szwaja, S., Grab-Rogaliński, K., Pyrc, M., *Bio-oil blended butanol as a fuel to the spark ignition internal combustion reciprocating engine*, *Combustion Engines*, 169(2), pp. 93-96, 2017. DOI: 10.19206/CE-2017-216, 2017.
- [4] Elfasakhany, A., *Performance and emissions of spark-ignition engine using ethanol-methanol-gasoline, n-butanol-iso-butanol-gasoline and iso-butanol-ethanol-gasoline blends: A comparative study*, *Engineering Science and Technology, an International Journal*, Vol. 19, pp. 2053-2059, 2016.
- [5] Grab-Rogaliński, K., Szwaja, S., *The combustion properties analysis of various liquid fuels based on crude oil and renewables*, *IOP Conference Series: Materials Science and Engineering* 148 (1), 012066 doi:10.1088/1757-899X/148/1/012066.
- [6] Grab-Rogaliński, K., Szwaja, S., *The Possibility of Use a waste Product of Biofuels Production-Glycerol as a fuel to the Compression Ignition Engine*, *Journal of KONES Powertrain and Transport*, Vol. 23, pp. 157-164, 2016.
- [7] Jankowski, A., Kowalski, M., *Creating Mechanisms of Toxic Substances Emission of Combustion Engines*, *Journal of KONBiN*, 4(36), DOI 10.1515/jok-2015-0054, pp. 33-42, Warsaw 2015.
- [8] Jankowski, A., Kowalski, M., *Influence of the Quality of Fuel Atomization on the Emission of Exhaust Gases Toxic Components of Combustion Engines*, *Journal of KONBiN* 4(36), DOI 10.1515/jok-2015-0055, pp. 43-50, Warsaw 2015.
- [9] Krutof, A., Hawboldt, K., *Blends of pyrolysis oil, petroleum, and other bio-based fuels: A review*, *Renewable and Sustainable Energy Reviews*, Vol. 59, pp. 406-419, 2016.
- [10] Kumar, K. V., Puli, R. K., *Effects of Waste Plastic Oil Blends on a Multi Cylinder Spark Ignition Engine*, *MATEC Web of Conferences, ICMAA*, Volume 108, pp. 1-4, 2017.
- [11] Rostek, E., *Biofuels of first and second generation*, *Journal of KONES Powertrain and Transport*, Vol. 23, pp. 413-420, 2016.
- [12] Tumuluru, J. S., Sokhansanj, S., Hess, J. R., Wright, C.T., Boardman, R.D., *A review on biomass torrefaction process and product properties for energy applications*, *Industrial Biotechnology*, Vol. 7 No. 5, pp. 384-401, 2011.
- [13] Vihar, R., Bašković, U. Z., Seljak, T., Katrašnik, T., *Combustion and emission formation phenomena of tire pyrolysis oil in a common rail Diesel engine*, *Energy Conversion and Management*, Volume 149, pp. 706-721, 2017.
- [14] Żółtowski, A., *Tyre pyrolysis oil as an engine fuel*, *Journal of KONES Powertrain and Transport*, Vol. 21, pp. 295-302, 2014.
- [15] Zurek, J., Kowalski, M., Jankowski, A., *Modelling of Combustion Process of Liquid Fuels under Turbulent Conditions*, *Journal of KONES*, Vol. 22, Issue 4, DOI: 10.5604/12314005.1168562, pp. 355-364, Warsaw 2015.

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