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THE ENERGY EFFICIENCY AND ECOLOGICAL BENEFITS OF LOW-POWER FURNACES POWERED BY SECONDARY BIOFUEL

Key words

Combustion, liquid fuel furnace, alternative fuel, FAME, power efficiency, ecological efficiency.

Abstract

The application of FAME obtained from waste vegetable oil has become a very attractive fuel, because, apart from being an energy carrier, it is also a solution for burdensome waste. Based on conducted research, the author presents the influence of FAME on the basic operational parameters of a low-power furnace. The following parameters were analysed: the air excess factor, the temperature of exhaust gases, and the concentration of toxic compounds in exhausts during the combustion process. The thermal energy was measured both for FAME and for its mixtures with heating oil. The appropriately applied combustion conditions as well as suitable composition of the fuel provide an ecological and effective supply for commercial low-power furnaces.

Introduction

The Polish biofuel industry and the directions of its development [8,19] are shaped by EU policy, especially by the 2009/28/WE (RED directive) [1].

In the Polish market, liquid biofuels have a reasonable share of renewable energy carriers [4]. Figure 1 depicts the share of particular liquid biofuels in the pool of all renewable energy carriers obtained in 2013.

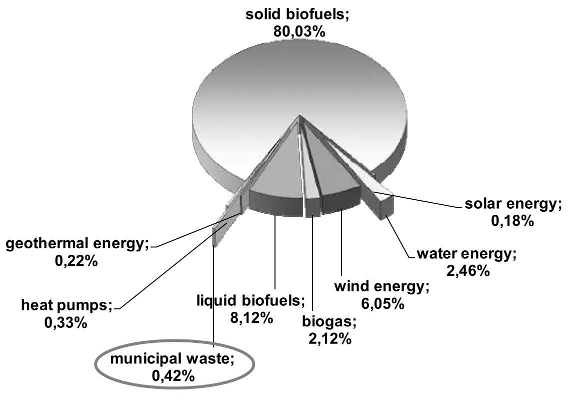

Fig. 1. The share of liquid biofuels in the pool of renewable Energy carriers obtained in w 2013 [4]

The targets defined by EU [2, 7] apart from their explicitness, raise doubts in terms of the simultaneous (parallel) utilization of biomass in the future and the development of bioenergy market. The essential limitation in this field may be an EU proposal for a reduction in conventional biofuels and the obligation to taking into account the ILUC emission (see the list of designations and acronyms) [7, 21].

A new EU approach is the introduction of double and quadruple classification of advanced biofuels for NCW fulfilment. According to the published EU Parliament and the Council's resolution of 11.09.2013 [11], the limitation of conventional biofuels and the increase in advanced biofuels may be expected.

It should be underlined that the introduction of a 6% limitation for conventional biofuels as well as the change in double and quadruple classification of biofuels should change their share in the market to 7 Mtoe (megaton of equivalent oil Mtoe = 41.868×10^{15} J) to fulfil the goal fixed in RED directive. According to the EU estimations, the present demand for advanced biofuels is about 1.3 Mtoe (derived mainly from used cooking oil and animal fats), which will be 5–6 Mtoe by 2020. That means an additional 1 – 2 Mtoe demand for such biofuels.

It is also worth mentioning that a constantly decreasing biofuel consumption since 2011 has been observed in Poland (data based on [5] depicted in Fig. 2). In 2012, the consumption was about 11.8% less than in 2011 and about 10.2% smaller in 2013 than in 2012. In 2014, this share was just 6.8% in comparison to 2013.

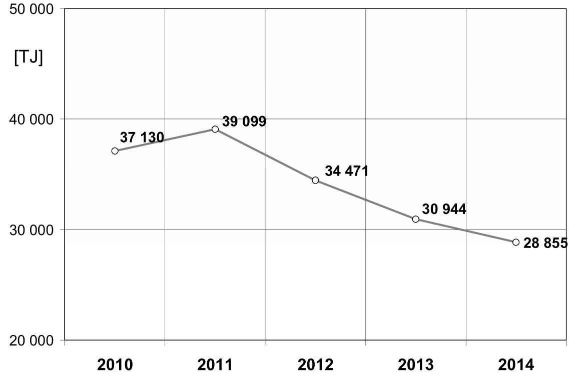

Fig. 2. The demand for liquid biofuels in 2010–2014 [5]

Liquid biofuels (bioethanol and biodiesel) in majority were used as the additives for petroleum-based engine fuels.

