

Article

Novel Design for Rotary Burner for Low-Quality Pellets

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Abstract: The burning of low-quality fuels causes several problems in the operation of combustion equipment, which can negatively affect the equipment's efficiency. The possibilities for the burning of pellets made from low-quality raw materials are limited mainly by the fusibility of the ash, which settles and melts on the surfaces of the burner, gradually causing it to clog. Smelted ash also causes a decrease in heat transfer efficiency, which negatively affects the overall efficiency of the heat source. A possible solution is provided by burners with a rotating combustion chamber, where the contact time of the molten ash with the walls of the burner is shortened, and thus there is no significant melting of the ash in the burner. This manuscript is dedicated to summarizing the current state of development of burners with a rotary chamber, presenting a novel design for such a burner, and providing an analysis of that design. To conclude, the results of experimental measurements on a classic burner and a burner with a rotary chamber are presented, including a comparison and evaluation mainly in terms of emissions. The novel-designed rotary burner achieved a higher heat output than the retort burner, but a similar thermal efficiency. The rotary burner produced 32.5% lower CO emissions, 12.5% higher NO_x emissions, 23% lower OGC emissions, and 44.7% higher PM emissions in comparison with a retort burner under the same conditions. This novel rotary burner concept could, after optimization, be a suitable option for efficient combustion of alternative biofuels.

Keywords: burner; low quality fuel; rotating chamber; renewable energy resource



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1. Introduction

Although burning alternative biomass is generally a beneficial approach, there are certain concerns involved. Due to the large ash concentrations and low melting points, the most dangerous aspect of this practice is ash melting. Molten ash becomes sintered matter and agglomerates when it attaches to the combustion chamber's walls, smothering the flame. Alternative biomass is inferior to traditional fuels because of flame smothering, which results in poor combustion and excessive emissions [1]. Many researchers have already tried to solve these problems in several ways.

Another option is to change the structural elements of the combustion equipment, particularly the burners designed to burn biomass at low ash-melting temperatures [2–4]. The direction of the fuel supply and combustion, which occurs in the vertical plane, is a significant drawback of standard retort burners used for the automated burning of bulk fuels. The drawback of this method is that, due to the high temperature and gravitational force, the heavier ash particles are trapped in the burner, where they cling to the walls and lead to clogging. By making it easier for fuel to tumble out of the burning chamber, more recent varieties of horizontal tube burners help to partially resolve this issue [5].

One possible alternative energy resource is straw. Usage of straw as an energy resource for burners and furnaces is problematic because of ash melting and the covering of heat exchange surfaces with slag [6]. Straw may, however, be an efficient and environmentally sound choice, not only satisfying rising energy needs as the economy expands but also

laying the groundwork for environmental conservation and societal sustainability [7]. The efficiency of straw in fluidized-bed combustion has been improved, and its performance is close to that of the traditional boiler, which uses coal, petroleum, and natural gas as fuels [8,9]. Therefore, on the basis of available technologies, research on the direct use of straw in fluidized-bed combustion is one of a number of effective and large-scale approaches to straw utilization, yielding benefits in terms of both energy and the environment [8,9].

Several initiatives have used straw as a source of energy. Early in the 1990s, the IEA project was one of the most significant. In that study, authors compared the potential and actual use of straw in energy generation in five European countries: the United Kingdom, Denmark, Sweden, the Netherlands, and Austria [10]. The primary objective of this endeavor was to research the use of straw and agricultural byproducts for the manufacture of heat or power. The study revealed various obstacles that make the use of straw challenging, such as challenging delivery arrangements and minimal economic impact, but also some skepticism regarding straw and other resources of a similar nature [11,12]. According to the project, 1 million tons of straw were utilized in Denmark to produce heat or electricity. Some power stations also co-fired straw with coal. In households, straw, straw pellets or other low-quality fuels are not used frequently [11,13].

