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Marek SWAT
Institute for Sustainable Technologies – National Research Institute, Radom
marek.swat@itee.radom.pl

METHOD FOR ECOLOGICAL COMBUSTION OF ORGANIC WASTE IN COMMERCIAL LOW POWER BOILER

Key words

Biomass, biomass combustion, energetic efficiency, ecological efficiency.

Abstract

The structure of primary energy in Poland still is formed by a high position of coal from domestic resources. The widespread use of this fuel encourages and facilitates “co-combustion of biomass with coal” in power boilers. Differences in the structure and behaviour during the preparation and combustion of coal and vegetable fuel are the cause of the difficulties with co-combustion of raw biomass in power boilers. Based on research, the effect of biomass characteristics on the basic parameters of the process of combustion and co-combustion of coal in a low-power boiler device was determined. Changes in excess air-ratios and exhaust gas temperatures, and changes in the concentrations of toxic components of exhaust gases during the combustion process were determined. The amount of heat generated in the boiler during the combustion of biomass and fuel blends of biomass and coal was determined. Controlled changes in process parameters of combustion conditions

(co-combustion) of coal and selected types of biomass allow for environmentally friendly combustion in commercial low-power boilers.

Introduction

The use of renewable energy sources has become an essential part of the energy industry. This condition is imposed by the European Union. Poland has committed to use 7.5% of primary energy from renewable sources in 2010, and this number is to be increased to 15% by 2020. Research centres, where numerous studies have been conducted, and investors of small and medium-sized enterprises in the country and the world have been interested in renewable energy sources, especially biomass for many years [2, 6, 9, 12, 17, 19]. The main direction of the use of biomass in Poland is heat production based on the direct combustion of the fuel in boilers.

Co-combustion is considered to be the easiest way to increase the production of energy from renewable sources. This is due to the relatively low funding for the modernization (the possibility of using existing boilers) and ecological benefits (reducing emissions of SO_2, NO_x and CO_2) [5, 7, 9, 17, 19, 21]. Disadvantages of the use of such combustion are currently problems associated with ensuring availability of biomass, sufficient storage of biomass, and the uncertainty associated with the constant increase of biomass. Biomass can cause environmental hazards and operational problems in the installation [3, 4, 9, 15, 19].

In Poland, the co-combustion of biomass and solid fuel is practically carried out on an industrial scale in most power plants [4, 16]. This process includes a variety of fuel configurations (different species of primary fuels and biomass) and technological configurations (grate boilers, dust boilers and fluid boilers). The research [1, 10, 11, 14, 17, 21] shows that the most common fuel is carbon co-combusted with wooden biomass (sawdust, wood chips, dust), biogas and waste from animal and vegetable production (rapeseed bagasse, chicory coffee bagasse, and bone meal, etc...) According to the authors, biomass, depending on the type, is characterized primarily by a relatively high humidity (35–50%) and low calorific value (6–20 MJ/kg) as compared to conventional fuels parameters.

“Small energetics” (individual heating, small industrial and municipal boilers) having a significant share of the total emissions of the environment, remains in the "grey zone" because of the lack of regulation of the interference in the use of technology to ensure compliance with emission standards for combustion processes. The share of small energetics in the process of energy production is estimated at 20–30% in the country [20], and, because of the poor condition of the operated installation, the sector's share of total emissions is much higher. Despite the dynamic development of the construction of small solid fuel boilers, devices are still operated with low efficiency and high emission rates.

1. Aim of the work

The aim of the work was to recognise the effect of biomass properties on the basic parameters of the processes of combustion and co-combustion with coal in low power boilers.

2. Realisation

The presented experiments involved the power processing of fuel mixtures prepared of waste materials derived from the food industry (cherry processing waste and sunflower oil pulp) and of coal.

The selected materials were subjected to laboratory tests to evaluate their properties such as fuel ash content, calorific value, the fuel elemental (C, H, N, S).

The essential parts of the work were conducted on a test stand that included a low-power boiler unit adapted to burning coal.

In the course of experiments conducted with the optimal parameters of boiler operation, the temperatures inside the furnace and thermal performance of the device were controlled. Observed factors were the temperature and composition of the gases emitted into the atmosphere.