A similar decreasing tendency is visible in regard only to biodiesel (Fig. 3). The total consumption of this fuel in 2014 was about 20.1% less than in 2010.

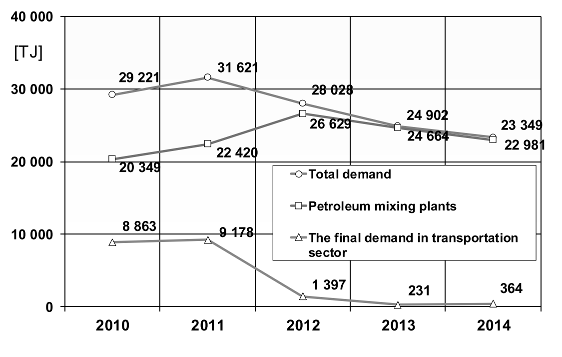

Fig. 3. The demand for biodiesel in 2010–2014 [5]

There is a lack of advanced biofuels in the Polish market, which may indicate the direction for the solution for EU requirements in terms of ILUC emissions in the GHG balance. The share of biofuels derived from waste fats and used cooking oil (the potential raw material for advanced biofuels) was zero in 2011 (Fig. 4), although the consumption of 44 ktoe had been projected (mainly FAME from used cooking oil) [12]. Starting from 2012, this amount was expected to double. There is also another concern, which is the postulate included in the National Action Plan [7, 8] concerning the introduction of the first advanced biofuels in 2017. These biofuels (about 132 ktoe) could increase the share of renewable energy sources in transportation.

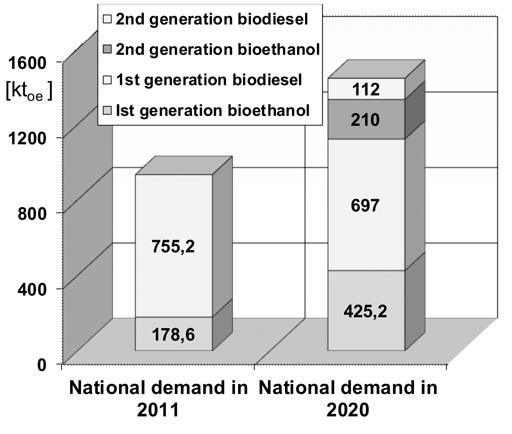

Fig. 4. The demand for biofuels in 2011 with respect to the expected level of consumption described in the National Action Plan [7]

Vegetable oils are natural lipids applicable both in food industry and in technology. In the Polish market, the majority of these fats are derived from rapeseed, flax and a small percentage of sunflower oil [12].

The food industry, gastronomy and households buy about 400 000 Mg of oil annually [6], where 90% is utilized completely and the rest 10% (40 000 Mg) is waste. Only 10 000 Mg annually of this waste oil goes to the specified recipients in the Polish market. About 10-12% of that pool comes from gastronomy, producing 1200 Mg of used cooking oil annually.

Up to 30 000 Mg of waste oils annually [6] are utilized improperly, being combusted, used as a fodder additive or simply discarded to the sewage. They change their chemical structure to calcium soaps, which cause severe difficulties in the wastewater treatment process. ITeE – PIB attempted to use FAME derived from waste vegetable oils as an alternative biofuel for commercial furnaces powered by liquid fuels.

1. Objective

It is proposed that there is a possibility and scope for using secondary fuel derived from waste cooking oil through esterification through the determination of the influence of this biofuel on the combustion process in commercial low power furnaces and the characterization of its effectiveness and the composition of resulting exhaust gases.

