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CONTRIBUTIONS TO THE USE OF CORN INSTEAD OF SAWDUST PELLETS AT SMALL POWER DOMESTIC BOILER WITH PELLETS

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Abstract

The aim of the work is to study the possibility of replacing wood sawdust pellets with grain at the heating systems. Due to the energy crisis experienced in the winter of 2022-2023, when the price of used pellets increased by 300% compared to the previous year, when in some periods wooden pallets disappeared from commerce, the study of the replacement of the energy sources with which the small power domestic boiler were designed to operate on wooden pellets is justified. It is known that corn has a high calorific value. Due to this fact in the present work the possibility of using corn and the effects of its use on boiler with pellets that do not have in the specifications the fact that they can also work with any granular biomass are studied.

Key words: corn, boilers with pellets, wood pellets, gear, gearmotor

1. Introduction

Domestic boiler with wood pellets is considered an ecological solution for heating homes and domestic hot water. Fossil fuels are replaced by pellets of renewable materials fig.1., mainly sawdust, which do not produce greenhouse gases by combustion [1].

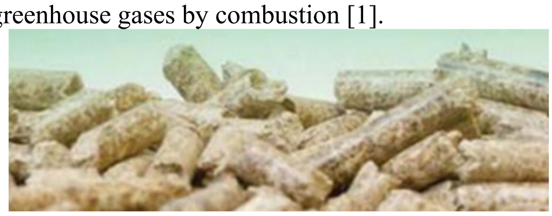

Fig. 1: Wood pellets

In areas where it is not possible to connect to the gas network, central heating can be done with the help of heat pumps, electric plants, wood, coal and, last but not least, pellet plants.

Each of these heating solutions has advantages and disadvantages, depending on how the respective location is used. Some of the solutions have a small impact on the environment, heat pumps, but require large investments [2]. Other central heating solutions, power plants, involve high costs in their use and without a system for producing electricity from renewable sources is not justified for now.

Coal and wood-burning boilers require the installation of a puffer to store the energy produced during the burning of the fuels and during the winter season, permanent heating of the system is necessary to prevent the installations from freezing. In the case of holiday homes, one of the viable solutions seems to be central heating with pellets.

Studies on the production of wood pellets, or wood and straw, have been done since 1818 [4], the combustion of different types of biomass and the comparison with gas combustion led to the conclusion that the carbon footprint is smaller in the situation of using pellets from wood [3].

As early as 2009, Ukraine, Belarus and Russia were large producers of pellets [5] and with the increase in the number of central heating systems with pellets, their production also increased. The geopolitical crisis led to a decrease in the supply of wood sawdust pellets, implicitly to an increase in pellet prices.

Pellet boilers are primarily ecological, they are automated and provide a degree of comfort in operation similar to that of gas or liquid fuel plants [6].

The domestic boilers have an efficiency of over 90%, and the automation ensures their safe operation.

Feeding and igniting the pellets is done automatically. The fuel is supplied from a bunker, the capacity of which differs depending on the model and the power of the pellet plant. Thus, a high operating autonomy can be ensured, from a few hours to 2-5 days.

There are also thermal plants specially designed to use granular biomass as fuel, such as corn, pellets, various grains and kernels. In the following, we study the use of corn in domestic boiler on pellets that do not have in the specifications the fact that they work with any granular biomass, more precisely domestic boilers that are designed to work with wood pellets.

2. Pellet boilers

The component parts of a pellet boiler are very well illustrated in [7], fig.2.

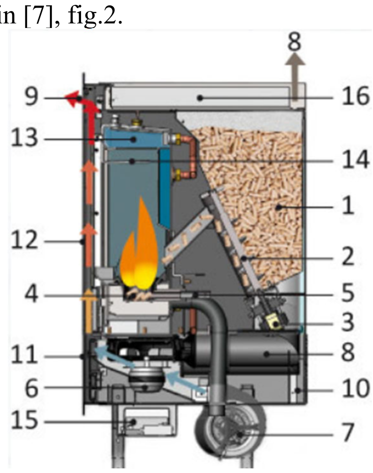

Fig. 2: Component parts of the pellet boiler [7]

For the boiler shown, the component parts are: **1** - pellet hopper, **2** - screw for conveying the pellets from the hopper to the combustion chamber, **3** - screw gearmotor, **4** - pellet combustion hearth, **5** - electric heating element for igniting the pellet, **6** - centrifugal fan for extracting the combustion fumes, **7** - hot air fan, **8** - fumes outlet port for connection to flue, **9** - front grille for delivering hot air to the room, **10** - combustion air port for connection to external intake, **11** - panel for controlling/monitoring the device's operation, **12** - dual door panels, **13** - wraparound water tank, **14** - combustion chamber block with door, **15** - integrated plumbing kit for maximum safety and easy installation, **16**- loading drawer.

