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Liquid Biofuels - promising energy source for a small scale power plants

Abstract: Basing on many years of experience in fuelling large stationary engines with palm oil Wärtsilä has started investigation into using other types of liquid biofuels (LBF) as an engine fuel for power generation. As a part of this investigation many engine tests using rapeseed oil, soybean oil, and animal fat were done. The tests described in this paper were done in parallel at two different locations. The first one was the research power plant located in Pieksämäki and the other one was the laboratory at VTT (Technical Research Centre of Finland). During the tests selected data required for evaluation whether the engine can handle investigated fuels and whether the emissions meet strict requirements have been collected analyzed and presented in this paper. Two different types of engines were used for investigation. The Wärtsilä 6L20 was used in Pieksämäki and the 4R32LN at VTT. Engines were run at different load but as for the engines for power generation the most important were parameters at full load. Therefore the study was focused on emissions at full load. As a reference the results from the LFO test were used. Results for selected fuels were compared with the reference test results. Following this comparison conclusions concerning each fuel were made.

Key words: *liquid biofuel, bio fuel, lbf, bio power plant, small-scale power plant, containerized power plant, biodiesel, stationary engines, heavy duty engines*

Biopaliwa ciekłe – perspektywiczne źródło energii dla energetyki rozproszonej

Streszczenie: W oparciu o wieloletnie doświadczenia z wykorzystaniem oleju palmowego jako paliwa do dużych stacjonarnych silników tłokowych firma Wärtsilä rozpoczęła badania dotyczące możliwości użycia innych ciekłych bio-paliw jako paliwa do silników przeznaczonych do małych elektrowni. Częścią tych badań były testy silnikowe z wykorzystaniem oleju rzepakowego, sojowego, oraz tłuszczu zwierzęcego. Badania opisane w tym artykule zostały przeprowadzone równolegle w dwóch różnych miejscach, w laboratorium VTT (Fińskie Techniczne Centrum Badawcze). Podczas badań wybrane parametry niezbędne do oszacowania czy silnik dobrze znosi badane paliwo i czy emisje spełniają przepisy, zostały zebrane, przeanalizowane i przedstawione w artykule. Do badań wykorzystano dwa różne silniki, silnik 6L20 w Pieksämäki oraz silnik 4R32LN w VTT. Silniki pracowały pod różnym obciążeniem, jednak głównie skupiono się na parametrach przy pełnym obciążeniu. Jako odniesienie przeprowadzony został test z użyciem oleju napędowego. Wyniki dla wybranych paliw zostały porównane z testem referencyjnym. Opierając się na tym porównaniu zostały wyciągnięte i przedstawione wnioski.

Słowa kluczowe: *biopaliwo, bio paliwo, bio elektrownia, energetyka rozporoszona, biodiesel, silniki stacjonarne, silniki przemysłowe*

1. Introduction

Biofuels generally are considered as renewable fuels and in many countries are treaded in a different to fossil fuels way. This special treatment comes from the benefit which replacing fossil fuels with biofuels gives. When the whole life-cycle of the fuel is considered (not only the exploitation period) it appears that renewable fuels cause much lower CO_2 emmisions, even thought the CO_2 emissions during the exploitation can be at the same level or even slightly higher. Thus public authorities support renewable energy sources by subsidizing the biofuel production (i.e. bioethanol production in USA) or by setting requirements for biofuel addition to fossil fuels (i.e. Germany, France). In Poland there is defined minimum share ratio (by energy) of biofuels in total fuel amount consumed for transportation purpose - these obligations have to be fulfilled by fuel providers. Because of various kinds of financial incentives between 2000 and 2009 world fuel ethanol production increased from 16.9 to 72.0 billion liters per year and world bio diesel production from 0.8 to 14.7 billion liters per year [1]. This growth was caused mainly by transportation sector. As far as the power generation sector is concerned, biofuels are also more often considered as a serious fuel. In this case it is also driven by the legislations, but in contrast to transportation sector not only the fuel price but also final income plays the main role. The final income depends, in addition, to income from sales of electricity and heat, on support scheme for energy from renewable sources. There are two bases for support policies: the first one is price and the second one is quantity. Nowadays there are two support schemes in EU: Feed-in tariff system (price based) and tradable green certificates system (quantity based). The feed-in tariff scheme (FITs) involves an obligation on the part of electric utilities to purchase the electricity produced by renewable energy producers in their service area at a tariff determined by the public authorities and guaranteed for a specified period of time [2]. Tradable green certificate scheme (TGCs) is both an accounting system that certifies RE production and a regulatory instrument available for public authorities to reach a specified goal for RE production [3]. From the point of view of a green energy producer green certificate is an additional source of income as long as there is a need on the market for it. Both systems have good and bad points. It is said that FITs because of its predictability is more attractive for expensive technologies while TGCs depends on the market need for certificates and thus induces development of low-cost short-term technologies. Nevertheless both support systems make producing energy from renewable sources profiTable. This also concerns liquid biofuels as a fuel for stationary reciprocating engines, especially in case of using very cheap bio-oils from by-products (e.g. animal fat). There are European countries which already implemented advantageous terms for bio oil plants of RES support. Italian legislations generally encourage investing in green power plants. There is tax reduction for bio fuelled plants and up to 280€ /MWh feed in tariff for energy from fuel of European origin. The most promising is investing in under 1MW green power plants. These solutions already resulted in investments in power plants fuelled with palm oil. Rapeseed oil and Soybean oil would be more profiTable because are widely produced in Europe. European Commissions legislations forces that the EU member states national trends for the support for RES will continue. In such environment liquid bio power plants investments become more and more promising.

