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Ryszard WASIELEWSKI, Krzysztof GŁÓD
Institute for Chemical Processing of Coal

Emission results of combustion process of fatty acids distillation residue in an oil boiler – comparison to heavy fuel oil

Key words: distillation residue of the fatty acids, combustion, oil boiler, emission of pollutants into the atmosphere

Introduction

During many production processes there are created accessory substances, which could be used at the site of the plant in auxiliary installations to e.g. manufacture technological media. Running these type of operations usually brings about an economic gain, but before they are undertaken, an environment impact analysis should also be conducted.

Paying more attention to environmental issues inclines to searching the alternative fuels, which could supersede fossil fuels. In many research activities conducted in technical scale, pilot and industrial scales there is suggested to replace diesel oil or heating oil from petroleum by liquid fuels like: bioethanol, biodiesel, butanol, water-oil emulsions and others (Marmentini Vivas & Zanoelo, 2011; Nigam & Singh, 2011; Chelemuge, Yoshikawa, Takeshita & Fujiwara, 2012; Ghorbani & Bazooyar, 2012; May-Carle et al., 2012; Sáez, Flores-Maradiaga & Toledo, 2012; Keramiotis, Zannis, Skevis & Founti, 2013; Lazaroiu et al., 2018; Plante et al., 2019). The main objective of the research is to achieve a stability of combustion process and a high heat capacity at the lowest possible pollution emission into the atmosphere.

In Poland, many research activities on energy utilization of liquid fuels of biogenic origin apply to animal and vegetable fats (Orszulik & Lenkiewicz, 2007; Szulc & Golimowski, 2010; Karcz, 2014; Krajewska, Śląska-Grzywna & Andrejko, 2015). An advantage of using heating oils, made from new and used vegetable fats and animal fats is that these fuels are biodegradable, nontoxic and also they come from renewable energy sources.

In one of the national industrial installations to process animal fats, the fat coming from meat industry is being processed. That material belongs to the category 3 of products unfit for consumption according to the Regulation (EC) No 1069/2009.

In the technological process fat is preliminarily cleaned by filtration with the use of the bleaching earth, and afterwards is broken (in reaction of hydrolysis at the elevated temperature, ca. 250°C and at the elevated pressure ca. 5.5 MPa). In this process there occurs a physical splitting of the material to water solution of glycerin and to fat acids. The fatty acids after separation from water solution of glycerin are distilled in order to isolate each fractions of fat acids. As a result of this process, also the residue after distilling fatty acids is obtained (so-called FADR) – which is a heavy fraction containing the heaviest hydrocarbons (> C18) in the amount of 5–8%, which requires further management. Fatty acids distillation residues make up a material of biogenic origin, formed only as a result of physical processing of animal fats without using additional chemicals.

At the Institute of Chemical Processing of Coal the research was undertaken to manage/use the FADR as a liquid fuel in the boiler house of the plant, exploiting oil boilers fired with heavy heating oil (HFO). The purpose of this research was to determine the impact of the FADR on the process of combustion and change of emission of the pollution to the atmosphere in comparison to combustion of HFO.

Materials and methods

Samples of the fatty acids distillation residues (FADR) and of the heavy fuel oil (HFO) currently burned in boiler room of the plant were subjected to examination of the essential parameters in terms of potential energy usage as a liquid fuel. To complete each separate determination (of the parameters) the same research methodology has been applied.

Density was determined by the aerometric analysis at the temperature of 60°C. Ignition temperature was determined by the Marcusson method. The sample was placed in an open crucible and heated with constant rate of ($3°C \cdot min^{-1}$). To the sample of a liquid fuel the flame of the blowtorch was brought closer, after achieving gain of the temperature by 1°C, till ignition of the volatile products released from the fuel. The ash content was determined in accordance with the technical procedure of Institute for Chemical Processing of Coal at the temperature of 815°C. Measurement of dynamic viscosity was made by means of the Engler viscometer. Selection of temperatures at which to measure the dynamic viscosity was dependent on the texture/consistence of the products and technological conditions during the test of combustion. Measurements of viscosity have been conducted at the shearing velocity of $500\ 1 \cdot s^{-1}$. To conduct an ultimate analysis the analyser of company named Elementar model Vario Cub was used. Distillation has been conducted in a typical setup of laboratory distillation used in research of coke tar and oils derived from its processing, in accordance with prerequisites specified in a standard PN-C-97055:2001. The higher heating value and lower heating value were determined in a calorimeter with application of the typical methodology to test the heating oils.