2. Existing Technical Solutions

Several different combustion methods and concepts for adding fuel to the boiler appear on the market for biomass combustion equipment. Very important roles from the point of view of fuel combustion are played by the construction of the fireplace, the method of combustion, and the supply of combustion air and its division into the so-called primary and secondary combustion zones [14]. Solid fuel boilers are structurally different according to the type of fuel being burned. Grate fireplaces are used for burning lumpy solid fuels in a so-called calm layer [15,16], a process involving volumetric combustion that does not require fuel homogenization. On the other hand, fuels with a fine grain size are not suitable for burning on a grate [17]. Fuel combustion takes place both in the fuel layer and above its surface, when the volatile component of the fuel burns [18]. Combustion on a fixed, immovable grate is used mainly for small outputs. Fuel is placed in the fireplace from above on top of the burning layer and does not move during combustion on the grate [19]. The added fuel is ignited by the flame and the glowing surface of the burning fuel. An inclined grate allows for the occasional movement of the fuel and is composed of a fixed and a movable row of grates [20,21]. By reciprocating the sliding movement of movable grates along fixed grates, the fuel is transported further along the grate. Another variant of burners with a movable grate are rotary burners [22–24], where the combustion space is formed by a cylindrical surface in which the burning fuel is mixed with the supplied fuel and combustion takes place in the entire volume of the combustion chamber created in this way, as, e.g., in patent application no. KR101426660 B1 [25], the principle of which is shown in the Figure 1.

Sawdust, which can be fed through the outer wall of the combustion chamber into the rotating center, can also serve as fuel in such a rotary burner, where the given fuel burns together with the air that is fed through the center of the chamber, as, e.g., in patent application no. FR2248747 A5. The wall of rotary burners is most often formed by a cylindrical steel tube with the fuel supply through the center or through the outer circumference of the tube. The wall can also be made of several twisted parts, which, during the rotation of the combustion chamber due to gravity, tilt away and thus allow the removal of ash, as in patent no. PL409167 A1.

The burning rate of solid substances in different burners is not a constant quantity, but depends on the surface-to-volume ratio of the solid substance, humidity, density, amount of combustibles per unit area, air access, etc. The greater the surface-to-volume ratio of a solid, the faster it ignites and burns. Moisture in solids reduces the burning rate. As regards density, the higher the density, the lower the burning speed.

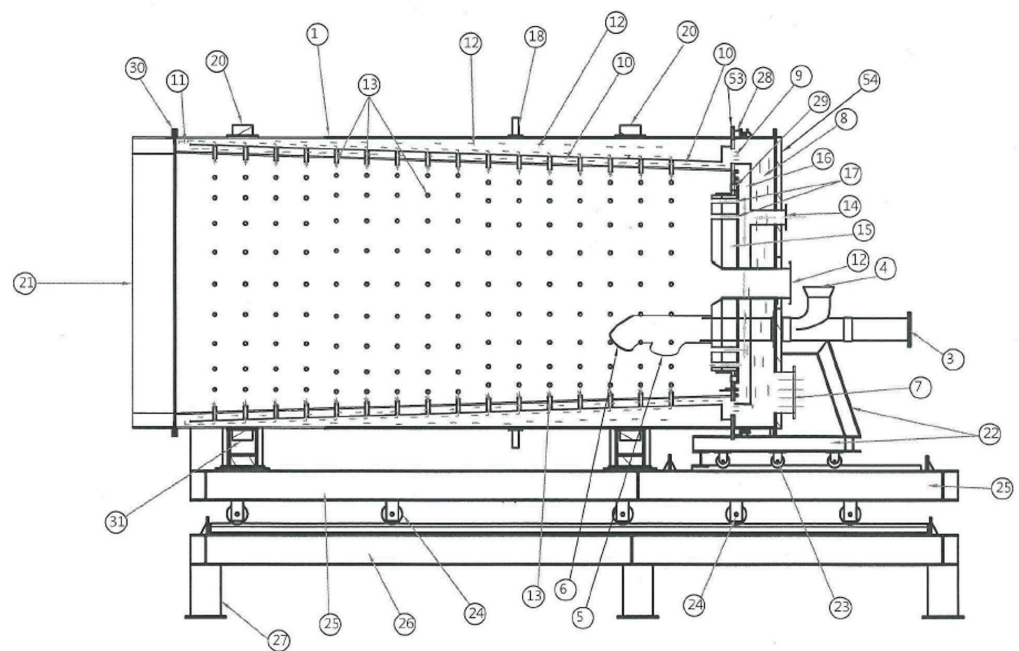


Figure 1. Patent no. KR101426660 B1.

The progress of the fuel burning rate during one cycle, derived from the burnout curve, represents the progress of the instantaneous consumption of combustion air in the furnace. The air-supply control for log-burning fireplaces is usually a simple manual control, and the air supply is more or less constant. If it is set to correspond to the average burning rate at the desired excess air, during the cycle there will be two areas with excess air (at the beginning and at the end of the cycle) and one area with a lack of air around the inflection point of the burn-up curve, and thus the maximum burning rate. This area is characterized by the maximum production of combustible debris. By adjusting the regulation of the supply of combustion air to the furnace to a suitably chosen excess of air, the extent of the area with a lack of air can be minimized, but at the cost of increased chimney loss and reduced efficiency.

