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Estimation of Sulfur Dioxide Emissions in an Automatic Boiler with a Retort Burner for Coal and Biomass in a Single-Family House Based on the Measurement of the Heat Consumed †

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Abstract: The paper presents the estimation of sulfur dioxide emissions as an effect of coal and pellet combustion in an automatic boiler equipped with a retort burner based on the actual heat consumption required for heating a building and heating domestic hot water for a single-family house in Poland. In Poland, automatic boilers with an installed retort burner are popular and can be used to burn various fragmented solid fuels. In Poland, the most popular solid fuel burned in boilers with a retort burner is crushed coal, called eco-pea coal. The second fuel used in automatic boilers with a retort planer is biomass in the form of pellets, which is classified as a renewable energy source. Heat consumption during the combustion of eco-pea coal was measured over a period of three years. Based on the heat consumption and coal and pellet combustion emission factors in the automatic boilers, the average annual emissions of sulfur dioxide using the eco-pea coal and pellets were estimated. The presented results of the analysis indicate a significant reduction in the sulfur dioxide emitted into the atmosphere by replacing eco-pea coal with fuel sourced from biomass in the form of pellets.

Keywords: sulfur dioxide; automatic boiler; retort burner; coal; pellet

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1. Introduction

During the combustion of solid fuels, emissions of various pollutants in the form of greenhouse gases affecting climate change and gases that have a direct negative impact on human health are generated [1]. One of the main products of the combustion of solid fuels, especially carbon, is sulfur dioxide (SO_2) [2]. Sulfur dioxide is a highly toxic gas [3] with a suffocating odor. Sulfur dioxide undergoes a series of chemical transformations in the atmosphere: it oxidizes to sulfur trioxide, which, through its reaction with the water present in the air, forms sulfuric acid. The resulting sulfuric acid undergoes electrolytic dissociation upon contact with water droplets and decomposes into SO_4^{2-} and H^+ ions. These compounds have strong acidifying effects and have harmful effects on the environment, most often in the form of acid rain [4].

In an automated boiler equipped with a retort burner and a solid fuel container, it is possible to burn both conventional fuel, such as crushed coal, and fuels from renewable energy sources in the form of biomass. Crushed coal is referred to as eco-pea coal [5] (Figure 1a), while compressed biomass in the form of wood is called pellet [6] (Figure 1b).

Retort burners in Poland are often chosen for single-family houses due to their versatility. A boiler with such a furnace is adapted to burning virtually any type of fragmented fuel [7].

An essential part of the retort burner is its integrated screw feeder that supplies the fuel. The rotating element of the feeder causes the individual lumps of solid fuel to fall,

due to gravity, from the feeder placed above the furnace and to gradually move towards the furnace.

(**a**) (**b**)

Figure 1. View of the fuel used in automatic boilers with a retort burner: (**a**) eco-pea coal, (**b**) pellets.

The shifted fuel travels to the combustion chamber, where it is burned at the correct temperature. The retort burner is usually round or rectangular in shape, and in its upper part, there are special air supply channels. By means of the working air supply supported by the operation of the supply fans, the air flows through the holes in the burner, moving directly between the lumps of eco-pea coal or pellets. Due to the appropriate efficiency of the blown air, the combustion process can take place at the correct temperature, ensuring the burning of the vast majority of chemical compounds that may otherwise penetrate the resulting exhaust gases.

The advantage of retort burners is that they combust eco-pea coal or pellets only in the upper layer, which is located in the upper part of the burner. In this way, it is possible to obtain the appropriate temperature and burn off all the volatile substances generated. Another advantage of using retort burners is the fact that such a solution facilitates the disposal of ash. The ash is pushed out by the eco-pea coal or pellets supplied by the bottom of the working part of the burner and falls outside its circumference, falling directly into the chamber used for its collection.

In Poland, in automatic boilers with retort feeders, comminuted coal is burnt most frequently, the combustion of which emits significant amounts of sulfur dioxide. As an alternative to coal, in automatic boilers equipped with retort burners, biomass can be burned in the form of pellets, which emits much lower amounts of carbon dioxide compared to coal. The aim of this study is to compare the sulfur dioxide emissions as a result of combustion of fragmented coal and pellets in an automatic boiler equipped with a retort burner in a typical single-family house in Poland.

2. Materials and Methods

The analyzed automatic boiler with a feeder is located in a boiler room in a single-family, two-story building. The central heating installation operates within the assumed parameters of the supply and return temperatures of the boiler, equal to 65 °C and 55 °C, respectively, and works in connection with the convection heaters and underfloor heating in the building. The boiler also heats domestic hot water. The building is inhabited by one family, consisting of two adults and two children. The average daily consumption of domestic hot water recorded with a water meter over the period of three years was 22.5 dm^3/person/day. The average annual heat consumption required for heating the building and domestic hot water, measured over the three-year period, was 61.24 GJ/year. The heating power in the heating season was determined on the basis of the PN-EN-12831:2006 [8] standard and amounted to 8.9 kW. During the three-year period, the boiler operated in the power range from 4 to 12 kW. Figure 2 shows a diagram of the heating

measurements during the operation of the automatic boiler with a retort burner in the analyzed single-family house.