Afterwards there have been conducted tests of combustion of both materials in industrial conditions with usage of fire and water tube steam boiler of the type of FH4000 made by LOOS.

This boiler is used to make steam for technological or heating purposes. Boiler installation does not have a system of the flue gas cleaning, which are fed directly into the stack. At the boiler the burner of a C.I.B. Unigas S.p.A. model PBY510 is mounted. This is a monoblock type burner with axial air flow to the burners, which ensures an even distribution of air essential for high efficiency of heating oil combustion in wide range of capacity. Hot flue gases from the burner flow through the fire tubes and outside water tubes. Table 1 lists basic operating parameters of the PBY510 burner. Figure 1 presents a diagram of boiler installation at which the research was conducted.

TABLE 1. Parameters of the oil boiler burner – heavy fuel oil (own studies)

Parameter	Unit	Value
Fuel flowrate	$kg \cdot h^{-1}$	130–400
Minimum capacity	kW	1 500
Rated capacity	kW	4 500

Comparative tests of combustion of HFO and FADR were conducted at the nominal and reduced capacities of the boiler. The boiler during combusting of each of the evaluated substance was operating at the conditions of the present burner capacity. Boiler capacity was controlled by means of changing the steam flow rate at the maintained constant thermal parameters of the boiler that are presented in Table 2.

Both tests were conducted according to the same testing procedure. A reference fuel (HFO) was pumped into the boiler burner from existing fuel supply installation equipped with a main tank and also with a small intermediate tank heated up to 120°C. On the other hand, FADR was supplied into the burner from a special plastic container through a heated small intermediate tank.

During each test there were conducted emission measurements in range

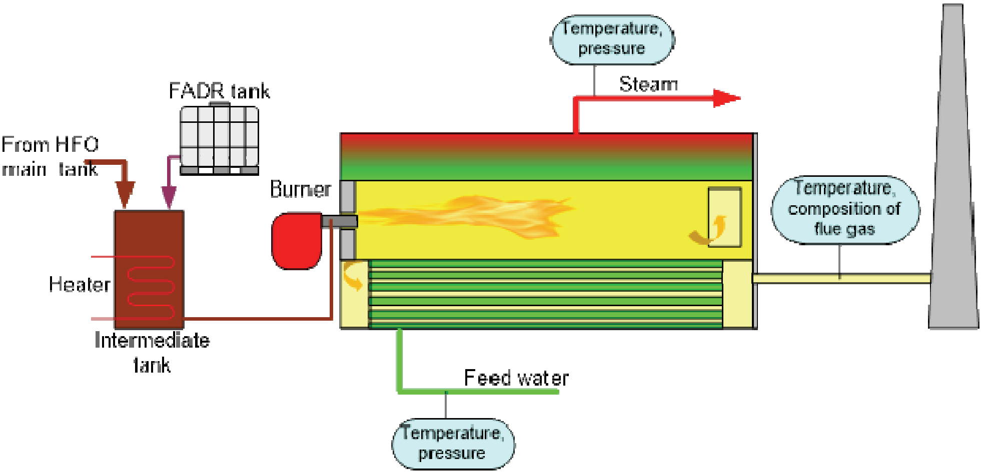

FIGURE 1. Diagram of oil boiler installation at which the research was conducted (own elaboration)

TABLE 2. Oil boiler operating parameters (own studies)

Parameter	Unit	Value
Steam temperature	°C	170–175
Pressure in boiler	bar	8.4–8.6
Feedwater temperature	°C	106

of: dust, CO and CO_2, NO_X, SO_2 and also polycyclic aromatic hydrocarbons (PAHs). Flue gas samples were taken in a measurement point localized in flue directly upstream of the stack.

