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THE EMISSION OF GREENHOUSE GASES DURING CO-FIRING OF CHOSEN BIOMASS WITH COAL

Key words

Biomass, sunflower oil cakes, co-firing fuels, fumes emission, carbon dioxide, hydrocarbons.

Abstract

This paper presents the results of research on the contents of selected greenhouse gases generated during combustion of wastes from the food industry with conventional fuel. The work was conducted with the use of a KGS 100 kW retort boiler, a 2 MW steam boiler, and a KJ -WD 14 kW boiler hopper. In order to conduct the research, six fuels were used: coal in the form of "eco-pea II" granulation 5-25 mm grain size and mixtures of carbon that is eco-pea and sunflower oil cake in the following mass ratios: 20:1, 10:1, 17:3, 5:1, and 4:1. Measurements taken during the research were of the concentrations of CO_2 and C_xH_y in exhaust fumes generated after burning the above-mentioned fuel in boilers with a constant amount of air supply that comprise their typical working conditions.

Based on the research on the process of co-firing sunflower oil cakes and eco-pea, it was stated that the concentration of carbon dioxide and hydrocarbons in the fumes decreases while increasing the oil cake content in the fuel in low, medium, and high power boilers, and the trend can be described by a linear function.

Introduction

Greenhouses gases are chemical compounds present in the Earth's atmosphere that lead to the retention of solar energy. Those are mainly carbon dioxide, nitrous oxide, water vapour, methane, Freons, and ozone. There has been an increase of these gases in the atmosphere over the last years, mainly due to burning fossil fuels, which causes an increase in the Earth's climate temperature [1–3]. This is why actions are taken, technological and legislative, aimed at limiting the burning of coal and replacing it with biomass or introducing co-firing of coal and biomass.

Issued by the EU, "a climate and energy package," which describes a system for trading allowances for greenhouse gas emission, obliges the EU members to decrease greenhouse gas emissions by the year 2050, including CO_2, by 50% compared with the level present in 1990. That is why using technologies, which reduce the greenhouse gas emissions, is an important aspect in protecting the atmosphere. One way of achieving this goal is by co-firing biomass with coal in coal boilers, because biomass is a renewable energy source causing a decrease in CO_2 emissions.

The Ordinance of the Minister of Economic Affairs of 19 December 2005 defines biomass as substances of plant or animal origin, solid or liquid, which are subject to biodegradation, originating from products, waste, and residue from agriculture and forestry, as well as from industry processing their products and elements of other biodegradable wastes.

Current food production technology processes generate a great deal of waste, which can be declared as biomass and utilized by co-firing with coal [4, 5]. An example of such a product may be oil cake, which is an abundant by-product of the sunflower oil manufacturing process [6–8]. The oil cakes are leftovers from the process of making sunflower oil, consisting of, depending on the kind and variety of the plant used, 45 to 65% of dry mass of seeds used in the process. This means that, for a tonne of pressed oil, there is a tonne of oil cakes. Their calorific value is 24 MJ/kg (for comparison: the calorific value for coal is 26-27 MJ/kg) [8–10], it is therefore feasible to use them.

The goal of this research was to examine the effect of biomass presence in the form of sunflower oil cakes in fuel mixtures on greenhouse gas emissions generated during co-firing in small, medium, and high power boilers.

1. Methodology

1.1. Fuel mixtures

Mixtures of 5-25mm eco-pea coal and sunflower oil cakes were tested at the following mass ratios: 20:1, 10:1, 17:3, 5:1, and 4:1. Physicochemical and calorific properties of each component are described in Table 1.

Table 1. Selected properties of fuels used in tests

Parameter	„Eco-pea" coal	Oil cakes
sulphur content [% m/m]	0.6	0.2
calorific value [MJ/kg]	26	25.6
ash content [% m/m]	7	6.2
particle size [mm]	15.3	–
protein content [% m/m]	–	30
fat content [% m/m]	–	8.5
fibre content [% m/m]	–	18.6
moisture [% m/m]	–	11

It was assumed that comparable calorific values of eco-pea coal and oil cakes do not have a significant influence on the energy aspects of the combustion process.

