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Analysis of the Possibility of Burning and Co-firing Oats in Automatic Solid Fuel Boilers

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The authors conducted a series of studies to identify the possibility of using standard automatic solid fuel boilers with a retort burner for burning alternative fuel in the form of oats. In addition to the results obtained, the importance of the share of biofuels, their use in industry and their applications in smaller production plants was discussed. Coal has also been presented as a large shareholder in energy production, which we have to reckon with, but also that legal regulations will develop and emissions problems in the low-energy sector cannot be avoided.

1. Introduction

In recent years, a high-energy transformation has been observed in Poland, which has a significant impact on environmental pollution resulting from the improper use of low-power heating devices. The effect of these changes is a significant increase in houses heating costs, the main reason is the increase in fuel prices. Individual heating accounts for a significant share of up to 20 - 30 % in the energy generation sector. This includes small municipal and industrial boiler houses, which due to their poor technical condition are even more involved in the production of toxic compounds.

In 1995, the first "Clean low carbon burning" program was launched in Poland, limiting emissions from municipal, industrial and individual boiler houses. The work on the program has resulted in energy emission criteria for the "ecological safety sign" for low-power boilers for solid fuels. Unfortunately, this certification is not obligatory and the vast majority of producers do not submit their boilers to the certificate. Since October 2017, the current legal act that determines the production and sale of boilers for solid fuels is the Regulation of the Minister of Development and Finance from August 1, 2017. The provisions contained in this regulation refer to the obligation to manufacture and sell boilers made in the fifth class in accordance with Standard EN 303-5 (2012). The full force of the legal act comes into force with the second half of 2018 (Ciupek et al., 2017).

The main reason for the introduction in Poland of restrictions for solid fuel heating boilers is excessive emission of harmful substances during the heating season. In Poland, the average heating period can last up to 6 months. At the same time, there is a large increase in dusting in the air with PM 10 and PM 2.5 particles as well as the local occurrence of photochemical smog. The formation of toxic compounds is influenced not only by the manufacturer implementing the technology, but also by the ordinary user. The right choice of the heating system directly affects the harmful substances will be emitted.

The need to limit the amount of harmful substances emitted from heating devices causes the need to change their construction. Another possibility of reducing harmful substances from boiler equipment is combustion or CO incineration (Urbaniak et al., 2015).

The paper discusses the issue of burning oat grains and applying it to co-combustion with hard coal in low-power boilers. Oats were used as an accompanying fuel because it is the third largest grain produced in Poland. In the economy it plays mainly the function of animal feed. In addition, observe the possibility of using oats as co-incinerated fuel.

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2. Low power heating devices for biomass burning

Low power heating boilers are usually used in domestic farms. These consist of a set of devices and components of installations, whose task is to generate and distribute heat in the building. The basic elements are the heat source and its distribution system and internal heating installations. The sources of heat include the fireplace, stove or central heating boiler. As far as biofuel fired boilers are concerned, their design should be adequate to ensure the correct combustion process. When operating low-power heating devices, it is essential to comply with the rules regarding the type of fuel and the manner and conditions of use (Partonelli et al., 2017).
Boilers with automatic fuel supply have a much more complex construction. An example of automatic fuel supply boiler is present in Figure 1. It consists, among others, of such devices as auger conveyor, extended control system of fuel and air supply, also fuel igniters and lambda probes. These devices allow to work with minimal service participation. When using a 25 kW boiler with corresponding fuel tank during the nominal boiler operation, the supply should last even for one week. Two standard burner types can be distinguished, one with bottom feed retort burner and the other with horizontal fuel feed. Commonly used materials burned in boilers of this type are pellets, oats and coal. The possibility of burning wood chips is limited due to their high humidity. From the storage tank, the fuel is served by means of a screw feeder and pushed from the bottom up to the retort plate. To initiate the combustion process, primary air is needed, which flows through the bed, secondary air is also needed, which circulates around the perimeter of the furnace just above the heat zone. The ash is pushed out by continuous feeding of fresh fuel. Typically, the screw feeder along with the furnace are made of fire-resistant materials. Boilers with horizontal burner are also very effective, usually they are adapted for burning pellets, but also oat seeds can be effectively burned in them. The speed of fuel feeding and the amount of fuel supplied depend on the type of fuel used and determined by means of the controller. Some boilers for a better controller setting are equipped with a lambda probe. The probe works on the principle of measuring the amount of oxygen in the exhaust gases and on the basis of this measurement selects the right amount of air needed for combustion. In boilers with automatic fuel supply, it is also necessary to protect against receding fire. For boilers with a retort burner, these are sensors located at the storage tank, if the temperature rises above the set value, fuel delivery is accelerated, which prevents entry (see for comparison Guiqiu, 2017).