To measure composition of the flue gas there was used an analyser GASMET DX4000 + analyser of oxygen. Analyser GASMET DX4000 is equipped with a heated sampling channel and it operates based on a method of analysis of absorption of the infra-red radiation of gases (FTIR). This system makes it possible to measure gas constituents concentrations in ranges of: CO_2: 0–100% and 0–45%, CO: 0–6,000 ppm and 0–50%, NO_2: 0–200 ppm, NO: 0–1,000 ppm, N_2O: 0–200 ppm, SO_2: 0–6,000 ppm, SO_3: 0–6,000 ppm, COS: 0–100 ppm, CS_2: 0–100 ppm, H_2O: 0–30%.

Flue gas samples to determine concentration of PAHs were retrieved through setup that consists of an aspiration probe, heated ash separator, moisture separator, tubes filled with sorption material (resin XAD-2 and activated carbon) and also of a gas aspirator.

Concentration of each PAH was determined by means of a gas chromatograph (Trace-GC) equipped with ZB-5MS column and flame ionization detector.

Results and discussion

In Table 3 there are presented physico-chemical properties of both burned materials. FADR is a viscous, fatty substance that has dark colour and also a distinctive and characteristic odour. Texture/ /consistence of the substance changes into liquid in temperature above 30°C. From research represented in Table 1 it results that HFO as well as FADR have similar physico-chemical properties. Nonetheless FADR is characterized by lower ash and sulphur content, which is beneficial due to

TABLE 3. Physico-chemical properties of the distillation residues and reference fuel (heavy heating oil) used in the test (own studies)

Parameter	HFO	FADR
Density at 60°C [$kg \cdot m^{-3}$]	864	882
$T_{flashpoint}$ [°C]	250	227
Ash [%]	0.36	0.28
Dynamic viscosity [$Pa \cdot s^{-1}$]		
in 60°C	0.0570	0.0255
in 80°C	0.0244	0.0142
C [%]	85.0	76.6
H [%]	13.51	12.45
N [%]	0.56	0.85
S [%]	0.62	0.16
Cl [%]	< 0.050	< 0.005
Distillation beginning [°C]	168	98
to 235°C [%]	2.0	1.9
235–270°C [%]	1.8	1.0
270–300°C [%]	2.4	3.0
300–330°C [%]	5.5	52.5
330–360°C [%]	35.9	–
Distillation residue [%]	47.5	31.9
Distillation losses [%]	4.9	9.7
HHV [$MJ \cdot kg^{-1}$]	45.222	39.914
LHV [$MJ \cdot kg^{-1}$]	42.251	36.619

potential pollution emission during combustion. Both materials practically do not contain chlorine, which prevents formation of polychlorinated dioxins and furans in a combustion process. FADR has a lighter character than HFO. Distillation of FADR starts and ends in lower temperature. Main ingredient of distillation of a tested sample of FADR is boiling fraction in the range of 300–330°C (52.5%). In contrast for HFO – boiling fraction is in the range of 330–360°C (35.9%). Lower heating value of both tested products is on a similar level, although it is slightly higher for heating oil. The results of research shows that usefulness of the tested material (FADR) as a substitute or a component of heating oil.

During operation of the boiler with the maximum of the burner capacity, combustion process proceeded stably, without explicit differences related to type of the fuel burnt. The obtained temperature of the flue gas at the maximum capacity of the boiler for both fuels was fluctuating in the range of 295–325°C. Combustion of the additional fuel can occur as well as simultaneously as separately to the combustion of heavy heating oil. During the research it was not ascertained technological contraindications in area of mixing FADR with HFO. Both substances do not exhibit symptoms of mutual chemical interaction. For both fuels as well as their mixtures there could be used existing storage layout and handling fuel to oil boilers.