3. Test stand

The basic element of the test stand was a low power energy device designed to burn solid fuels, mainly coal.

The stand used a universal boiler type KJ-WD, with a thermal output of 15 kW, from PPHU "PIECBUD".

The stand is equipped with a system for measuring and recording the temperature in the combustion chamber and in the exhaust system. The combustion chamber has a system of three sliding temperature sensors (special sleeves in the water jacket) with heat-resistant guards with K-type thermocouples and temperature recorder type KD7 manufactured by Kobold.

A combustion chamber of the boiler is equipped with a system for measuring the amount of air supplied to the combustion. To measure the amount of air used, the Hoffer turbine (probe RPR-51S HO) used flow laminators and mass flow rate computers (Masstrol ST2L10P from KEP). For the analysis of the exhaust gas, a microprocessor analyser (GA-21 plus) is used from Madura. To measure the concentrations of hydrocarbon an MC-218 analyser from Hermann was used. The stand is equipped with a system for measuring and recording the energy output of the boiler during combustion. Measurements of the energy of the boiler were performed with an electronic energy meter (PolluTerm) from SENSUS, which registers the energy of heating medium (GJ) and the momentary power (kW).

4. Test results

Before the tests, the fuel properties were assessed, starting with determining the basic chemical composition of the materials used in the study. The results of elemental composition tests of prepared fuel compositions are shown in Table 1.

Table 1. The composition of elements in tested fuels

Type of fuel	Element concentration [%]				
	Coal	Hydrogen	Oxygen	Nitrogen	Sulphur
Coal ("Eco-grain")	75.74	5.35	6.7	1.49	0.69
Cherry processing waste	43.5	6.4	43.7	0.70	0.14
Sunflower pulp	45.2	5.1	38.1	0.15	0.11

From the materials listed above, the fuel mixtures were prepared, which were used for further tests. Table 2 shows the basic parameters of the tested fuels.

Table 2. The basic parameters of the tested fuels

Type of fuel	Parameter			
	Humidity	Ash	Fly particles	Calorific value [MJ/kg]
	[%]			
Coal ("Eco-grain")	6.37	7.25	32.3	28.5
Cherry processing waste	7.3	1.33	80.8	17.1
Sunflower pulp	8.1	4.32	72.7	16.1

Figs. 1 to 8 presents the results of the combustion of fuels derived from food processing waste (cherry processing waste, sunflower oil pulp). Figure 1 shows the change in the excess air ratio λ during the combustion of selected fuels. The presented data indicates that this parameter fluctuated around the value 2. In all cases, the combustion of fuels of the process a small change of the excess air ratio was observed in the period of 20 to 100 minutes. Coal in the same time period required changes of λ ~2.2, cherry processing waste λ ~2.0, sunflower oil pulp λ ~1.8. This time period can be for all test cases considered to be the primary process of laminar combustion, which is the stabilisation of changes of excess air ratio and the temperature of the process. The biggest change of the excess air ratio was found in all cases of combustion at the beginning and end of the process. The beginning is a rapid combustion of vaporized fly particles of fuel with the simultaneous propagation of flame in a large mass of fuel on the grate. The smallest change of λ was found for cherry processing waste (from 3.9 to 1.9). The end of the combustion process is the inhibition of oxidation by combustion products of the primary process. Combustion in this period requires the smallest changes of λ for sunflower oil pulp and cherry processing waste (from 2.0 to 4.5 and 4.7), and the largest changes were required for coal (from 2.2 to 5.9).

There was a momentary slight change of the λ in a few cases (involving a mixture of 50, 25 and 15% of the cherry processing waste and sunflower oil pulp), resulting from changes in the composition of the instantaneous fuel blends, due to differences in their density. Despite the very good mixing of the components before the tests, their partial separation occurred during fuel delivery, which results in an erratic operation of the furnace. No indication was observed that the composition of fuel mixtures on the grate furnace burned directly affect the value of the excess air ratio (λ).