3. Proposed Technical Solution

The design of our burner is based on the existing design solutions of manufacturers of similar burners. The basic requirement is to ensure better mixing of fuel with air. Combustion of low-quality fuels requires the use of a rotary chamber, which prevents slag formation on the walls of the combustion chamber. Combustion air is most often transported into the combustion chamber together with fuel through the back wall of the combustion chamber.

This method is also used in our proposed design. At the same time, the supplied air is divided, and part of it is led through the outer cover, which serves as an air distributor. Here, the air is not supplied statically, as in a similar burner from some manufacturers, where the air supply moves together with the combustion chamber. Our designed burner uses a planetary gear that transmits power from the electric motor to drive the fuel feeder, rotate the cylindrical combustion chamber, and rotate the air-control aperture.

By rotating the air-control aperture, it is possible to distribute the air more evenly in the outer cover distributor, which transports it later into the burning chamber. The proposed burner is shown in Figure 2. The drive is provided by an electric motor, which is directly connected to the helical fuel feeder. On the feeder shaft is located the sun gear of the planetary gear first row, where this gear row transfers torque to the second planetary gear row. In the second row, the sun gear is connected directly to the burning chamber, which is rotating. Here the planetary gear is driving the sun gear and is also driving the ring gear, which is connected to the air-control aperture. This air-control aperture has

unevenly distributed shape elements, which regulate air flow into the burning chamber. The air-control aperture is rotating against the direction of the burning chamber rotation and this rotational movement provides better mixing of burning fuel with air, which should lead to lower emissions. The mounting flange serves not only as a mounting element, but also has shape elements, which direct air flow to the burning process.

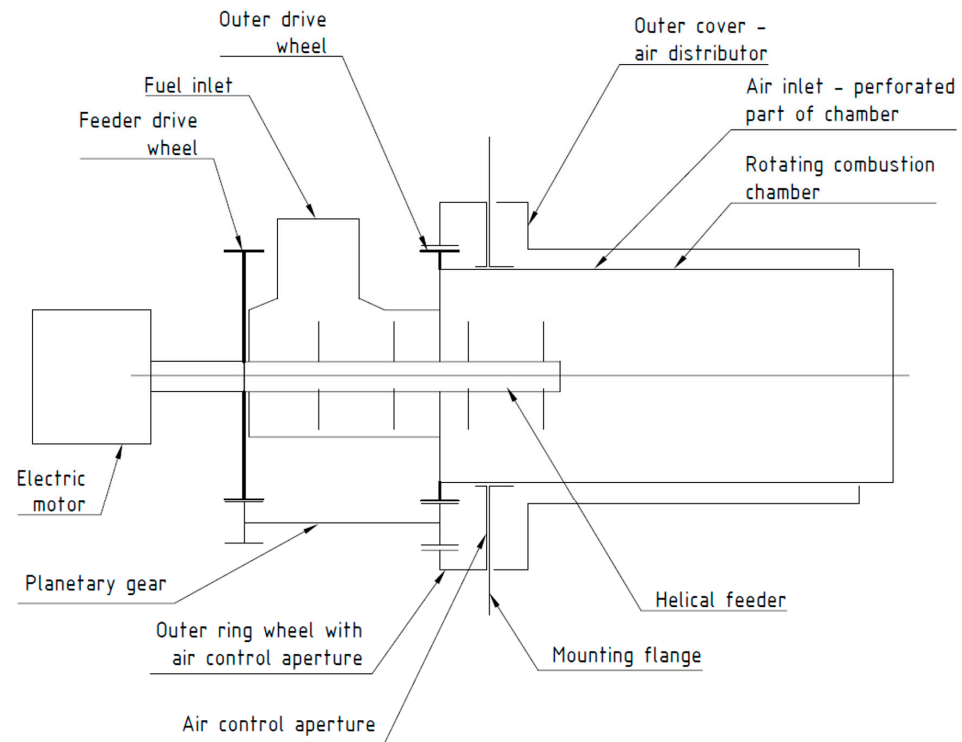


Figure 2. Schematic diagram of novel rotary burner.

Air flow is ensured through a separate adjustable inlet, which is connected to the fuel inlet. The air flow is divided into primary air and secondary air, with the primary air being directly fed into the fuel entering the combustion chamber. A similar method is used in patent no. KR101426660, in which air facilitates fuel injection into the combustion chamber. Originally, this method was also used in the device in patent no. FR2248747, which was intended for burning sawdust. The air-flow sketch is in Figure 3.