2. Investigated Fuels

From the economical point of view there is broad variety of liquid bio-oils attractive to use as a fuel. Some due to their price because there are by-products and some because of broad variety of financial incentives (i.e. fuel of European origin in Italy). Following bio-liquids, which could be used as a fuel in a bio-power plant, were under investigation:

- Animal fat
- Rapeseed oil
- Soybean oil

Fundamental properties of investigated fuels are shown in Table 1. Values presented in Table 1. for LFO and animal fat were measured before the tests, data for soybean oil and rapeseed oil were taken from literature [4].

Table 1. Properties of fuels under investigation
Tabela1. Właściwości badanych paliw

Property	Unit	LFO	Animal Fat	Soybean oil [4]	Rapeseed oil [4]
Viscosity,@40°C (@38°C)	mm2/s	3.046	52.92	(32,6)	(37)
Net heating value	MJ/kg	42.86	36.74	39,62	39.7

The application of bio-oils as a fuel for reciprocating engines can be limited by a broad variety of oil parameters. Some oil characteristics may result in faster wear or corrosion of engine components and can be observed during the long term tests or exploitation (e.g. acidity, ash content). But some of them constitute a substantial obstacle for the oil application of engine fuel (i.e. viscosity). Following the data concerning fuel viscosity in Table 1. it can be clearly seen that this parameter for bio-oils is much higher than for LFO. Higher viscosity may cause improper spray formation. The atomization of high viscous liquids is not sufficient and causes incomplete combustion which can result in carbon deposition in combustion chamber. To eliminate this problem liquid bio oils are usually preheated before feeding it to the engine. Unfortunately bio-oils usually are very sensitive to high temperatures. High temperatures can result in polymerization of unsaturated fatty acids. This occurs when cross-linking starts to occur between molecules, causing the formation of very large agglomerations and consequent gumming [5]. In spite of the fact that viscosity of investigated biofuels is of the same order of magnitude (higher than LFO) they differ. Basic data concerning each investigated fuel is presented below.

Animal fat was tested in laboratory engine at VTT and in the 6L20 CPP in Pieksämäki as well. Using animal fat as engine fuel is attractive from the economical point of view due to its price because it's widely seen as a by-product from the food industry.

Rapeseed oil is widely available and it is produced in EU. This feature makes it very attractive because of support schemes applied in some European countries. This fuel was precisely tested in a research containerized biopower plant in Pieksämäki.

Soybean oil is also widely available but in contrast to Rapeseed oil it is produced mainly in USA, Brazil, and Argentina – EU doesn't play a role on this market [6]. Nevertheless CPP is not a solution limited to EU market and thus the reason for testing the fuel available on the other continents.

3. Experimental Setups

Experiments were conducted in parallel at two locations. The first one was the research power plant located in Pieksämäki and the other one was the laboratory at VTT (Research Centre of Finland). Most important information concerning technical specification of each experimental installation is presented below.

Pieksämäki research power plant

Power plant located in Pieksämäki is a containerized power plant and consist of two containers (fig.1).