1.2. Combustion conditions

The obtained results were verified on research stations equipped with a KJ -WD14 kW hopper boiler, a KGS 100 kW retort boiler, and a 2 MW steam boiler. Starting batches of coal (i.e. 5, 100 and 200 kg) were supplied to the combustion chambers of 14 kW, 100 kW, and 2 MW (respectively), and the ignition process was initiated. After the combustion of pure coal had stabilized, mixtures of eco-coal (5, 25, and 100 kg) and oil cakes (0.25, 1.25, and 5 kg, respectively) were supplied to the combustion chambers. Testing was conducted with the air/fuel ratio of 1.80 for a 14 kW boiler, 2.10 for a 100 kW boiler, and 2.40 for a 2 MW boiler. A similar procedure was used for subsequent mixtures in which the following amounts of oil cakes were added to 5, 25, and 100 kg batches of eco-coal: 0.5 kg, 0.75 kg, 1 kg, and 1.25 kg (14 kW boiler); 2.5 kg, 3.75 kg, 5 kg, and 6.25 kg (100 kW boiler); and 10 kg, 15 kg, 20 kg, and 25 kg (2MW boiler). The amount of biomass component was chosen so that it amounted to 4.8, 9.1, 13, 16.7, and 20% of the whole input.

1.3. The method of analysing exhaust composition

A Madur GA-21 analyser was used to analyse the effects of combustion with an electrochemical sensor, which enabled the researchers to measure the amount of C_xH_y in exhaust gases. It also employs an infrared absorption sensor measuring the amount of CO_2. The measuring probe was installed perpendicularly to axis of the boiler's flue. Measurements were started 15 minutes after supplying the fuel mixture to the combustion chamber. The assessment of carbon dioxide and hydrocarbon concentrations was done using arithmetic mean from three series of measurements, each consisting of 300 measurements at a rate of 30 per second. Each measurement series was conducted on a separate day.

2. Results

A comparison of effect of the presence of oil cakes in the fuel mixture on the CO_2 concentration in exhaust gases measured for low, medium, and high power boilers is presented in Figs. 1–3.

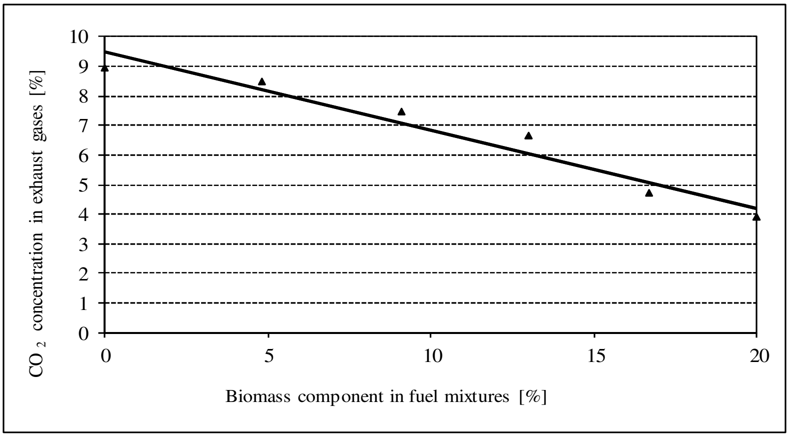

Fig. 1. CO_2 concentration in exhaust gases from a 14kW boiler

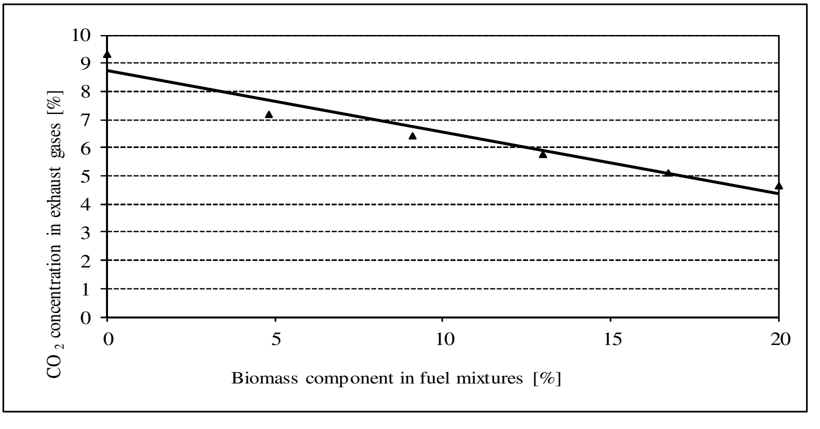

Fig. 2. CO_2 concentration in exhaust gases from a 100 kW boiler

Combustion of eco-coal in the 14 kW boiler generates 8.96% CO_2, whereas a mixture of 9.1% oil cakes and 90.9% coal leads to a decrease of CO_2 concentration to 7.45%. Increasing the oil cake amount to 16.7% resulted in a decrease of CO_2 concentration to 4.72. The analysis of the combustion of 80% coal and 20% oil cakes mixture was also conducted. In this case, the CO_2 concentration dropped to 3.89%.