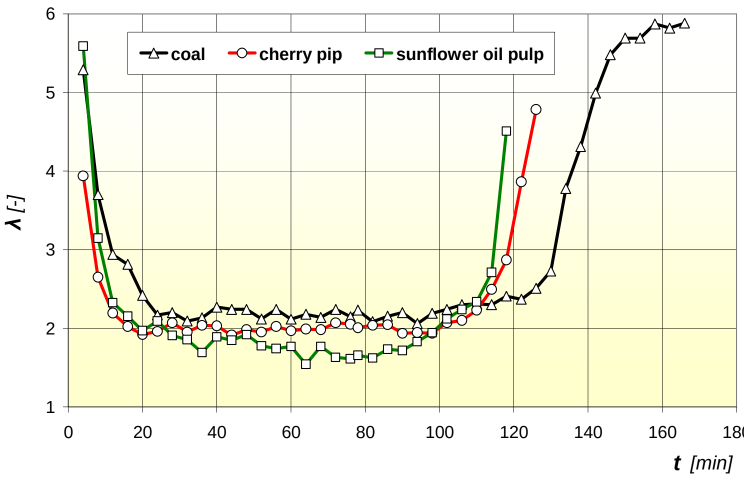

Fig. 1. Variation of excess air ratio during combustion of coal, cherry processing waste and sunflower oil pulp

In whole combustion process, the average excess air ratio was greatest for coal, $\lambda_{av\,c} = 3.03$, and smallest for cherry processing waste, $\lambda_{av\,p} = 2.28$ (see Fig. 8).

Figure 2 presents the changes of the exhaust gas temperature measured in the exhaust pipe. During the tests, the temperature varied in the range 150–350°C, taking the most common values in the range of 200–330°C.

Comparing the obtained data with the values of the excess air ratio (λ), it can be concluded that increasing the exhaust temperature decreases the coefficient λ, and, conversely, the exhaust gas temperature decrease is observed as an increase of excess air ratio. It follows that with constant amount of fuel dispensed into the combustion the factor that effects the coefficient λ and exhaust gas temperature may be the amount (portion) of fuel combusted at any given time on the grate of the furnace.

In all performed fuel combustion processes, it was observed (following the sharp increases of exhaust gas temperatures in the beginning – the combustion of evaporated fly particles) that the speed of the exhaust gas temperature rise was slowed (locally reduction of the temperature of the process) in relation to the takeover of power by the fuel bed on the grate of furnace.

The lowest average exhaust gas temperature in the whole combustion process (see Fig. 9) was observed for sunflower oil pulp, Tav sp = 187°C, the largest for coal "eco-grain", Tav c = 256°C.

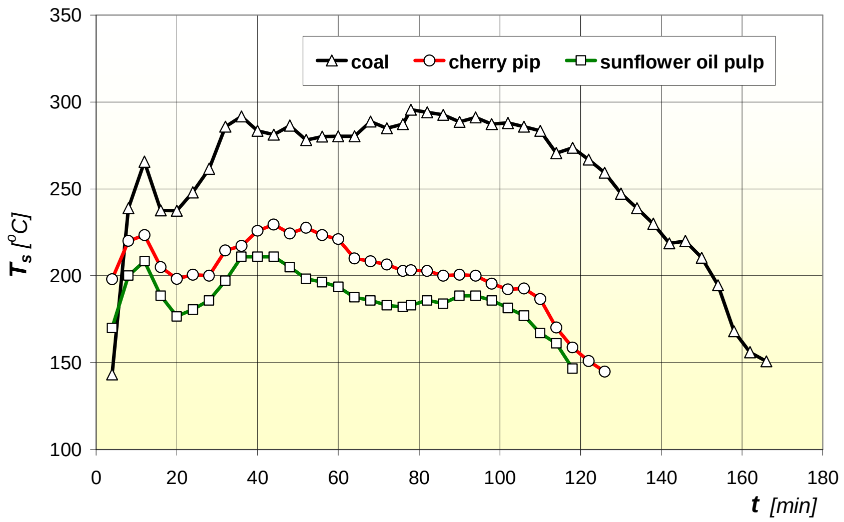

Fig. 2. Variation of temperature of exhaust gases during combustion of coal, cherry processing waste and sunflower oil pulp

Figure 3 presents a comparison of the energy values received by the heat installation during combustion tests of coal or selected types of biomass, and Figs. 4 and 5 present the energy obtained during combustion of fuel mixtures of coal and biomass.