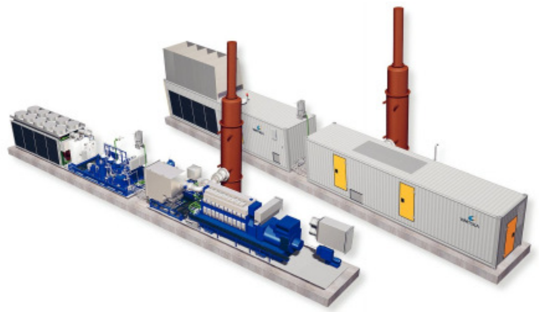

Fig. 1. Wärtsilä 20 CPP Containerised Power Plant
Rys. 1. Elektrownia kontenerowa Wärtsilä 20 CPP

The Containerised Power Plant (CPP) solution was originally intended for heavy fuel oil (HFO) and for a 9-cylinder in-line Wärtsilä 20 (9L20) engine [7]. The electrical output from a Wärtsilä 9L20 CPP is 1.5 MW. In Pieksämäki instead 9L20 the engine 6L20 was installed. The reason was that the power output of 6L20 is slightly below important from the economical point of view Italian limit for small scale power plants. The technical data of the CPP is shown in Table 2.

Table 2. Technical data for the Wärtsilä 20 CPP [7]
Tabela2.Dane techniczne elektrowni Wärtsilä20 CPP[7]

Engine	Wärtsilä 9L20 or 6L20 1000 rpm
Generator	Standard 50 Hz/11 kV, 50 Hz/400 V 60 Hz versions on request
Electrical power	1539 kW or 998 kW
Fuel	HFO 380 cSt at 50℃, 980 kg/m3 or LBF (HFO/LBF separators included)
Ambient temperature	0–43℃
Noise level	70 dB(A) at 10 m
Containers	40 ft high cube, CSC certified
Length	12.2 m
Width	2.5 m
Height	3.0 m
Weight	Genset container certified for 40 tons auxiliary container 25 tons

The Containerized Power Plant in Pieksämäki is shown in Figure 2.

Fig. 2. Wärtsilä 20 CPP in Pieksämäki
Rys. 2. Elektrownia Wärtsilä 20 CPP w Pieksämäki

Due to the facts that the exhaust gas temperature for biofuels is slightly lower than for HFO and SCR system requires high temperatures, before the tests following modifications had been made to increase it: a larger opening in the turbocharger nozzle ring and an air waste gate in the charge air receiver. Reduced turbocharger speed and re-circulating charge air increase the exhaust temperature [7].

The interior of the container where engine is located is shown in Figure 3.

Fig. 3. Wärtsilä 20 CPP interior of the container
Rys. 3. Wärtsilä 20 CPP wnętrze kontenera

The CPP was equipped with SCR system (fig. 2.). However the sampling probe for the emissions was located straight after the engine – between the engine and the SCR unit (fig.4.)

Fig. 4. Location of the sampling probe
Rys. 4. Miejsce poboru próbek gazów wylotowych

The CPP equipped with 6L20 engine and with SCR system was located in Pieksämäki for research purpose however it's a new already commercially available product able to meet strict emissions limitations.

Laboratory at VTT

The engine at VTT was installed for scientific purpose. The installed engine was Wärtsilä Vasa 4R32 LN. In contrast to CPP engine during these tests the VTT engine wasn't equipped with SCR system. Exhaust gas sampling was done after the engine without any catalyst system. This location of the sampling apparatus provides that the measured emissions directly describe the processes which take place in the engine.

It's a 4 cylinder inline engine with a 320mm bore. The engine was fitted with basic mechanical fuel injection.

4. Results

During the tests many parameters were collected. The test engine at VTT due to its scientific purpose was equipped with much more sensors and metering equipment than the engine in a power plant in Pieksämäki. However many of them collect data for a specific investigations. The data which is necessary for the evaluation whether the engine can work properly providing sufficient performance and low emissions fuelled with investigated fuels was collected during both tests. According to the fact that investigated fuels are going to be applied to power generation area, the most important parameters were: efficiency and emissions. Therefore these parameters are widely described in this chapter.

VTT tests

At VTT only animal fat was tested. The results for animal fat were compared with the results obtained during reference test conducted using LFO. All the data presented below are shown as a ratio to the data collected during reference test. The reference test was conducted using LFO at 100% load. Reference test results are denoted as _ref.

Efficiency of the engine was calculated from the consumed fuel and the generated electricity. The efficiency of the engine fuelled with animal fat and LFO as well is shown versus the load in Figure 5.