Combusting coal in the 100kW retort boiler generates 9.34% CO_2. During the combustion of a mixture consisting of 9.1% oil cakes, CO_2concentration was at 6.44%. Increasing the oil cake amount in the mixture to 16.7% resulted in a decrease of CO_2 concentration to 5.12. The analysis of the combustion of 20% oil cakes and 80% eco-coal mixture was also conducted. During the process, a further decrease of CO_2 concentration was reported, reaching 4.66%.

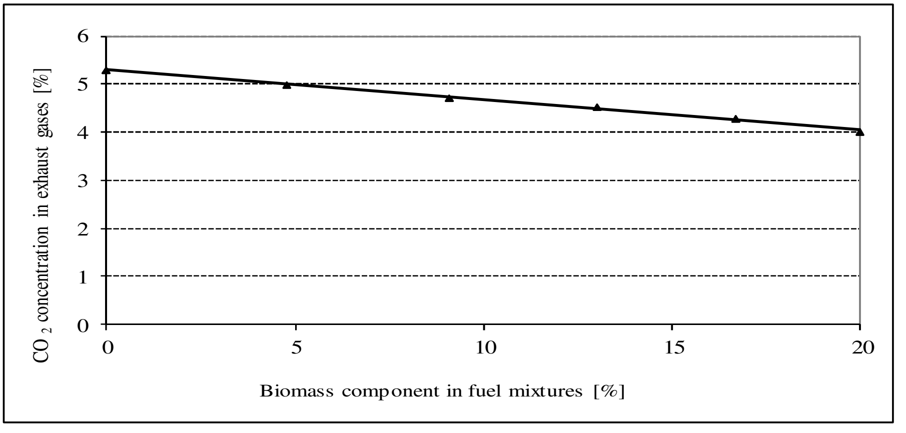

Fig. 3. CO_2 concentration in exhaust gases from a 2MW boiler

Conducting coal combustion in a 2 MW boiler generates 5.28% of CO_2 in exhaust gases. During the combustion of a mixture consisting of 9.1% oil cakes and 90.9% coal, the CO_2 concentration was at 4.71%. Increasing the biomass component in the fuel mixture to 16.7% led to a decrease in the CO_2 concentration to 4.28%. Further increasing the oil cake component amount to 20% led to a decrease in CO_2 concentration to 3.99%.

The biggest decrease in CO_2 concentration was observed during the combustion of a mixture consisting of 20% oil cakes in low and medium power boilers. The smallest decrease was observed in the high power boiler. CO_2 emission is relative to coal presence in the fuel mixture. Therefore, increasing the oil cake presence leads to a decrease in CO_2 concentration in exhaust gases.

Figure 4 presents the results of the influence of oil cake presence on hydrocarbon concentrations in exhaust gases in low, medium, and high power boilers.

Combusting coal in the 14 kW boiler generates 503 ppm C_xH_y, whereas combusting a mixture of 9.1% oil cakes and 90.9 coal results in a decreased concentration of hydrocarbons at 413 ppm. Increasing the biomass component in the fuel mixture to 16.7% led to a decrease in C_xH_y concentration to 307.5 ppm. The analysis of the combustion of 80% eco-coal mixture and 20% oil cakes was also conducted. In this case, a further decrease in C_xH_y concentration to 278.6ppm was observed.

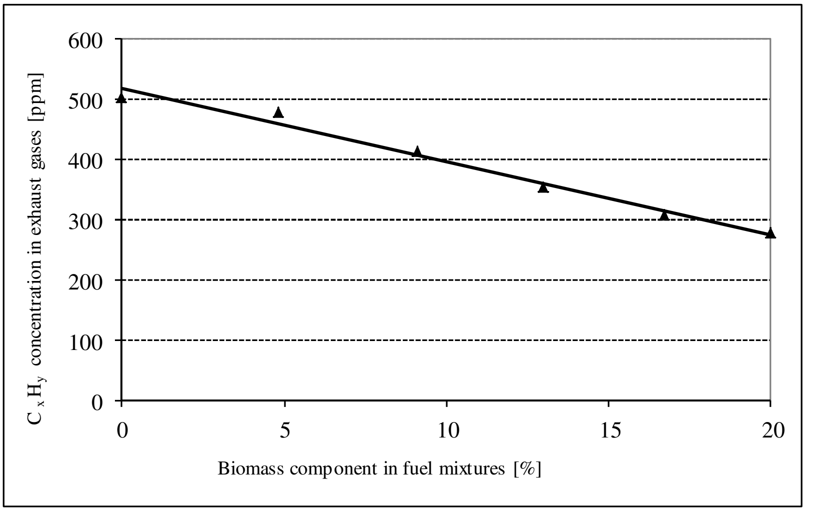

Fig. 4. Hydrocarbon concentrations (C_xH_y) in exhaust gases emitted from a 14 kW boiler

