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Bio-oil blended butanol as a fuel to the spark ignition internal combustion reciprocating engine

The article presents results on combustion of the bio-oil blended butanol in the spark ignition engine. Bio-oil is a mixture of hydrocarbons condensing to liquified phase while cooling it down to ambient temperature. In general, the liquid called bio-oil is a byproduct of the pyrolysis process of organic matter. Results from analysis presented in the manuscript include the following: in-cylinder pressure traces and toxic exhaust emissions. Finally, comparison of these results with results from combustion of n-butanol reference fuel were provided. Obtained results indicate satisfactory, eco-friendly possibility for utilization of bio-oil in the internal combustion engine

Key words: *bio-oil, pyrolysis, butanol, IC engine*

1. Introduction

Pyrolytic bio-oil is a mixture of hydrocarbons that arises as a result of the thermal processing of organic matter in the pyrolysis. During pyrolysis the substrate is heated to a temperature in the range 300-1000^{o}C the absence of oxygen, the process is endothermic. Depending on the temperature, pressure, heating rate and the particle size of the parts, is obtained the various proportions of products in the form of: gases, liquids, solids. For low temperatures 300-450^{o}C and longtime of the material in the reactor 600-6000s the largest share of the pyrolysis products are solids. In the medium temperature range (from 450-700^{o}C) and a range time of from 1 to 5 seconds, most liquid products formed, and the maximum temperature (700-1000^{o}C) and the shortest time less than 1 second are gaseous products. For the production of bio-oil by pyrolysis is used the middle range temperature as the most efficient. In other article, research into the production of bio-oil from pyrolysis of waste was carried out using: the worn out tires, plastics waste, fruit, fish waste, etc. [6, 8].

According to the authors in the world it is 29 million tons of tires recyclable, and only 6.6 million tonnes will be processed. The remaining waste is not processed due to the lack of cost-effective method. In the study, they carried out the pyrolysis of used tires, cut into pieces measuring about 10x10 cm, at a temperature of 450-500^{o}C over a period of 8 hours. As a result of thermal decomposition of tires are: oil pyrolysis, pyrolysis gas, charred residue and steel wire. The pyrolysis bio-oil was distilled at three temperatures of 160°C, 204^{o}C and 350^{o}C. The most received medium fraction. Then, they compared the characteristics of the bio-oil and diesel parameters. The results were as follows: characterized pyrolysis oil is more viscous, which amounted to 2.12 mm^2/s, than diesel oil (3.54 mm^2/s). The distillation fractions were characterized by a lower viscosity, which ranged from 1.18 mm^2/s fraction light to 1.36 mm^2/s for fraction hard. The density of the pyrolysis oil was higher than 860 kg/m^3. Diesel oil fulfill the requirements of DIN EN 590 in the density range of the diesel fuel, which should not exceed 860 kg/m^3. Fractions of the distillation are a density of 825 kg/m^3 to 885 kg/m^3. Only light fraction fulfilled the requirement of the standard. Another parameter which is significant in terms of suitability of the fuel is the acid number. For commercial diesel oil amounted to less than 0.08 mg KOH/g, and the pyrolysis oil 4.33 mg KOH/g, a distillation fraction of bio-oil for this parameter was in the range 2.45-3.77 mg KOH/g. The standard allows the acid number of no greater than 0.5 mg KOH/g of oil, therefore, only diesel to meet this criterion. The next parameter comparable was the flash point for oil amounted to less than 55°C and fulfilled the requirements of the standard. Pyrolytic bio-oil also met this criterion and the ignition temperature was 53°C, and the fractions lit up at 5.5°C light fractions to 40°C heavy fractions. Based on the study, the authors found that the separated fractions of pyrolysis oil can not constitute an independent fuel, because they do not meet the standard requirements [12].

Other scientists have conducted studies on the pyrolysis oven, where the heat source is microwave, but Beneroso D., T. Monti, E.T. Kostas and J. Robisnos critically assessed the microwave pyrolysis process. They emphasize that the experiments in the laboratory scale will never be implemented in the industry, because there is no microwave source with adequate power and which will be worked continuously. And the second problem is to transfer energy from the electromagnetic wave to the material batch, which is not always efficient [2].