Fig. 3: Feeding with pellets [8]

As a principle, all pellet mills work like this: the motor-reducer drives the auger for determined periods of time, depending on certain parameters. During this time, the auger doses pellets from the hopper into the firebox 4, fig.3. If there are no errors, the vacuum and temperature sensors do not detect the vacuum or the high temperature in the combustion chamber, the electrical resistance will ignite the fuel in the firebox and the fan will suck air into the combustion chamber to maintain the combustion.

Worldwide, solutions are being sought for the manufacture of energy pellets from various wastes [9], biomass [10], [11], [12].

Binders in pellets are used to improve bonding, lubrication, burning properties, abrasion characteristics [12], [15], [16], [17].

When making pellets from wood waste, it is not necessary to use additives as binders, the lignin present in the wood acts as an adhesive for the pressed fibers.

According to [12], corn is a material that can be used as a binder. The calorific value of some fuels is presented in table 1.

Table 1: Calorific value of biomass fuels

Fuel	Calorific power (kcal/kg)
1. starch	4000
2. cereals	4000
3. straw	3500
4. wet wood	1500-2500
5. dry wood	3000-4000
6. waste pellets of various wood species	4000-4300

The current energy crisis has led to a 300% increase in pellet prices. It has reached the abnormal situation where the price of grain is half of the price of pellets from wood waste, a situation in which the study of replacing pellets from wood waste or wood and straw with corn is justified.

3. Fuels used in pellet boilers

Most of the pellets sold are made from sawdust resulting from wood processing.

Pellets are produced from: wood sawdust of various essences, sunflower husks or cereal straw. The pellets have a diameter of 6 mm and an average length of 15 mm. The moisture content of the pellets is usually below 8%; the resulting amount of ash below 0.5% and the calorific value approximately 4300 kcal/kg, correspond to the standard, EN 14961-2 which certifies the type of pellets.

Pellets used for heating homes are, as a rule, packed in 15 kg bags.

The smaller the amount of ash resulting from combustion, the smaller the deposits, the less often the burner and boiler are cleaned, the quality of the pellets used directly influencing the ease of use of such plants.

There are numerous studies on pellet processing [13], [14]. Corn is grown on large areas in the country.

Corn is composed of: 72% starch, 10% cellulose and hemicellulose, 9% protein and 8% oil and other components [12]. Corn is used in the production of ethanol and as food. Fodder corn is used to feed animals.

4.Aspects of using corn for domestic boilers

First of all, it must be taken into account that burning corn does not emit sulfur oxides, oxides that result from the use of fossil fuels, because corn does not contain sulfur [18], [19]. Secondly, corn is neutral in terms of CO_2 emitted into the environment when it is burned in thermal boilers. Some sources even show that corn absorbs more CO_2 during growth than it releases in the combustion process. Also, the ash resulting from the burning process can be used as a fertilizer, so it does not contaminate the soil or the water table.

In the specialized literature [20], [21], [22], [24] it is specified that the shape and size of corn kernels vary greatly from one variety to another, even on the cob. The grains at the top are small and spherical or oval in shape. The ones at the base have almost the same weight as the ones in the middle, but their shape differs from the ones in the middle. The shape of the grain can be trapezoidal, elongated-trapezoidal or rounded. The length of the grain can be equal, smaller or larger than the width. The sizes are variable, the largest grains having a length of approximately 15 mm, there are also parts of 20 mm corn cobs, and the other sizes allowing the grain to be transported between the flanks of the augers used, fig.4., without blocking the transport routes of the pellet boilers.

Studies regarding the performance of a pellet boiler fired with agricultural fuels have also been done [25], [26], the conclusion being: “The automatic feeding system and the lambda control were unable to adjust to an optimal level for a broad variety of non-woody biomass fuels; The design of the combustion chamber is not optimal for all the biomass fuels; Adequate ash management devices were important to enable the boiler to manage fuels with high ash contents; Ash accumulation on the heat exchanger walls rapidly reduced the boiler efficiency”[25].

Fig. 4: Auger with feeding tube [22]

Studies were also made for the use of corn in power plants [27], [28]..., the conclusion being that the burning of corn led to higher CO and NO emissions and a higher ash production compared to wood, and the boiler should modified to provide greater air flow, improve combustion and facilitate ash removal.

During three months, tests were done with a mixture of corn kernels (moisture about 15%) with wood pellets in various concentrations, as in table 2, the plant used was Fornello Royal B, 25 kW, a medium plant with a hopper, pump circulation, forced draft, no self-cleaning, central used in the 4th season only on weekends. The value of the calorific power of the corn grains and pellets used for the tested mixture is minimum 4000 kcal/kg, maximum 4300 kcal/kg, depending on the wood pellets used and the variety and humidity of the corn.