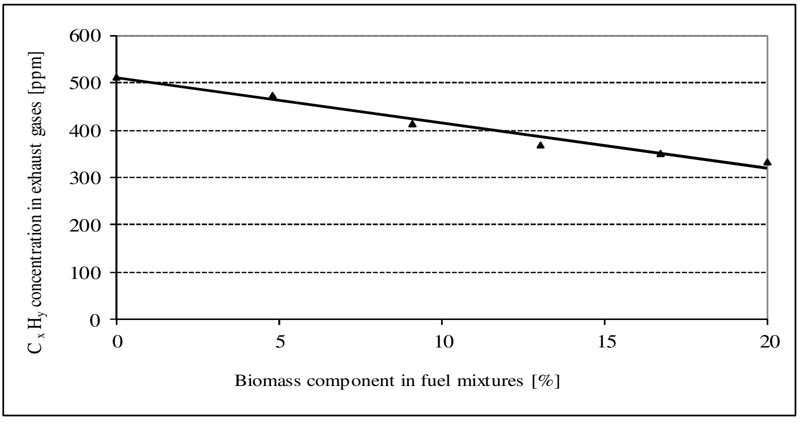

Fig. 5. Hydrocarbon concentrations (C_xH_y) in exhaust gases emitted from a 100 kW boiler

Combusting coal in the 100 kW retort boiler generates 513.4 ppm C_xH_y. During combustion of a mixture consisting of 9.1% oil cakes, hydrocarbon concentrations were at 413.5 ppm. Increasing the biomass component in the fuel mixture to 16.7% led to a decrease in C_xH_y concentration to 350.3 ppm. The analysis of combustion of 20% oil cakes and 80% eco-coal mixture was also conducted. During the combustion of such a mixture, a further decrease in C_xH_y in the exhaust to the level of 332.3 ppm was observed.

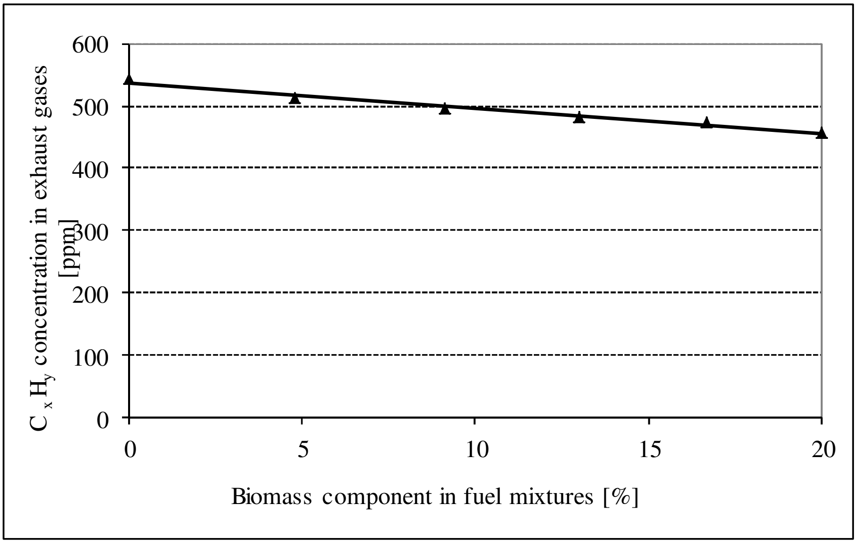

Fig. 6. Hydrocarbon concentrations (C_xH_y) in exhaust gases emitted from a 2MW boiler

Combusting eco-pea coal in the 2 MW boiler generates 542.5 ppm C_xH_y. During combustion of a mixture of 9.1% oil cakes and 90.9% coal, hydrocarbon concentrations were at 496 ppm. Increasing the biomass component in the fuel mixture to 16.7% led to a decrease in the hydrocarbon concentration to 474 ppm. Further increasing the oil cake component amount to 20% resulted in a decrease in the C_xH_y concentration to 456.3 ppm. The biggest decrease in the C_xH_y concentration in exhaust gases was observed during the combustion of a mixture consisting of 20% of oil cake presence in low and medium power boilers. The smallest decrease in the C_xH_y concentration in exhaust gases was observed in the high power boiler.