Figure 1: Example of a boiler with automatic fuel supply

3. The characteristics of the drawer burner

The drawer burner is adapted to the combustion of a fuel such as coal, fine coal, pellets, or oat grain. Examples of a drawer burner are present in Figure 2 and Figure 3. The burner has its own deflector, which can be easily removed and cleaned. The furnace and deflector are made of heat-resistant cast iron. The primary air is fed through the lower openings in the burner. The shape of the hearth, which is rounded, allows to completely burn the fuel. Fuel supply does not cause much friction due to appropriate design.

Figure 2: View of the drawer burner

Figure 3: View of standard retort drawer burner II generation

4. Possibilities of using oats in the combustion process

In the animal feeding process, oat grain does not play a big role compared to other cereal species. This is due to the fact that it contains a lot of raw fiber and crude fats. Oats are grown on weak soils and contaminated by industry as it consumes significant amounts of heavy metals and leads to the reclamation of these soils. In recent years, oat cultivation has found a different branch of use in addition to food consumption. The strategy of modern oat growing includes burning it for heating purposes. Such cultivation seems undoubtedly easier to implement than growing energy crops. When growing energy crops, there are additional problems associated with the purchase of equipment for cultivation, harvesting and an additional storage area. The concept of grain combustion is used in Scandinavia and is increasingly considered in domestic energy farming. Oats as an energy carrier has a calorific value of about 17 MJ/kg, when for medium grade hard coal it is about 24 MJ/kg. It follows that 1.5 kg of oats replace about 1 kg of coal.

Burning oats in traditional coal boilers goes well when they are additionally equipped with a special burner and feeder. In addition, efficiency of 90 % is obtained by using full automatic dosing of grain. There were boilers on the market for heating not only farms, but also public buildings such as schools and production halls. The low price of oats also makes it advantageous for heating purposes because it is two times cheaper than wheat or coal. The high fat content of the husk, causes favorable flammable properties. The oat is easy to store and transport, because as a grain it has good bulk properties and is easily transported in sacks (Urbaniak et al., 2017).

5. Research methodology

In boiler with a nominal power of 15 kW, a drawer burner was placed in place of the retort burner, which was used to burn the oat-coal mixture and the oat grain itself (Ciupek et al., 2018). The assumption of the tests was to analyze the operation of the boiler while working with 100 % of thermal power and 50 % of thermal power. The boiler works in an open system. Fuel is fed from the hopper with a constant speed screw feeder. The fuel flow can be adjusted using the controller by setting the working time and break time. The boiler is equipped with a blower fan. The heat is transferred through heat exchangers to the buffer tank. The first stage of each measurement was to determine the appropriate boiler power. Simulation of variable working conditions was possible due to the use of a system of heat exchangers cooled by a variable stream of tap water. The power was set by measuring the mass of the water stream leaving the heat exchanger, the temperature at the inlet and at the exit of the exchanger. The calculations were made using Eq(1).

$$P = \frac{Q}{t} \cdot 4.18 \cdot (T_p - T_z) \qquad (1)$$

where:
Q - water stream, [kg]
t - time of measurement of water mass stream, [s]
T_p - temperature of return from the exchanger, [K]
T_z - supply temperature exchanger, [K]

After determining the power and bringing the system to a steady state, the exhaust gas was analysed using the KIGAZ 150 exhaust gas analyzer. The concentration of O_2, CO, CO_2, and the flue gas temperature was measured while the analyzer calculated the excess air coefficient based on the measured data. Temperature measurements were made by means of legalized PT100 platinum sensors, they are used to measure temperature in the range from 203 K to 823 K, their measurement and registration was carried out using a KEITHLEY 2000-200 multimeter connected to a multiplexer. The signal was recorded using the LabView program, thermocouples were placed at the entrance and exit of water pipe of the boiler and in entrance and exit of water pipe of the heat exchanger. Each measurement of 120 minutes after two hours for the same mixture increased power to a nominal power of about 15 kW and then after reaching the steady state, the temperature and flue gas leaving the boiler were measured. Flue gas measurements were made within 300 s, while the temperature was measured automatically every 3 s (Bartoszewicz et al., 2010).

6. Analysis of combustion of coal - oats mixture

The fuel used for the study was a mixture of coal and oat grain. The proportions applied were 50 % of the mass shares of each mixture. This composition of the mixture should best reflect the possibility of co-firing biofuel with coal in low-power boilers. The prepared mixture was placed in the fuel tank and tested. Measurements were made for two boiler loads: 50 % of thermal power (about 7.5 kW) and 100 % of thermal power (about 15 kW). The results of the tests carried out for the mixture of coal and oat grain are presented in the figures below.