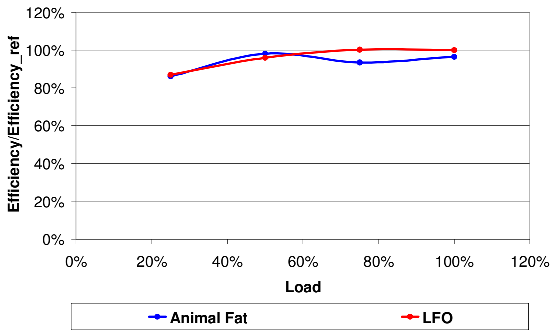

Fig. 5. Relative engine efficiency vs. load for animal fat and LFO
Rys. 5. Względna sprawność silnika dla tłuszczu zwierzęcego oraz oleju napędowego

As for the emissions the data for smoke, NOx, HC, CO emissions were collected.

The Filter Smoke Number parameter describing the smoke emissions is presented in Figure 6.

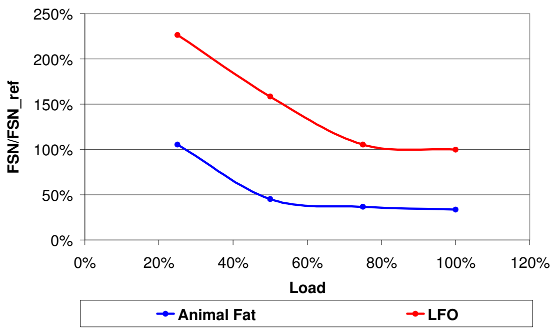

Fig. 6. Relative FSN vs. load for animal fat and LFO
Rys. 5. Względna wartość FSN dla tłuszczu zwierzęcego oraz oleju napędowego

The NOx specific emissions are shown in Figure 7.

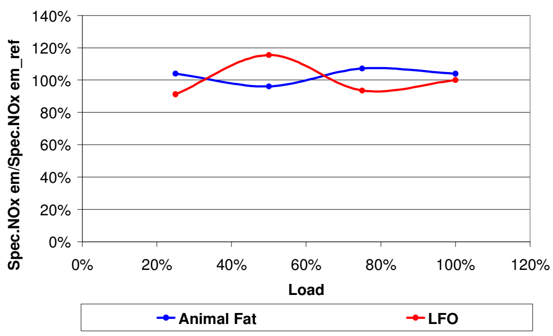

Fig. 7. Relative specific NOx emissions vs. load for animal fat and LFO
Rys. 7. Względna wartość jednostkowej emisji NOx dla tłuszczu zwierzęcego oraz oleju napędowego

The HC specific emissions are presented on graph in Figure 8.

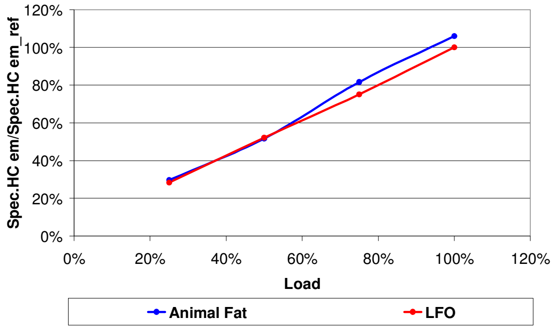

Fig. 8. Relative specific HC emissions vs. load for animal fat and LFO

Rys. 8. Względna wartość jednostkowej emisji HC dla tłuszczu zwierzęcego oraz oleju napędowego

The CO specific emissions are shown in Figure 9.

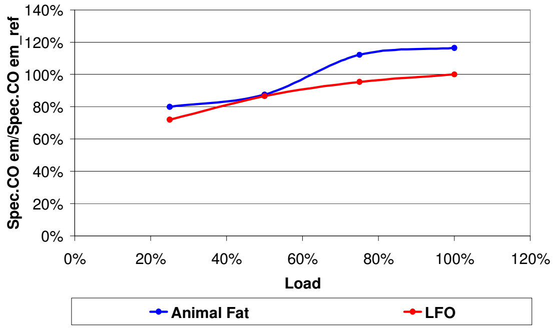

Fig. 9. Relative specific CO emissions vs. load for animal fat and LFO

Rys. 9. Względna wartość jednostkowej emisji CO dla tłuszczu zwierzęcego oraz oleju napędowego

Pieksämäki tests

In Pieksämäki all of the described fuels, including animal fat, were under investigation. In this case there was no LFO reference test. Presented parameters are shown as they were measured. Due to the facts that animal fat was widely compared with LFO at VTT and its influence on engine performance and emissions is known, in this case results obtained with this fuel can be treated as an indicator for other fuels.