Summary

Analysing greenhouse gases concentration in exhaust gases resulting from combusting coal and mixtures of coal with increasing amounts of oil cakes, it can be concluded that CO_2 and C_xH_y concentrations decreased, providing that the amount of oil cakes presence in the mixture increased in fuel mixtures in low, medium, and high power boilers. During carbon dioxide and hydrocarbon concentration analyses for low, medium, and high power boilers, it was noted that the decrease in aforementioned parameters is linear for each boiler type. However, the decrease in CO_2 and C_xH_y concentration is unique for all boiler types. The biggest decrease in carbon dioxide and hydrocarbon concentrations was observed in the 14 and 100kW boilers, whereas the decrease for the 2MW boiler was half as high as for low and medium power boilers.

The conducted research revealed that co-firing eco-pea coal and oil cakes added to the fuel mixture in amounts no smaller than 20% in low and medium power boiler decreases carbon dioxide emission by 50% and hydrocarbons by 15%, which fulfils relevant EU regulations. Nearly twice as low emission of described parameters in high power boilers compared with low and medium power boilers can be caused by lower efficiency of 2MW boiler compared with the efficiency of 100kW retort boiler or 14kW hopper boiler.

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References

1. Karcz H., Butmankiewicz T., Pędzik P.: Ograniczenie emisji gazów cieplarnianych, a możliwości paliwowe polskiej energetyki, Piece Przemysłowe&Kotły, 7–8/2013, s. 8–20.
2. Rozewicz Z.: Efekt cieplarniany, a zmiany klimatyczne, Energetyka 6/2002, s. 385–388.
3. Barchański B.: Węgiel jako surowiec energetyczny, a efekt cieplarniany, WUG: bezpieczeństwo pracy i ochrona środowiska w górnictwie, 1/2009, s. 3–13.
4. Kurczabiński L.: Kwalifikowane paliwo węglowe do niskoemisyjnych kotłów nowej generacji – Instal 4/5/2006 s. 77–78.
5. Malińska K.: Problemy ochrony środowiska w przedsiębiorstwach przemysłu spożywczego. Instytut Inżynierii Środowiska Politechnika Częstochowska – VII Ogólnopolska Sesja Popularnonaukowa „Środowisko a zdrowie – 2005", Częstochowa, 2–3 czerwca 2005 r. – materiały konferencyjne.
6. Chmielak T.: Technologie energetyczne. WNT, Warszawa 2008.
7. Kaltschmitt M., Hartmann H., Hofbauer H.: "Energie aus Biomasse", Springer Verlag, Berlin 2001, s. 427–477.
8. Obidziński S.: Ciepło spalania i wartość opałowa odpadowych surowców pochodzenia roślinnego. Inżynieria Rolnicza, 4/2002, s. 37.
9. Cieślikowski B., Juliszewski T., Łapczyńska-Kordon B.: Utylizacja na cele energetyczne produktów ubocznych technologii biopaliw. Inżynieria Rolnicza. Nr 12/2006, s. 51–57.
10. Gradziuk P.: Możliwości wykorzystania surowców pochodzenia rolniczego na cele energetyczne. Roczniki Naukowe Stowarzyszenia Ekonomiczno-Rolniczo-Agrobiznesowego Seria. T. 1, Z. 3, 1999, s. 233–238.

Emisja gazów cieplarnianych podczas współspalania wybranej biomasy z węglem kamiennym

Słowa kluczowe

Biomasa, makuchy słonecznikowe, współspalanie paliw, emisja spalin, ditlenek węgla, węglowodory.

Streszczenie

W publikacji przedstawiono wyniki badania zawartości wybranych gazów cieplarnianych powstających podczas procesu spalania odpadów z przemysłu spożywczego paliwem konwencjonalnym. Prace były prowadzone z wykorzystaniem kotła retortowego typu KGS o mocy 100 kW, kotła parowego o mocy 2 MW oraz kotła zasypowego typu KJ-WD o mocy 14 kW. Do realizacji tego zadania badawczego użyto sześciu paliw, tj. węgla kamiennego w postaci tzw. ekogroszku sortymentu groszek II granulacji 5–25 mm oraz mieszanin węgla w postaci ekogroszku z makuchami słonecznikowymi w stosunku masowym 20:1,10:1, 17:3, 5:1, 4:1. Oceniono stężenie CO_2 oraz C_xH_y w spalinach powstałych po spaleniu wyżej wymienionych paliw w warunkach stałej ilości dostarczonego powietrza typowej dla standardowej pracy poszczególnych kotłów.

Na podstawie wyników badań procesu współspalania makuchów słonecznikowych z ekogroszkiem stwierdzono, że stężenie CO_2 i węglowodorów w spalinach spada wraz ze wzrostem zawartości makuchów w paliwie podczas prowadzenia badań w kotłach małej, średniej i dużej mocy, a trend tej zależności można opisać funkcją liniową.