The objective was accomplished through research on the influence of different FAME-heating oil mixtures on the combustion energetics and its emission of toxic exhausts. The assumption was that the combustion of the fuels proceeds without any technical alteration of the commercial furnace.

2. Research stand

The research was conducted on a test stand intended for the examination of combustion processes of liquid fuels (Fig. 5). Due to the necessity of testing the fuels in relation to the PN-96024:2011 norm [15], a low power furnace equipped with an appropriate burner was applied.

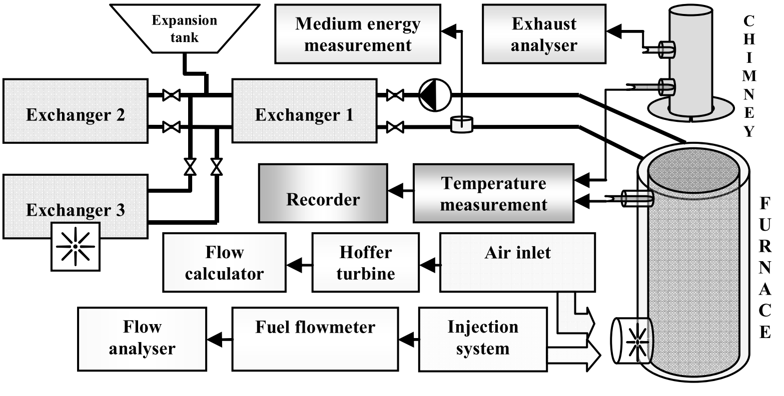

Fig. 5. The layout of the test stand for liquid fuel combustion

The 13.8 kW furnace Wertich WO 15 made by Ulrich was selected for testing. Its construction was modified by the application of custom-made heat-resistant sleeves in a water jacket designed to include additional thermal sensors.

The applied system for temperature measurement and acquisition in the combustion chamber allowed for 6-point measurements (4 sliding, K-type thermocouples and two additional in outlet part). The signals from thermocouples were recorded on a KD7 universal receiver by Kobold. The acquisition system allowed for data exportation to the computer.

The combustion chamber was equipped with an air flowmeter. In this role, the author applied a Hoffer turbine (RPR-51S HO) with flow laminator and mass flow calculator Masstrol ST2L10P by KEP.

Two geared flowmeters by KEM coupled with F110P meters by FLUIDWELL were used to measure the fuel flow.

The analysis of combustion gases were performed on microprocessor analyser GA-21 by MADUR. The analyser allowed for chemical analysis of the exhausts in terms of oxygen, carbon monoxide and carbon dioxide, nitrogen monoxide and nitrogen dioxide and sulphur dioxide content. Moreover, the analyser calculated the air excess factor λ, chimney loss SL, combustion efficiency η, and unburnt residual losses IL. The measurements of hydrocarbons were performed using a MC-218 analyser by Hermann.

The research stand was equipped with a system measuring and acquiring the energy emitted by the furnace during combustion. The measurements of these parameters were performer by electronic heat meter PolluTerm by SENSUS, which recorded the energy of heating medium (GJ) and actual power (kW) and other measurements.

3. Results and discussion

In the tests, the following parameters were used (Table 1). The samples were named as follows: B20 – 20% of FAME in the mixture with heating oil; B100 means 100% of FAME; OO100 – 100% of heating oil, etc.

Table 1. The selected parameters of tested fuels

	Parameter	Heating oil	FAME
1	Firing [°C]	88	170
2	Calorific value [MJ/kg]	39.8	37.5
3	Density at 15°C [g/cm³]	830	882
4	Viscosity at 40°C [mm²/ s]	2.64	4.8
5	Sulphur content [mg/kg]	776	0.1

Figures 5 to 9 depict the changes in the emissions of toxic compounds in exhaust gases, while Figures 10 to 13 present the combustion efficiency of tested fuels.