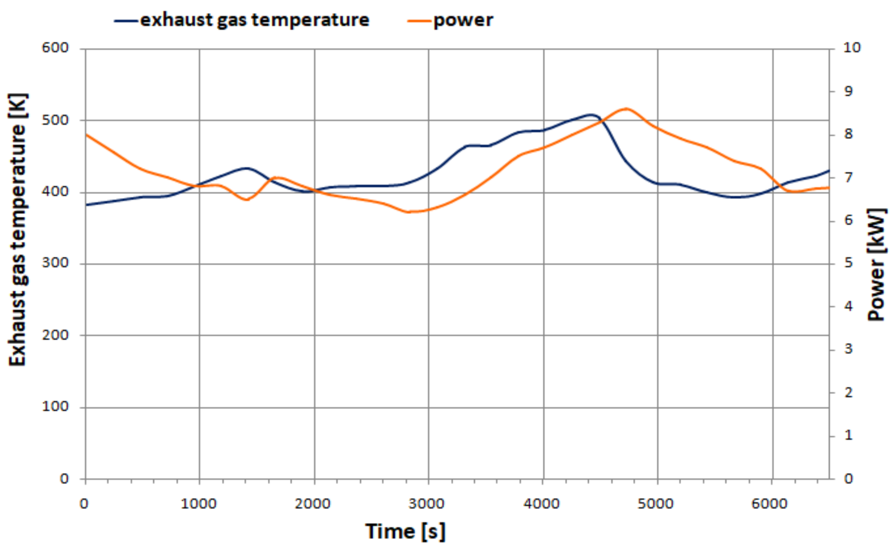

Figure 4: Exhaust gas temperature and power change for mixture of coal and oat grain at minimal thermal power

In the Figure 4 which shows the temperature of flue gas leaving the boiler in relation to the power, it can be seen that the temperature of the exhaust gases throughout the test process behaves similarly it varies from 389 K to 505 K depending on the air blow, while the power after about 50 minutes begins to grow and reaches 8 kW while the measurement was started at 7.1 kW. In the next stage of the research, the power for the mixture of coal and oats was increased to 100 % of thermal power.

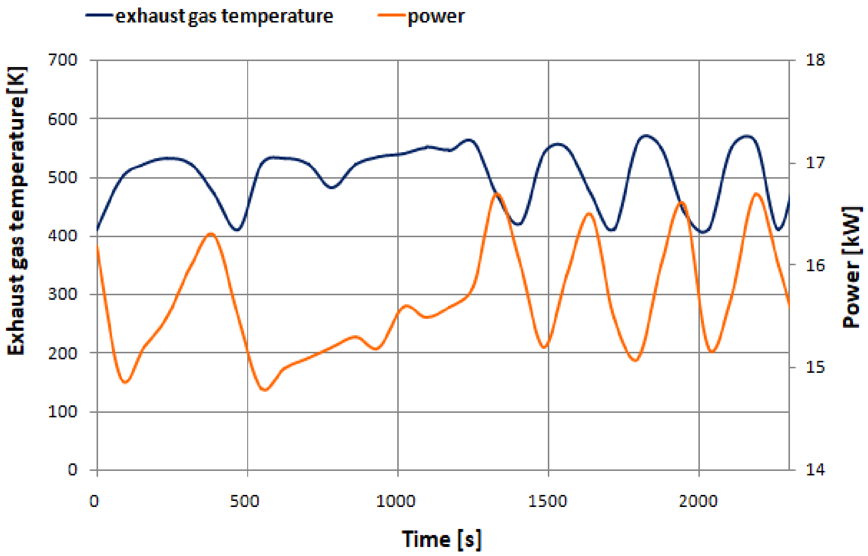

Figure 5: Exhaust gas temperature and power change for mixture of coal and oat grain at maximal thermal power

In the graphs showing exhaust gas temperature and power for both 50 % of thermal power and 100 % of thermal power, one can see a problem with the stabilization of power. For the first measurement, this power increases over time and ranges from 7 to 8.5 kW. However, when working on the power of about 15 kW, the boiler behaves the other way around, and after more than 24 minutes, the power begins to fluctuate between 15 kW to 16.6 kW. This is related to the use of two different fuel mixtures. Coal and oat grain have different physical and chemical properties. Oat grain has a much lower energy density, which means that it burns faster than coal, so it is difficult to adjust the feeder so that the system works fully automatically and with constant power. Exhaust temperature for one and the other boiler power is high and ranges from 389 K to 505 K - 50 % of thermal power and 410 K to 581 K - 100 % of thermal power.