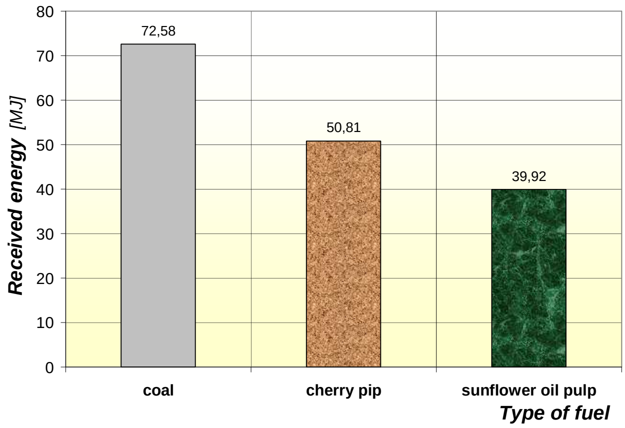

Fig. 3. The amount of heat energy generated in the system of boiler during combustion of coal, cherry processing waste and sunflower oil pulp

The presented data shows that, during the combustion of the same mass of fuel in similar conditions of the thermal process, the energy produced increases with the decrease in the share of biomass in combusted fuel blend from 41.09 MJ for fuel with 100% sunflower oil pulp (50.81 MJ for cherry processing waste) to 72.58 MJ for fuel composed of 100% carbon.

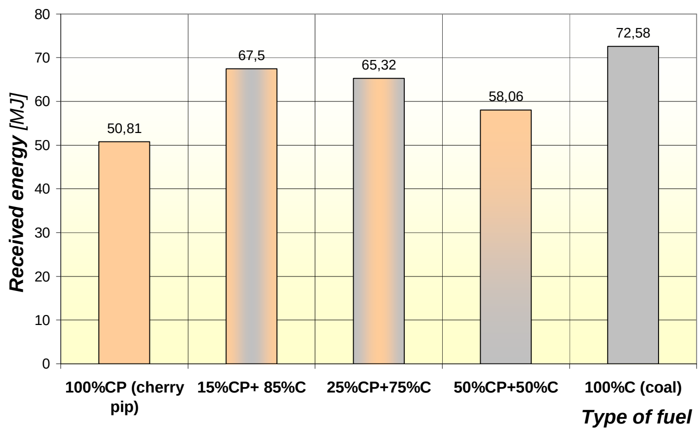

Fig. 4. The amount of generated energy in the boiler during combustion of mixtures of cherry processing waste and coal

It has been found that the energy obtained from the combustion of cherry processing waste, compared to the energy obtained from the combustion of coal is 10% greater than the result from the comparison of calorific values of these two fuels. The uniform, regular, spherical particle size of bulk cherry processing waste (greater surface in contact with air) makes the process of combustion increase the thermal efficiency of the boiler. The combustion of fuel mixtures of coal and cherry processing waste (50, 25, and 15%) results in energy comparatively close to the ratio of calorific values of these mixtures.

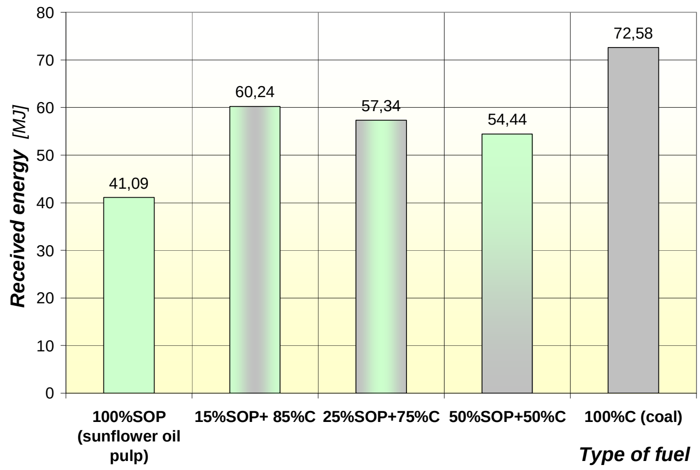

Fig. 5. The amount of generated energy in the boiler during combustion of mixtures of sunflower oil pulp and coal