The combustion of B20 requires a higher air excess factor (λ = 2.5) in comparison to the “pure” heating oil (λ = 2.37), which produces a slight decrease in exhaust temperature to 151^{o}C (166^{o}C for heating oil), resulting in a 10% higher carbon oxide concentration and a 10% lower concentration of nitrogen oxides. A reduction in sulphur dioxide concentration was also reported. The limitation of toxic exhaust components proportional to the bio component content in the mixture is evidence for the constitutive and non-thermal character of observed changes.

The thermal effectiveness of the furnace supplied with B20 was comparable to 100% heating oil (Fig. 10).

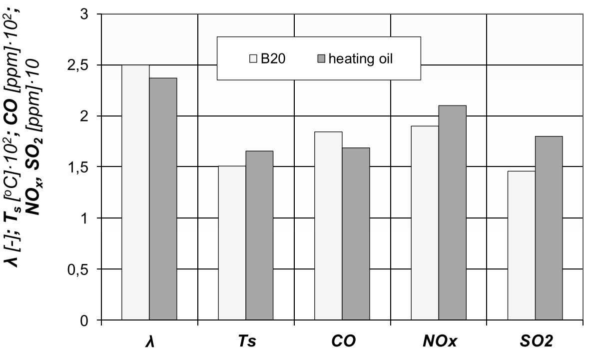

Fig. 6. The comparison between combustion parameters for B20 and heating oil

The further increase in the percentage content of bio-component in the mixture deepens the changes in the combustion process. The B50 fuel (Fig. 7) requires a higher air excess factor than B20 (λ = 2.7), which means a 15% increase in comparison to heating oil, resulting in a 12% decrease in exhaust temperature (145°C). The concentration of carbon oxide raises, resulting in a 18% increase in comparison to heating oil. The decrease in nitrogen oxides and sulphur dioxides is 30% and 52%, respectively, which proves the constitutive character of the observed changes. Supplying the furnace with B50 resulted in a 10% decrease in power efficiency.

Supplying the furnace with the fuel containing more than 50% bio-component causes significant changes in the combustion process. A considerable change in mixture viscosity (B70) leads to ineffective spraying of the fuel, where propagation of oxidation should be similar to the heating oil. The intensity of oxidation decreases despite the higher air excess ratio (λ = 2.85, which is 20% higher in comparison to the heating oil). That results in a significant decrease in exhaust temperature (15%) and incomplete combustion. This in turn results in a 25% increase in carbon oxide concentration in exhausts when compared to the heating oil (Fig. 8). Additionally, a 25% decrease in the concentration of nitrogen oxides is evidence for the typically thermal character of observed changes, which is low temperature in combustion zone (overcooling), excessive oxidation, and slow propagation of oxidation.

Nearly 70% decrease of sulphur dioxide concentration observed for B70 fuel has a typically constitutive character, because the mixture contains 70% less sulphur. This characterizes a 15% decrease in power efficiency of furnaces supplied with this type of fuel (Fig. 12).