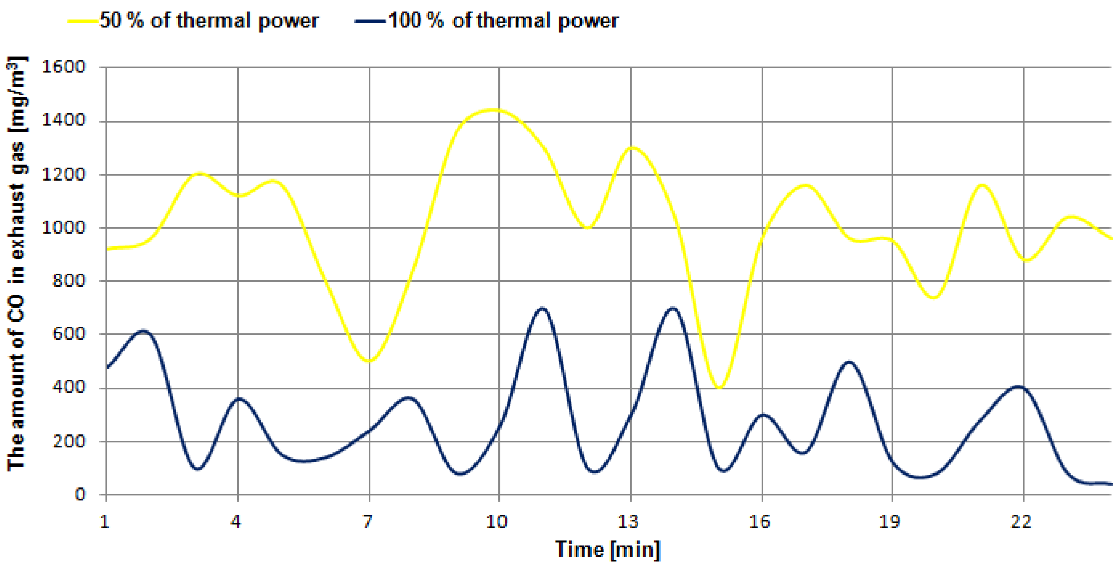

Figure 6: The degree of emission as for the minimal and maximal power.

Emissions of carbon monoxide are clearly higher for a 50 % boiler case. The average value is from about 829 mg/m^3, this decrease is related to the increase in power at a later stage of boiler tests. The emission of carbon monoxide during operation with the rated power is much lower and amounts to approximately 90 mg/m^3. A comparison of average boiler performance results is presented in Table 1.

Table 1: Parameters of boiler work.

Parameters of boiler	50 % of thermal power	100 % of thermal power
Boiler power [kW]	7.8	14.3
Temperature [K]	436.1	459.1
CO_2 [vol.%]	6.4	10.7
O_2 [vol.%]	14.5	10.2
CO [mg/m^3]	829	179

7. Conclusions

The purpose of the experimental part of the work was to analyze the co-combustion of coal and oats in a boiler with a nominal power of 15 kW. The tests were carried out for the nominal power of the boiler and when the boiler is operating at 50 % of thermal power. The boiler in which the tests were carried out is a standard boiler used in households. In Poland, the total share of private energy in the production of thermal energy is around 20 - 30 %. Due to the poor technical condition of boilers, the emission of pollutants from them is much higher than from renewable energy. Therefore, it is necessary to undertake research on new technologies and fuels, which will be able to allow a cheap and simple way to reduce the emission of harmful substances into the atmosphere.

The combustion analysis related to basic parameters such as flue gas temperature, heat power and carbon monoxide emission. All the above-mentioned factors are much better when the boiler is working with nominal power. The results obtained regarding emissions of carbon monoxide testify in favor of the biofuel used. The value of carbon monoxide emission for the oat-coal mixture when the boiler is operated at 100 % of thermal power amounts to approximately 179 mg/m^3. The obtained results regarding carbon monoxide emission are within the norm, they meet the criterion of boilers in class 5 (the highest) of EN 303-5: 2012. The standard permits for these boilers emission of carbon monoxide less than 500 mg/m^3. In the case of boiler operation with 50 % thermal power, class 5 conditions were not met. However, this does not change the fact that it is more beneficial in terms of environmental protection to burn the mixture of oat grain with coal or oat grain only, which produce much less harmful compounds to the atmosphere.

Behind the use of solid biofuels such as oat grain is also the price of this raw material. At the moment, the price of oats is at the level of 500 PLN/Mg, while that for coal is around 1000 PLN/Mg. The price of coal is twice as large, despite its higher calorific value, and it is more beneficial to use oat grain as fuel for energy production.

Summing up, installing a drawer burner in a traditional boiler enables burning and co-firing solid fuels with coal. The temperature of exhaust gases for the mixture of coal and oat in the case of boiler operation with nominal and minimum power does not differ significantly. The benefits of incineration and co-firing of solid biofuels are mainly the reduction of emissions of harmful compounds into the atmosphere and lower costs of fuel purchase.

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