Tables 3 and 4 show the comparison of the calorific value and the energy generated during the combustion of the different varieties of mixtures of biomass with coal. Only for the case of the combustion of pure sunflower oil pulp was the obtained energy close to the ratio of calorific values sunflower oil pulp and coal. For other cases of the combustion of mixtures, the thermal efficiency of boiler was decreased.

Table 3. Calorific value and obtained energy for combustion of mixtures of cherry processing waste and coal

Mixture composition [%]		Calorific value [MJ/kg]	Received energy [MJ]	W_{pip}/W_{coal} [%]	E_{pip}/E_{coal} [%]
Cherry processing waste	Coal				
100	0	17.1	50.81	60	70
50	50	23.1	58.06	81	80
25	75	25.8	65.32	91	90
15	85	26.8	67.5	94	93
0	100	28.5	72.58		

Table 4. Calorific value and obtained energy for combustion of mixtures of cherry processing waste and coal

Mixture composition [%]		Calorific value [MJ/kg]	Received energy [MJ]	W_{pulp}/W_{coal} [%]	E_{pulp}/E_{coal} [%]
Sunflower oil pulp	Coal				
100	0	16.1	41.09	56	55
50	50	22.6	54.44	79	75
25	75	25.6	57.34	89	79
15	85	26.7	60.24	93	83
0	100	28.5	72.58		

Figures 6–8 present the concentration of toxic gaseous combustion products for the analysed types of biomass and coal.

Figure 6 shows the changes in the concentration of carbon monoxide in the exhaust gas. The presented data shows that, in the initial stage of combustion, the temperature rise in the furnace caused a decrease in the concentration of CO from about 1600 ppm for coal to about 800 ppm in the main, laminar combustion stage. For cherry processing waste and sunflower oil pulp, the concentrations were 1300–1600 ppm in the beginning and 500–600 ppm during laminar stage.

Probably the primary factor affecting the value of the carbon monoxide concentration was a momentary temperature of the furnace. The low temperature of about 200–400°C in the initial period caused that the oxidation process of steam-gas produced in the furnace proceeded with relatively low yield. The temperature increase to a level 700–900°C during the laminar stage meant that a substantial part of gases produced was combusted. The reason for the observed temperature rises in the later period was the energy derived from the combustion of previously emitted carbon monoxide and hydrocarbons.

Analysis of the results of the effect of the excess air supplied to the combustion of coal and biomass on the concentration of carbon monoxide confirm the fact resulting from the analysis of the combustion process that increasing the value of the excess air ratio usually corresponds with the decrease of the carbon monoxide concentration in the exhaust gas.

In addition, analysis of the results of the effect of temperature in the combustion zone on the concentration of carbon monoxide, resulting in co-combusted of the blends, confirms the fact resulting from the analysis of the combustion process of fuel components that an increase in combustion temperature causes a decrease in the concentration of CO in the exhaust gas. The reduction in CO emissions was observed for all the tested mixtures at a constant load and constant excess air ratio supplied to the combustion chamber.

During combustion, the lowest mean CO concentrations were found for cherry processing waste – 661 ppm, and the largest was found for coal – 1013 ppm (see Fig. 8).

The increase in the percentage of biomass in a mixture with coal resulted in a proportional decrease (cherry processing waste, sunflower oil pulp) of the concentration of carbon monoxide in the exhaust gas.