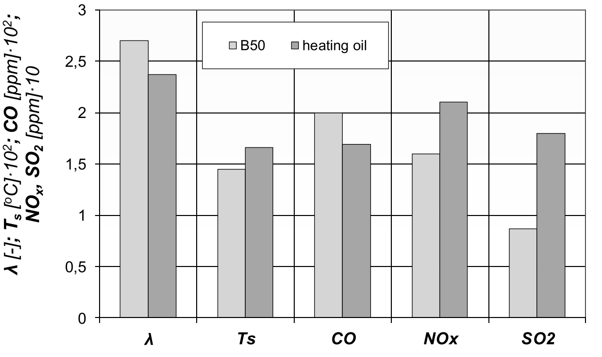

Fig. 7. The comparison between combustion parameters for B50 and heating oil

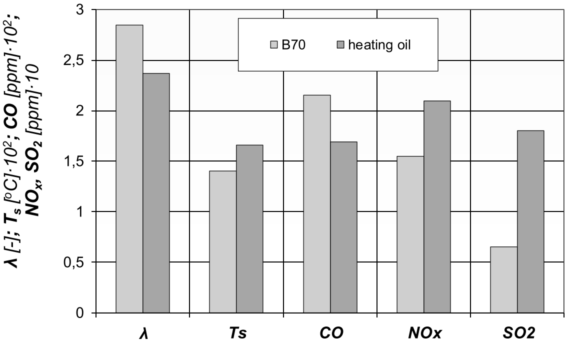

Fig. 8. The comparison between combustion parameters for B70 and heating oil

The combustion processes supplied with “pure” FAME is possible (Fig. 9), but it is burdened with problems related to fuel spraying (spread range, drop size). The combustion of FAME in the set-up described above requires a much higher air excess ratio of $\lambda = 2.99$ (more than 25% higher than for heating oil). The intensity of oxidation drops, causing a 35% increase in carbon oxide concentration (incomplete combustion) and nearly a 30% decrease in the emission of NO_x. The power efficiency of a furnace burning FAME is 20% lower in comparison to one burning heating oil (Fig. 13). The only advantage of this type of supply is zero emission of sulphur dioxide in the exhaust.