In Ghana, looking for alternative ways of obtaining fuel in order to become independent of fossil fuels. Potential see in the peel of oranges as a substrate for the production of bio-oil by pyrolysis. With the increase in demand for processed oranges and orange while increasing crop to 1.6 million hectares in the coming years they could replace 6.7% of all fuels, both diesel and gasoline to bio-fuel in the processing of 10% of waste from oranges. The authors pay more attention to one fact that bio-oil rather be used as a fuel additive and not as a stand-alone fuel. With the support of sector fruit processing by governments and increasing the production orange waste, production bio-oil from peel orange is the most real [1].

Successive authors see potential in waste from the fishing industry. In 2008, fish production reached 144 million tons, half of which is waste. The waste from the fish oil content ranges from 40-65%. Currently, the removal of fish waste is costly in terms of both economic and ecological. The authors presented the properties of fish oil (waste from salmon). Moreover, they attempted mixed with pyrolysis oil produced from softwood sawdust. The experiment showed that the mixture separate after several minutes, a slight improvement of the miscibility of adding methanol [6].

Other ecological aspect which provide decrease in emission of exhaust gases is use of alcohol fuel in an engine. Using an alcohol in an CI engine is difficult because of its properties which not allow to ignite it as a single fuel. Use a hydrocarbon-alcohol blends in CI engine cause decrease in CO_2 and soot emissions what is discussed by Tutak et al. [9–11].

In the literature a studies can be found, were pyrolysis oil was successfully used to supply a diesel engine. The paper presents the results of the experiment on combustion of mixture pyrolysis bio-oil with alcohols in spark ignition engine [5, 13].

2. Description of the research stand

The test bed consists of the following:

- Single cylinder engine with variable compression ratio (b = 85 mm; s = 115 mm; V = 650 cm^3; ε = 6–14),
- Port fueled system for both gaseous and liquid fuels with heaters for warming up fuels (Fig. 1, 2),
- Dynanometer with breaking power of 5.5 kW,
- Electronic engine control system for spark timing and fuel control,
- Signal gas analysers,
- Data acquisition system with A/D converter resolution of 16 bits and sampling frequency of 100 kHz per each channel,
- Primary fuel applied to investigation was n-butanol due to satisfactory dilution rate of bio-oil in it.

The test stand outline is presented in Fig. 3.

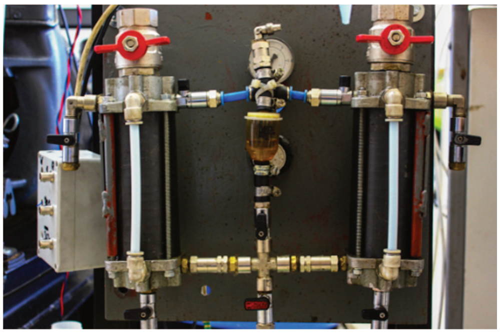

Fig. 1. Dual fuel supply system

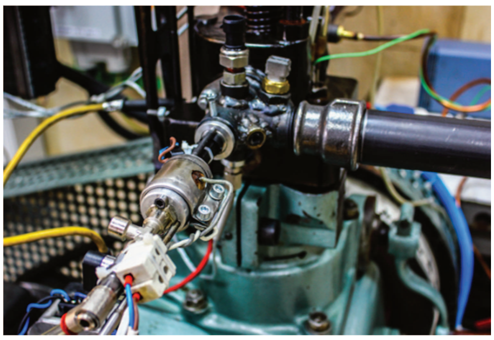

Fig. 2. Heating and fuel injection system

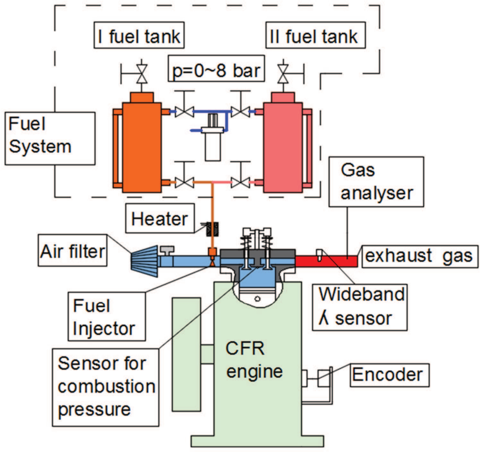

Fig. 3. Scheme of research test stand

3. Analysis of results

Tests were conducted to obtain the data as follows:

- In-cylinder pressure,
- Fuel and air temperature,
- Crank angle,
- Lambda ratio,
- THC, CO, NO_x emissions.