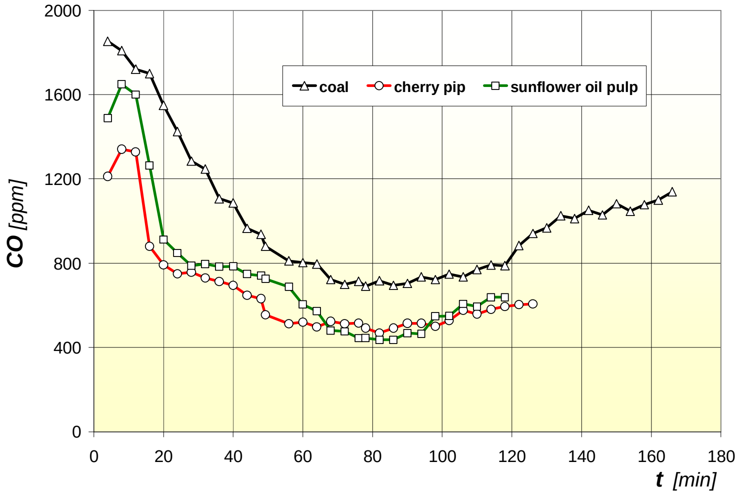

Fig. 6. Variation of carbon monoxide concentration in exhaust gases during combustion of coal, cherry processing waste and sunflower oil pulp

Analysis of the results of the effect of temperature in the combustion zone on the concentration of nitrogen oxides formed during the combustion of biomass and coal indicates that the increase in combustion temperature causes an increase in the total concentration of nitrogen oxides NOx in the exhaust gas.

In the combustion of coal, NOx held the largest share of the high values of oxide concentrations in fuels, both because of the amount of elemental nitrogen in fuel (1.49%) and because of the relatively high excess air ratio (λ ~2.2) in the main laminar combustion stage. The thermal oxides during combustion only occurred at high temperatures (above 700°C).

The result of combustion of cherry processing wastes was the formation of the lowest values of average concentrations of NOx ($NO_{x\ av\ p}$ = 103 ppm – see Fig. 8) in the whole process, mainly thermal oxides, even though the fuel contained 4 times the amount of elemental nitrogen than the sunflower oil pulp. In this case, the lowest average excess air ratio $\lambda_{av\ p}$ = 2.28 and low average temperature of combustion (exhaust gas temperature $T_{s\ av\ p}$ = 202°C) had the dominant role.

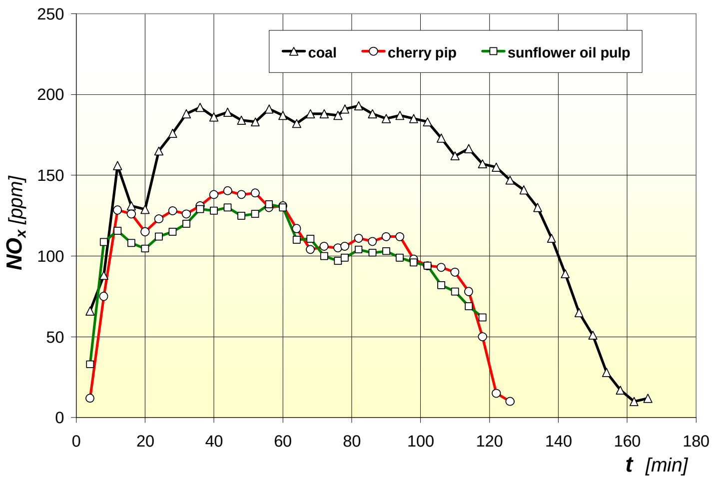

Fig. 7. Variation of nitrogen oxides concentration in exhaust gases during combustion of coal, cherry processing waste and sunflower oil pulp

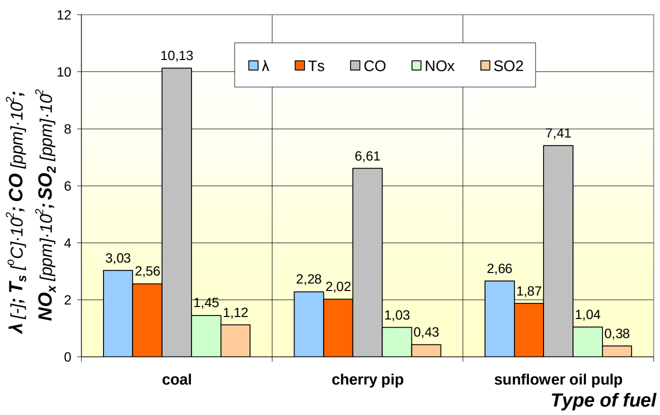

Fig. 8. Average values of changes of excess air ratio, exhaust gas temperature, carbon monoxide concentration, nitrogen oxides concentration and sulphur dioxides in exhaust gases during combustion of coal, cherry processing waste and sunflower oil pulp

The results of nitrogen oxide emissions during the combustion of coal and biomass blends, as expected, show an increase in the concentrations of NO_x due to the increase in the percentage of carbon in the blend during co-combustion of cherry processing waste and sunflower oil pulp.