Because the value of the calorific power of the corn grains and pellets used for the tested mixture is in the range in which the domestic boilers are designed, it will be checked experimentally if the boiler designed to work with wood pellets can also be used for burning the mixture with corn kernels.

Table 2: The composition of the mixture pellets-corn

Combustible	% corn	40	50	80	90
	% wood pellets	60	50	20	10
1. Lot number		1	2	3	4

In the first phase, the method of igniting the fuel in the boiler with the hearth cleaned and the ash removed was studied. The obtained results are listed in the table 3, fig.5 .

Table 3: Result

Criteria analyzed:	Lot 1	Lot 2	Lot 3	Lot 4
1. Success rate / 1 ignition (%)	100	100	62,5	37,5
2.Succes ignition	87,5	87,5	37,5	25

rate /12 hours (%)				
3.Continuous operation 12 hours	75	62,5	37,5	0
4. Continuous operation 8 hours	100	100	50	37,5

In the case of the first two batches ,fig.5, with the boiler cleaned the fuel mix caught fire in each experimental attempt. In the case of batch 3, the boiler worked in 62% of the cases, and the last batch in only 37% of the tests. Even if after ignition the boiler works with the mixtures from batches 3 and 4, due to the low ignition rate with a clean hearth, the boiler will certainly not be able to operate commanded by the room thermostat.

It was found that after ignition, the burning speed of the corn mixture differs from the burning of wood pellets, in the sense that it burns longer and the amount of heat released is greater. It also results in a greater amount of ash, forming in hearth and slag. The boiler allows the regulation of the duration of operation of the motor-reducer, thus implicitly the amount of fuel transported in the firebox. After several attempts it was concluded that it should be adjusted to the lowest gear, minimum amount of fuel supplied.

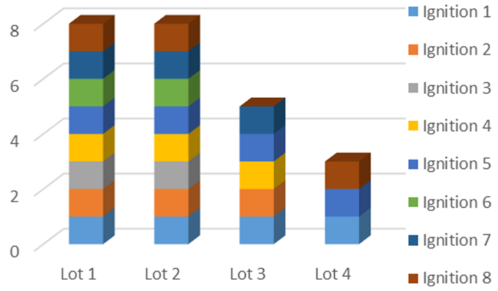

Fig. 5: Clean boiler ignition rate

In the technical book of the boiler, no values are given for the air flow of the fan, different steps are given, which will be tested experimentally if the boiler works or not. Also, the speed of the fan had to be increased, after several attempts it was concluded that for proper operation it is necessary to go to maximum ventilation. Increasing the amount of corn leads to overloading of the reducer and there is a risk of failing the safety elements. In the reducer one of the gears is made of a weaker material and it will wear.

Due to the fact that pellet boilers are automated, they allow the installation of a thermostat to regulate the air temperature. After reaching the temperature at which the thermostat was adjusted, it stops the operation of the boiler and restarts it when the temperature drops below the adjusted value. So, during a day, the boiler will start several times without the firebox being cleaned before each start. If the slag formed in the boiler clogs the glow plug, the fuel will not be able to be ignited. Also, if the formed ash blocks the air supply, the boiler will not start and if it is working, it will stop. A failed ignition regardless of the cause leads to an error and the boiler stops working.

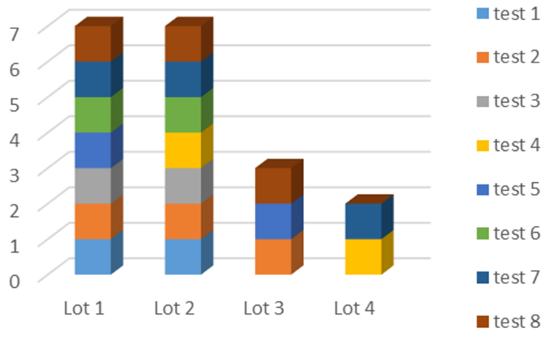

Fig. 6: Succes ignition rate in 12 hours

Because of this, the success rate of ignitions during 12 hours and the ability to operate without cleaning the hearth for 12 hours and then for 8 hours had to be studied. The results are passed in tab 3, fig.6, fig.7 and fig.8.

Regarding the ignition rate during 12 hours of operation, fig.6, the thermostat commanded the operation of the boiler to maintain the set temperature. The boiler worked for 12 hours in 87% of the cases for batches 1 and 2, and with batches 3 and 4 the boiler worked less than 38% of the time.

In fig.7. the results obtained during the operation of the boiler continuously for 12 hours were presented. It can be seen that the boiler could not work in all the tests with any of the lots for 12 hours, in the case of lot 1 the boiler worked in 75% of the cases, the air flow being blocked by deposits from the firebox.

In fig.8. the results obtained during the operation of the boiler continuously for 8 hours were presented.