After data processing the following parameters were determined:

- Indicated mean effective pressure (IMEP) shown in Figure 4,
- NO_x, THC and CO from exhaust gases depicted in Figures 5,6 and 7, respectively,
- Combustion pressure (Fig. 8, 9) and its derivative over crank angle dp/dCA (Fig. 10),
- Pressure vs. volume plotted in Fig. 11.

As presented in Figure 4, the IMEP for pure butanol is approximately 20% higher when compared to butanol and 20% bio-oil blends. However, the IMEP for bio-oil blended butanol the characteristics is flat, hence this is less sensitive to spark timing.

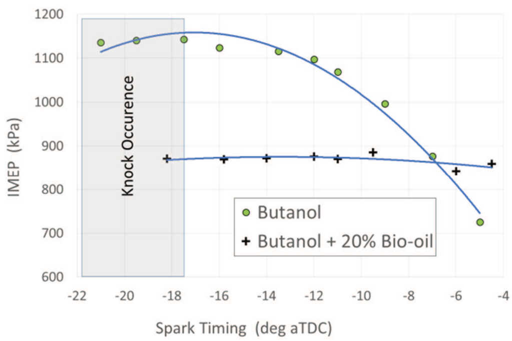

Fig. 4. Indicated mean effective pressure vs. spark timing

Concerning the toxic emissions, it is found that NO_x emission has its maximum at spark timing in the range from –12 to –6 CA deg after TDC. Total unburned hydrocarbons are at their minimum for spark timings from –16 to –10 CA deg aTDC. CO emission is low at spark timing from –12 to –6 CA deg aTDC. This is at the same spark timing range in which the NO_x is high. Thus, as seen in Figures 5-7 the exhaust emissions for THC, CO and NO_x characterizes with trends typical for other common fuels used in the SI engine as eg. gasoline. However, THC look different what might be caused by several poly-aromatic hydrocarbons species diluted in water in the bio-oil. Thus, for their thermal dissociation longer time is required, that can be achieved by ignition discharge more advanced.