Analysis of the results of the effect of the type of fuel on the concentration of SO_2 formed in the combustion process leads to the conclusion that the emission of sulphur dioxide in the exhaust gas is mainly dependent on the elemental content of elemental sulphur in fuels tested.

During the study of combustion of coal, cherry processing waste and sunflower oil pulp the SO_2 concentration was found to be proportional to the sulphur content in the fuel.

Generally, it can be said that the increase in the percentage of biomass with coal mixtures reduces SO_2 emissions during combustion.

Conclusions

- Changes in process parameters, for both the combustion conditions, as well as the co-combustion of coal and certain types of biomass and its impact on emissions of pollutions (CO, NO_x, SO_2), support the conclusion that the increase in the value of these parameters improves the quality of thermal conversion process of the materials by reducing the concentrations of certain pollutants; however, at the same time, the quality of the combustion process is reduced due to other pollutants.
- An increase in combustion temperature – as an independent variable parameter – improves combustion, reducing the concentration of carbon monoxide, but at the same time increases the emission of sulphur dioxide and nitrogen oxides NO_x. The increase in the oxygen supplied with the air to the combustion chamber caused a significant reduction in the concentration of carbon monoxide and sulphur dioxide, while increase in concentrations of NO_x. These relationships were observed for all tested fuels.
- Analysis of the energy properties of mixtures of carbon and selected types of biomass showed that the high calorific value of biomass allows the participation of dry biomass in the mixture up to 50%.
- An ecological method of combustion and co-combustion (the assumed maximum thermal efficiency) of selected types of biomass is to control the oxidation process by changing the excess air ratio λ, especially in the initial period of rapid increases in temperature (combustion of evaporated fly particles). The intensity of oxidation during this period determines the nature of the combustion in the main part of the laminar combustion.
- A change in the excess air ratio during this period should not be larger than λ_{pulp} <0.4/min λ_{pip} <0.2/min, which reduces the increase rate of NO_x at $eNO_{X\ pulp}$<14.5 ppm/min and $eNO_{X\ pip}$ <10.4 ppm/min. The intensity of the oxidation of CO shows a satisfactory level of eCO_{pulp}> 48 ppm/min and eCO_{pip}> 55 ppm/min.
- In laminar combustion, the excess air ratio should be maintained at the level of λ ~2.0 for cherry waste and λ ~1.8 for sunflower pulp.

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Metoda ekologicznego spalania odpadów organicznych w komercyjnym kotle małej mocy

Słowa kluczowe

Biomasa, spalanie biomasy, sprawność energetyczna i ekologiczna.

Streszczenie

Strukturę energii pierwotnej w Polsce wciąż kształtuje wysoka pozycja węgla z zasobów krajowych. Powszechne stosowanie tego paliwa sprzyja i ułatwia tzw. współspalanie biomasy z węglem w kotłach energetycznych. Różnice w budowie i zachowaniu podczas przygotowania oraz spalania węgla i paliwa roślinnego są przyczyną pojawiających się trudności eksploatacyjnych przy współspalaniu surowej biomasy w kotłach energetycznych. Na podstawie przeprowadzonych badań określono wpływ właściwości biomasy na przebieg podstawowych parametrów procesu jej spalania i współspalania z węglem kamiennym 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 biomasy i mieszanin paliwowych biomasy z węglem kamiennym. Kontrolowane zmiany parametrów procesowych warunków spalania (współspalania) węgla i wybranych rodzajów biomasy pozwalają na ekologiczne prowadzenie procesów spalania w komercyjnych kotłach małej mocy.