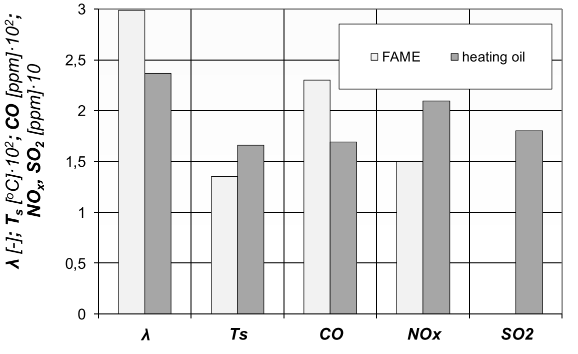

Fig. 9. The comparison between combustion parameters for FAME and heating oil

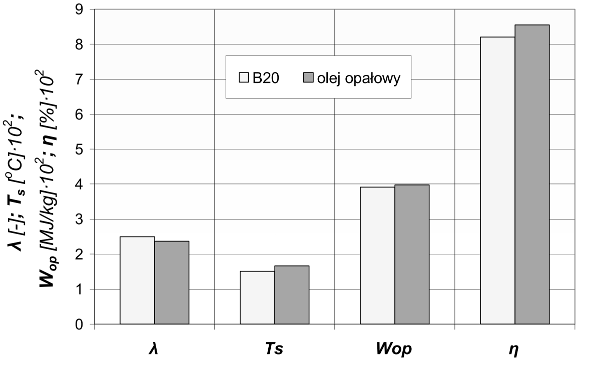

Fig. 10. The comparison between power efficiency for B20 and heating oil

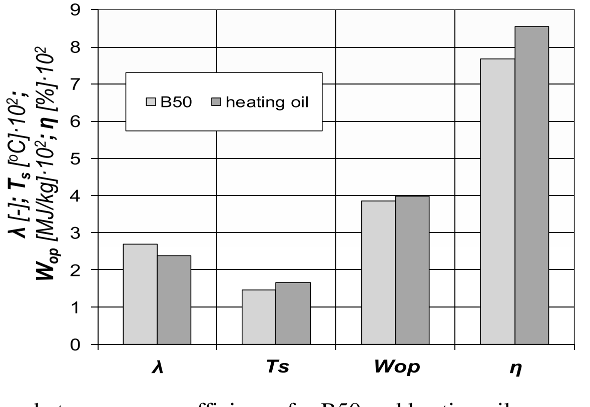

Fig. 11. The comparison between power efficiency for B50 and heating oil

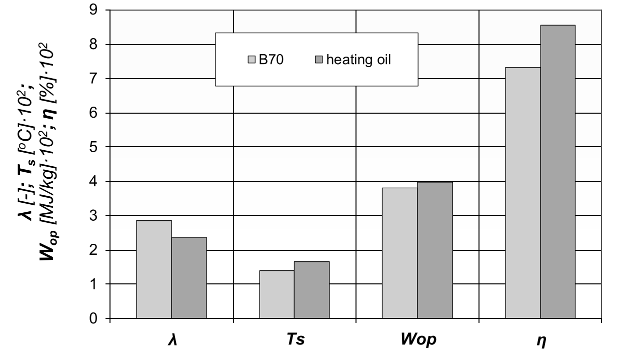

Fig. 12. The comparison between power efficiency for B70 and heating oil

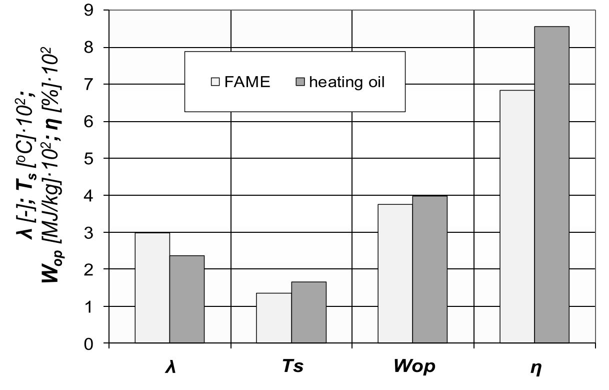

Fig. 13. The comparison between power efficiency for FAME and heating oil

Conclusions

Based on obtained results and their analysis, the following conclusions may be made:

- Nearly 20% share of FAME in the mixture with heating oil limits the emission of NOx by 10% and SO_2 by 20%. In contrast, the emission of CO raises by 10% but the power efficiency is comparable to the heating oil as a fuel.
- A percentage content of bio-component more than 50% changes the character of combustion, caused by different fuel viscosity and the difficulties with spraying it into the combustion chamber. Insufficient spraying leads to the deterioration of oxidation, which significantly differs from that observed for heating oil. The intensity of oxidation decreases despite the higher air excess factor. This results in the lower power efficiency of the furnace.

- The combustion processes supplied with FAME is possible but burdened with insufficient fuel spraying. The increase in carbon oxide concentration (exceeding 30%) and the power efficiency is considerably lower. The only advantage of this type of supply is zero emission of sulphur dioxide in the exhaust.
- The optimum combustion of fuel bio-components (spraying quality, spread range) would be achievable by the use of a more "viscosity-tolerant" injector that could provide lower emissions of CO and other oxides by the similar power efficiency of the furnace.

List of designations and acronyms

FAME – *Fatty acid methyl esters*
GHG – *Greenhouse Gases*
GUS – *Central Statistical Office*
ILUC– *Indirect land-use change*
KPD – *National Action Plan*
NCW – *National Indicator Targets*
RED – (*Renewable Directive*)
UE – *European Union*

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Efektywność energetyczna i ekologiczna kotła małej mocy zasilanego biokomponentowym paliwem wtórnym

Słowa kluczowe

Spalanie, kocioł na paliwo płynne, paliwo alternatywne, FAME, sprawność energetyczna i ekologiczna.

Streszczenie

Zastosowanie FAME pochodzącej z odpadowych olejów roślinnych jako paliwa nabiera coraz większego znaczenia, ponieważ oprócz tego, że może być źródłem energii – rozwiązuje również problem utylizacji uciążliwych dla środowiska odpadów. Na podstawie przeprowadzonych badań określono wpływ FAME na przebieg podstawowych parametrów procesu spalania w urządzeniu kotłowym małej mocy. Określono zmiany współczynnika nadmiaru powietrza, zmiany temperatur gazów spalinowych, zmiany stężeń toksycznych składników spalin w trakcie procesów spalania. Ustalono ilości energii cieplnej wytworzonej w instalacji kotłowej w trakcie spalania FAME i jego mieszanin paliwowych z olejem opałowym. Kontrolowane zmiany parametrów procesowych warunków spalania FAME i wybranych mieszanin z olejem opałowym pozwalają na ekologiczne prowadzenie procesów spalania w komercyjnych kotłach małej mocy.