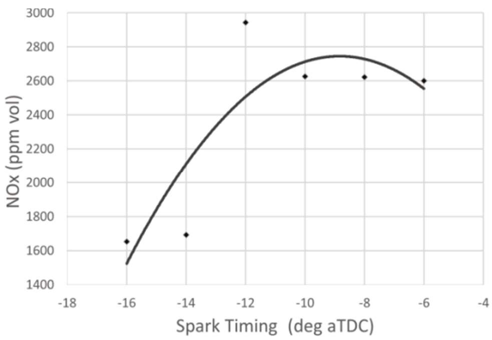

Fig. 5. NO_x emission as a function of the spark timing

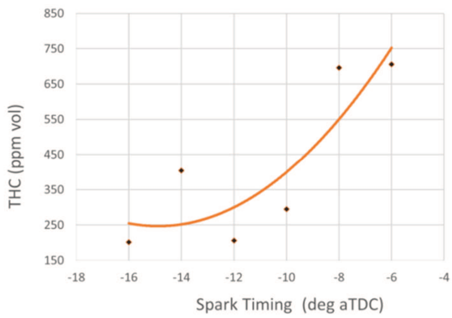

Fig. 6. THC emission as a function of the spark timing

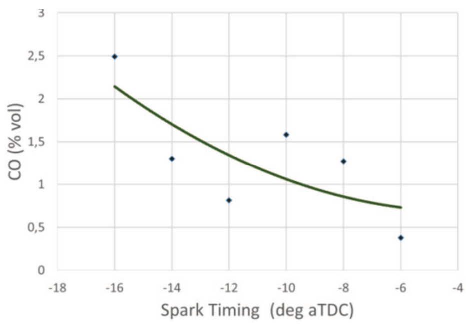

Fig. 7. CO emission as a function of the spark timing

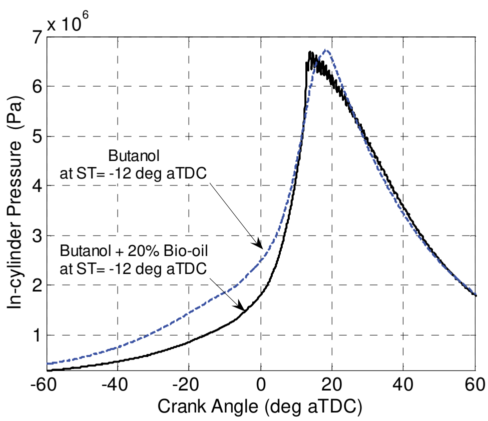

Fig. 8. In-cylinder pressure vs. crank angle

When butanol was blended bio-oil in 20%, anyone can observe tremendous increase in combustion pressure rate as presented in Figure 8 and after filtering in Figure 10. Figure 9 shows closer look on pulsations generated at the end of combustion. They resulted mainly from this high pressure rate observed at the main combustion phase.

As shown in Figure 8 and in Figure 9, pressure pulsations accompany the combustion event of butanol-bio-oil. The pressure pulsations are characterized with peak-to-peak of 400 kPa. Such intensity for pulsations can be considered as harmful to the engine [7].

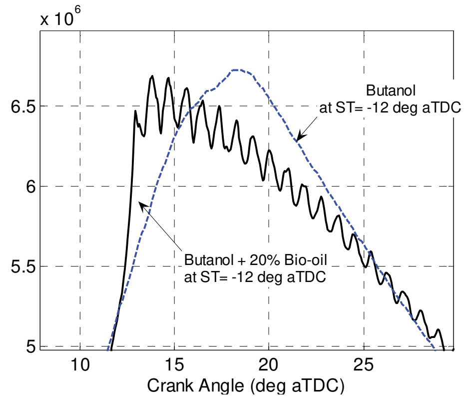

Fig. 9. Zoom on in-cylinder pressure vs. crank angle

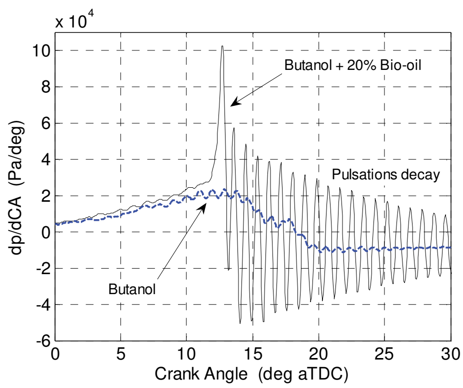

Fig. 10. Pressure rise rate in the function of the crank angle

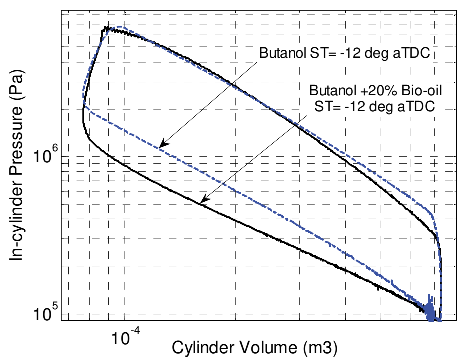

Fig. 11. In-cylinder pressure profile as a function of the cylinder volume

As presented in both Figures 8 and 11, one can conclude that to reduce pressure pulsations and reduce in this way knock intensity, the engine fueled with butanol blended bio-oil had to work at lower load by approximately of 20%. Hence, the throttle was closed to the required position to maintain the specific engine load.

4. Conclusion

The following conclusions can be drawn from the research:

- Bio-oil can be combusted in the IC engine after its dilution in alcohol eg. n-butanol.
- Due to lower heating value if compared to other fuels the bio-oil in blends decreases overall heating value, so does engine performance.
- Bio-oil as additive to other fuels increases combustion rate, what can cause several symptoms of combustion knock, hence knock reduction measures are required to be implemented in this purpose.
- As far as toxic emission is concerned, addition of 20% bio-oil to butanol fuel reports similar emission as is typical for other fossil based fuels.

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Nomenclature

CA crank angle
CI compression ignition
CNG compressed natural gas
DI direct injection
IC internal combustion
IMEP indicated mean effective pressure
LPG liquified petrolum gas
SI spark ignition

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