Changes of concentrations of basic ingredients of actual flue gases during tests are presented in Figures 2 and 3. Averaged values of concentrations of each ingredients of the flue gases meas-

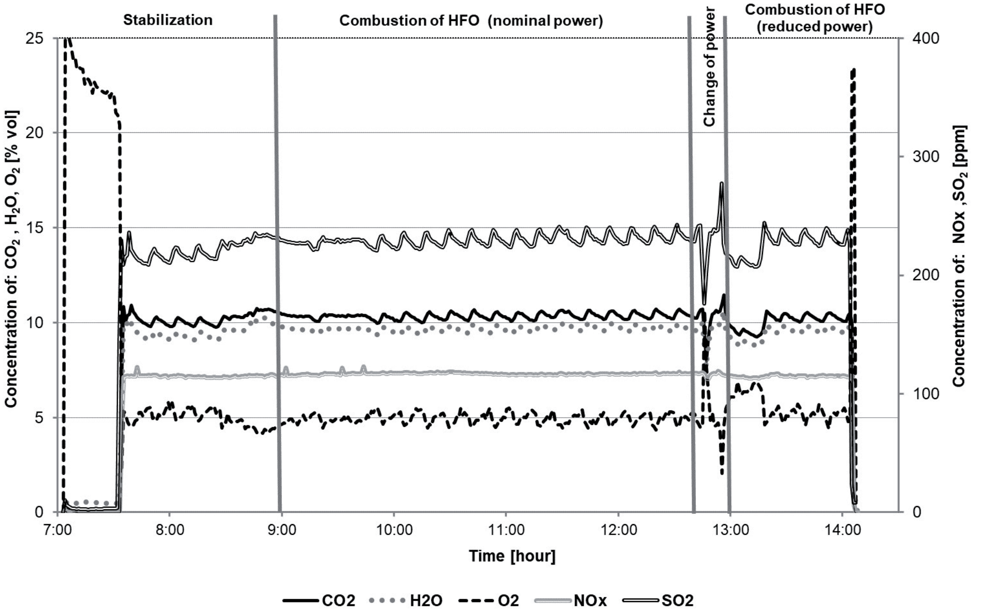

FIGURE 2. Concentration of main ingredients of the flue gases during combustion of heavy heating oil (real flue gases) (own studies)

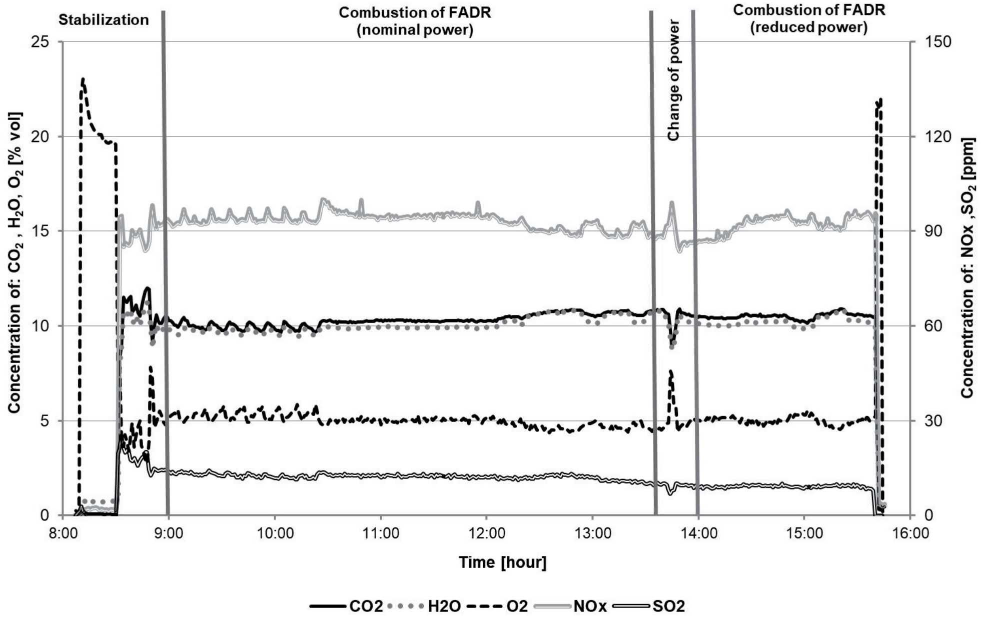

FIGURE 3. Concentration of main ingredients of the flue gases during combustion of the distillation residue (real flue gases) (own studies)

ured during stable work of the boiler are shown in Table 4.