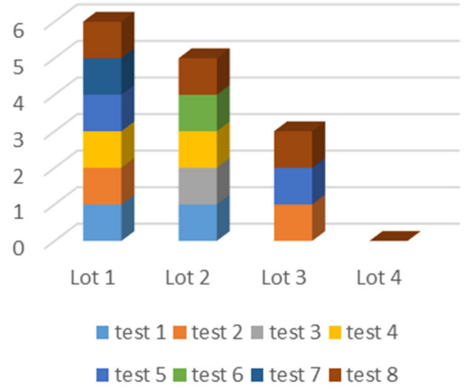

Fig. 7: Continuous operation 12 hours

It can be seen that the boiler worked continuously in all the tests with batch 1 and 2, with the other 2 batches the deposits blocking the air flow in more than 50% of the cases, which led to the shutdown of the boiler.

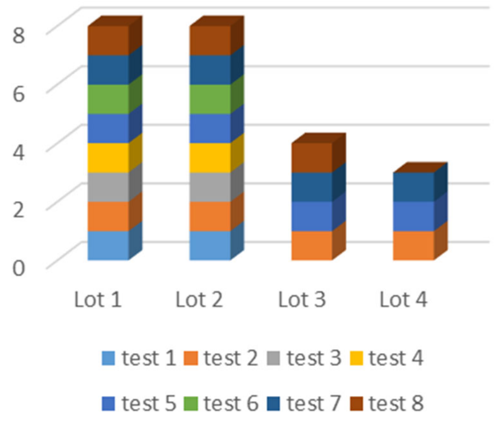

Fig. 8: Continuous operation 8 hours

In the experimental study using lots 3 and especially 4, rapid slag deposition was observed, reaching in some situations the fuel inlet opening to be blocked, fig.9.

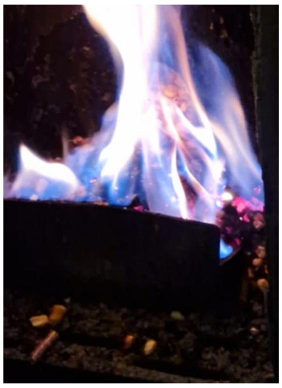

Fig. 9: Slag deposition

If the boiler continues to operate, the gears in the reducer driving the auger are overloaded fig.10. The reducer is one with several stages, with cylindrical gears with straight and inclined teeth. In the first step, a toothed wheel made of softer material is used, so that in the case of overloads, it will fail without burning the motor that drives the reducer. In the figure below, it can see the toothed wheel with inclined teeth, that is the toothed wheel that gives way first.

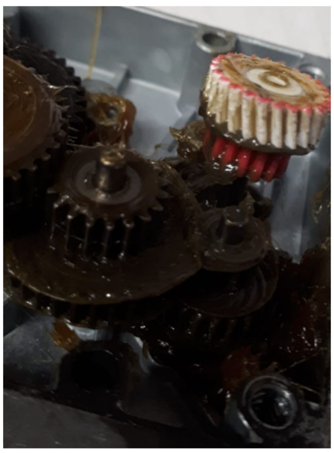

Fig. 10: The reducer

The toothed wheel whose toothing gave way was replaced with one manufactured by additive manufacturing. It was 3D modeled with the help of Inventor, after which it was 3D printed with the help of an FDM technology printer, fig.11.

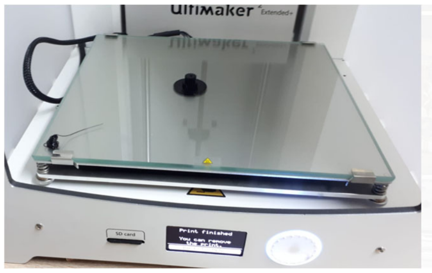

Fig. 11: 3D printer

This work is not the subject of the used gear wheel manufacturing, so no references will be made to the materials used and other aspects of the processing.

5. Conclusions

As a result of the tests, the following conclusions can be drawn:

- For domestic centralized heating, a mixture of 50% wood pellets combined with 50% corn can be used, the price of the mixture being approximately 75% of the price of pellets obtained entirely from wood. In the work, advancing some prices was avoided because they differ in different periods of the year, keeping instead the ratio between the price of corn and that of wood pellets constant, 1/2;
- If when using wood pellets, the boiler can operate without cleaning for a period of up to 24 hours, depending on the quality of the pellets used, in the case of using the mixture with corn, the period of operation without cleaning decreases to approximately 8 hours;
- Increasing the quantity of corn above 50% of the volume will lead to wear of the reducer;
- When using the pellet mixture, it is recommended to clean the heat exchangers more often due to the greater amount of ash produced by burning the fuels;
- The use of corn reduces the costs of fuel of domestic boilers, can replace part of the amount of fuel in case of a crisis, but it also reduces the comfort of using the domestic boiler and and the lifetime of the boiler.

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