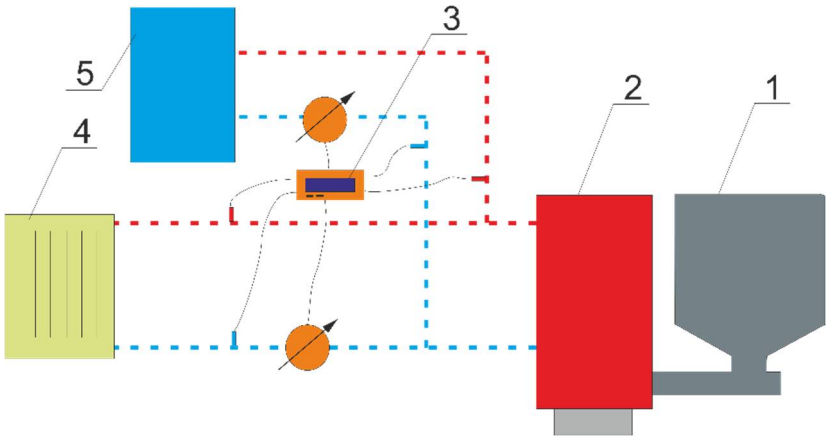

Figure 2. Schematic diagram of the measuring station for heat recording for the purposes of heating the building and producing domestic hot water: 1—fuel container with fuel feeder, 2—boiler, 3—heat recorder for heating the building and domestic hot water, 4—central heating installation, and 5—domestic hot water heater.

The average annual efficiency of the heat production and transport heating system was calculated using the following formula:

$$H = 1000 \times Q/(B \times w)\ [-] \quad (1)$$

where Q is the annual energy required for heating the building during the heating season and domestic hot water [GJ], B is the fuel consumption expressed in megagrams [Mg], and w is the calorific value expressed in kilojoules per kilogram of fuel [kJ/kg].

The average annual efficiency of the heat generating and transmitting system was 0.56.

3. Results and Discussion

The average annual sulfur dioxide emissions of the operating automatic boiler used for heating the building and producing domestic hot water was determined according to the following formula:

$$E = (B \times E_{fSO2} \times w)/(1{,}000{,}000)\ [\text{kg/year}], \quad (2)$$

where Q is the annual energy required for heating the building during the heating season and the domestic hot water, B is the fuel consumption expressed in megagrams [Mg], and w is the calorific value expressed in kilojoules per kilogram of fuel [kJ/kg], while E_{fSO2} is the sulfur dioxide emission factor for automatic boilers in [g/GJ].

In the case of the eco-pea coal, the amount of fuel burned during the year was measured, while the mass of the pellets burned during the year was determined on the basis of the efficiency of the heat generation and heat transport η, the calorific value of the pellets w, and the measured annual average energy required for heating the building and heating the domestic hot water Q:

$$B = 1000 \times Q/\ (\eta \times w)\ [\text{Mg/year}], \quad (3)$$

In order to heat the building and domestic hot water, the forecast average annual weight of the pellets burned in the retort boiler was about 21% higher compared to that of eco-pea coal, which is due to the lower calorific value of the pellets in relation to the eco-pea coal (Table 1). On average, the annual emissions of carbon dioxide during the

combustion of pellets were about 27 times higher compared to the eco-cork, which was a result of the significant sulfur content in the coal.

Table 1. Summary of the fuel consumption, parameters of eco-pea coal and pellets, and sulfur dioxide emissions.

Type of Solid Fuel	Calorific Value (w)	Annual Mass of the Solid Fuel Combusted (B)	Emission Factor for Sulfur Dioxide (E_{fSO2})	Average Annual Emissions of Sulfur Dioxide €
-	kJ/kg	Mg	g/GJ	kg
Eco-coal	24,000	4.534	410	44.61
Pellet	19,000	5.76	15	1.64

In order to heat the building and domestic hot water, the forecast average annual weight of the pellets burned in the retort boiler was about 21% higher compared to that of the eco-pea coal, which is due to the lower calorific value of the pellets in relation to the eco-pea coal. On average, the annual emissions of carbon dioxide during the combustion of the pellets were about 27 times higher compared to the eco-coal, which was a result of the significant sulfur content in the coal.

4. Conclusions

When choosing the type of fuel to burn in automatic boilers with retort burners, it is worth paying attention to sulfur dioxide emissions that travel into the atmosphere. In Poland, fragmented coal and pellets are popular fuels in small households. In the case of the pellets used for the analyzed single-family house, the emissions of sulfur dioxide were 1.63 kg/year, while in the case of the eco-pea coal, the emissions of carbon dioxide were 44.61 kg/year. The emissions of sulfur dioxide were as much as 27 times lower in the case of the pellets compared to the eco-pea coal. It should be noted here that not only is the combustion of pellets more environmentally friendly, but pellets are also classified as renewable energy sources.

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