In calculations of average values were neglected the temporary states of instability of the combustion process, which have taken place during combustion of the distillation residue of the fatty acids at the reduced capacity of the boiler.

TABLE 4. Main composition of the flue gases (real flue gases) during combustion of the reference fuel (heavy heating oil) and the fat acid distillation residue (own studies)

Compound	Unit	Mean value/Population standard deviation							
		HFO				FADR			
		nominal power		reduced power		nominal power		reduced power	
CO_2	%	11.57	0.12	11.69	0.65	11.60	0.17	11.84	0.09
CO	ppm	5.70	1.11	2.13	1.10	3.76	1.66	1.88	0.74
NO_2	ppm	0.08	0.25	0.10	0.30	0.00	0	0.00	0
NO	ppm	132.02	2.26	132.26	10.40	104.91	4.12	103.92	3.22
NH_3	ppm	0.001	0.01	0.00	0.00	0.380	0.38	0.050	0.05
SO_2	ppm	256.87	2.69	261.33	14.31	13.82	1.05	10.37	0.34
SO_3	ppm	0.00	0.0	0.00	0.0	0.34	0.13	0.47	0.05
COS	ppm	0.0071	0.01	0.0217	0.01	0.0002	0.0	0.0000	0.0
H_2O	%	10.80	0.11	10.93	0.64	11.29	0.24	11.49	0.16

The combustion process of both substances was stable during the tests. However, concentration of NO and SO_2 in flue gas presented insignificant fluctuations. It was observed that those fluctuations for HFO were more evident for reduced burner efficiency then for nominal. The data shown clearly indicates a lower emission of SO_2 during combustion of FADR, which derives mainly from the very low content of sulphur in this material. Also emission of nitric oxides in case of combustion of FADR was lower in comparison to heavy heating oil in spite of a bit higher content of this element (i.e. nitrogen) in FADR. It was found that the burner of the tested boiler works clearly more effectively at the level of higher capacity. This is reflected in comparison of emission of the same pollutants during combustion of each of the tested materials for two levels of boiler capacity (see Table 1). The only exception is emission of ammonia NH_3, which is higher during combustion of FADR. Concentrations of NH_3 calculated for the only one emitter of this compound do not exceed, however a 10% hourly reference value and do not exceed mandatory standards of air quality in Poland, which is evidence of its slight influence on air. The largest concentration fluctuations in

TABLE 5. Emissions of polycyclic aromatic hydrocarbons [$\mu g \cdot m^{-3}_n$] (own studies)

Compound	Emission (recalculated into 3% oxygen content in dry flue gas)			
	HFO		FADR	
	nominal power	reduced power	nominal power	reduced power
Naphtalene	1.5	4.9	2.7	0.9
Acenaphtylene	18.1	17.1	9.9	12.2
Acenaphtene	2.7	3.4	5.5	4.7
Fluorene	1.0	4.6	2.9	1.5
Phenanthrene	5.8	18.4	30.2	12.6
Anthracene	96.4	99.5	55.1	102.0
Fluoranthene	2.4	8.0	6.2	5.2
Pyrene	17.6	18.6	11.9	18.1
Benzo(a)anthracene	0.9	0.9	4.1	3.8
Chrysene	2.5	0.9	4.9	3.2
Benzo(b+k)fluoranthene	27.7	33.9	23.4	33.0
Benzo(e)pyrene	0.9	0.9	5.1	1.8
Benzo(a)pyrene	2.0	7.3	1.8	4.8
Perylene	111.5	7.2	5.7	4.9
Dibenzo(a,h)anthracene+indeno(1,2,3)pyrene	0.9	0.9	6.4	4.6
Benzo(g,h,i)perylene	0.9	0.9	9.1	4.1
Total PAHs	289.4	222.8	184.8	214.7

flue gas were observed for NO and SO_2 (with HFO much higher at reduced efficiency). In Table 5 there are arranged concentrations of each 16 PAHs in flue gases during combustion of HFO and FADR in a tested oil boiler (referred to the 3% O_2 content basis).