During the tests selected data were collected. The crucial parameters are analyzed in this paper. In contrast to VTT results, emissions from CPP are presented as concentration in the exhaust gas.

The results from the tests of each fuel are presented in Figure 9.

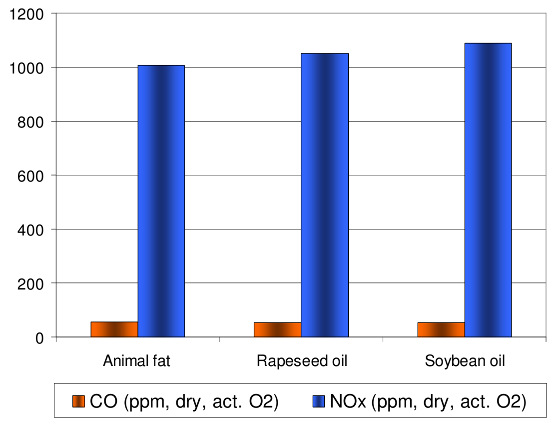

Fig. 10. CO and NOx emissions for all investigated fuels at 100% load

Rys. 10. Emisja CO oraz NOx dla przebadanych paliw przy pełnym obciążeniu

5. Conclusions

The purpose of conducted investigations was to find out what was the influence of some of widely available bio-oils on engine performance and emissions. The tests were conducted for following fuels: animal fat, soybean oil, rapeseed oil, among which animal fat was tested on two different engines and thus it could be directly compared with LFO. Selected engine parameters were compared. The efficiency of the engine running on animal fat at full load was slightly lower than the efficiency for LFO fuelling. At 75% load the efficiency for animal fat got bit worse but at 50% load it was better than for LFO (fig. 5). As for smoke emissions the animal fat fuelling caused significant change – the FSN decreased of about 60% for all of 3 investigated loads (fig. 6.). NOx emissions remained at the same level – there was no significant change (slight reduction at full load) (fig. 7.). As for HC emissions slight increase was observed at 75 and 100% load (fig. 8). The CO emissions for animal fat were generally higher than for LFO but not more than 20%. Only at 50% load the CO emissions were at the same level (fig. 9.). Generally it can be concluded that besides the significant positive influence on smoke emissions replacing LFO with animal fat doesn't affect much engine performance and emissions. As for the other investigated biofuels (rapeseed oil and soybean oil) NOx and CO emissions were measured. These fuels were tested only in CPP. Animal fat which was widely compared with LFO was tested at both places. The CO and NOx emissions for rapeseed oil, soybean oil and animal fat as well were presented on one graph (fig. 10.). It can be clearly seen that there was no significant change in emissions for these fuels. The NOx emissions for soybean and rapeseed were slightly higher than for animal fat wile the CO emissions remained at the same level.

It is worth reminding that presented emissions are directly measured values and don't correspond to the benefit of biofuels when whole life-cycle of the fuel is considered (i.e. short-term carbon cycle).

During the engine tests no major faults and problems were noticed. The temperature of each investigated fuel was precisely controlled providing required viscosity and avoiding fuel polymerization. From obtained results it can be concluded that if the fuel treatment apparatus works precisely engine can be easily fuelled with biofuels.

Concerning the EU and global trends for RE support, small-scale power plants based on reciprocating engines fuelled with biofuels appear to be attractive form of producing green energy.

Nomenclature/*Skróty i oznaczenia*

LBF Liquid biofuels/*biopaliwa ciekłe*
VTT Technical Research Centre of Finland/*Techniczne Centrum Badawcze Finlandii*
RES Renewable Energy Sources/*OZE odnawialne źródła energii*
RE Renewable Energy/*odnowialna energia*
FITs feed-in tariff scheme/*system gwarantowanych cen*
TGCs Tradable green certificate scheme/*system zielonych certyfikatów*
CPP Containerized Power Plant/ *elektrownia kontenerowa*
SCR Selective Catalytic Reduction/*Katalityczna redukcja selektywna*
LFO Light fuel oil/
HFO Heavy fuel oil/

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