Although emission of PAH is not, in a tested case, limited by the emission standards however it is worth to notice that, despite differences for each hydrocarbons their combined concentrations in the flue gases are lower for combustion of FADR in comparison to HFO in both tested capacity levels of the boiler.

Measured emissions of the selected flue gas ingredients were compared with legal mandatory standards of emission. Values of acceptable emissions of NO_x, SO_2 and dust regarding combustion of liquid fuels were taken from the Resolution of Environment Minister from 1 March 2018 (appendix 4) and were compared to values obtained during phase of stable combustion of heavy heating oil and also of the distillation residue. This comparison is featured in Table 6.

Featured data indicates the fulfillment of the emission standards of SO_2, NO_x and ash regarding tested installation with combustion of both liquid fuels, but for FADR it has been observed twenty-fold lower emission of SO_2. Emissions of NO_x during combustion of FADR are 30% lower in comparison to combustion of HFO. Measurements of concentrations of particulates in the flue gases demonstrated that, both combusted materials have in this range a very similar characteristics. The level of ash/particulates emission for both fuels is noticeable, especially at the minimum capacity of the boiler. Admittedly still FADR is characterized by lower ash content in comparison to the tested HFO.

Conclusions

Physico-chemical properties of FADR point to possibility of using this material in a combustion process as a substitute of HFO or as a component of liquid fuel. During industrial tests it was stated that combustion of FADR in a tested oil boiler does not cause any difficulty and does not require intervention in existing technological layout of the boiler room. No threats were demonstrated related to the increase of pollu-

TABLE 6. Comparison of pollution emissions* during combustion of HFO and a FADR with the emission standards valid for the oil boiler installation (own studies)

Emitted substance	Unit	Permitted emission	Measured emission			
			HFO		FADR	
			nominal power	reduced power	nominal power	reduced power
SO_2	$mg \cdot m^{-3}_u$	850	813	827	44	33
NO_x	$mg \cdot m^{-3}_u$	400	300	300	239	237
Dust	$mg \cdot m^{-3}_u$	50	47.0	47.0	43.2	46.0

*Substance concentration in flue gas in stipulated conditions recalculated into 3% oxygen content in flue gas.

tion emission in to the atmosphere. Boiler installation meets emission standards required for combustion of liquid fuels. Combustion of FADR contributes to the reduction of the previous emission of pollutants from burning of the HFO, significantly in scope of SO_2. Energy usage of FADR can bring also additional ecological and economical effects, because this material is considered as zero emission biomass in relation to CO_2 (i.e. it is CO_2 neutral).

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Summary

Emission results of combustion process of fatty acids distillation residue in an oil boiler – comparison to heavy fuel oil. The results of the research on energy usage of the fatty acids distillation residue are presented. Distillation residue constitutes a material of biogenic origin, which is created only as a result of physical processing of animal fats without using additional chemicals. This material exhibits similar physicochemical properties as the heavy heating oil and may be its substitute. Industrial comparative tests of combusting of distillation residue and also of the heavy heating oil in an oil boiler were conducted. The research was conducted at the rated and minimum capacities of the boiler. It has been stated that combusting of the distillation residue of the fatty acids in a tested oil boiler does not bring about any technological difficulties. No threat of the elevated emission of pollutants into the atmosphere was exhibited. Installation of the boiler fulfill all emission standards required for combustion of the liquid fuels. Combustion of fatty acids distillation residue contributes to the reduction of the previous emission of pollutants from burning of the heavy fuel oil, significantly in scope of SO_2.

Authors' address:
Ryszard Wasielewski
(https://orcid.org/0000-0001-6955-2215)
Krzysztof Głód
(https://orcid.org/0000-0003-3863-1863)
Instytut Chemicznej Przeróbki Węgla
ul. Zamkowa 1, 41-803 Zabrze
Poland
e-mail: rwasielewski@ichpw.pl
kglod@ichpw.pl