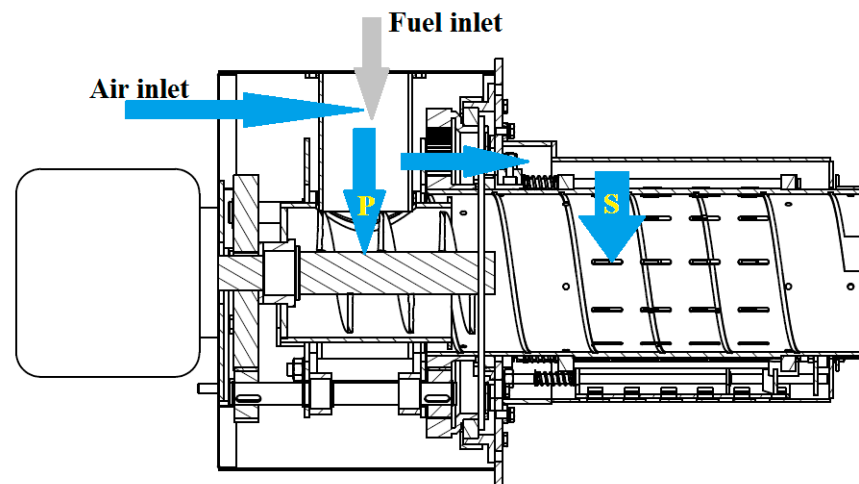


Figure 3. Air flow in proposed burner (P—primary air, S—secondary air).

The newly designed burner combines the advantages of existing devices with suitable novel features to enable the desired combustion parameters to be achieved. The secondary air is led through the burner housing via the secondary-air-controlling aperture baffle, which ensures the distribution of air into the secondary-air inlet, which is formed by openings on the cylindrical combustion chamber. The design is shown in Figure 4.

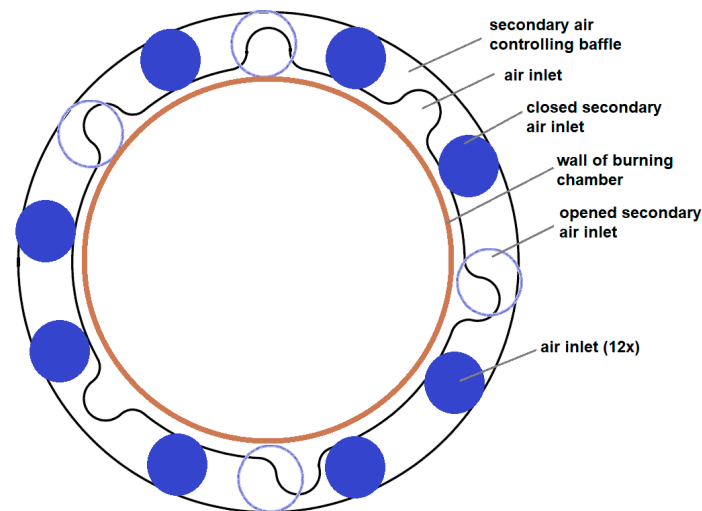


Figure 4. Secondary-air-controlling aperture.

The secondary-air-controlling baffle rotates against the direction of rotation of the combustion chamber, and by overlapping the air inlet and the controlling baffle, the flow of secondary air is directed.

4. Materials and Methods

Emissions from the combustion of solid and alternative solid fuels are highly dependent on the design of the combustion equipment. Emissions from biomass combustion can generally be divided into emissions that are primarily influenced by combustion technology and combustion conditions and emissions that are influenced by fuel properties. When burning wood in fireplaces and stoves, water vapor, carbon dioxide (CO₂), nitrogen (from the air), ash and fly ash, carbon monoxide (CO), organic gaseous carbon (OGC), nitrogen oxides (NO_x), and unburned particles (soot) can be emitted. Emissions caused by incomplete combustion are primarily the result of insufficient mixing of combustion air and fuel in the combustion chamber, a total lack of available oxygen, too low a combustion temperature, or too short a time. These parameters are related to each other through the reaction rate for the basic combustion reactions. However, when sufficient oxygen is available, temperature is a very important factor due to its exponential effect on reaction rates. Optimizing these variables generally contributes to reducing emissions from incomplete combustion. The conversion of fuel carbon to CO₂ takes place in several steps and using several reaction pathways. CO is the most important final intermediate. The rate at which CO oxidizes to CO₂ depends primarily on temperature. CO can be considered a good indicator of combustion quality. Nitrogen oxides produced during wood burning are mainly nitric oxide (NO) and nitrogen dioxide (NO₂). They arise at a high temperature (above 1000 °C) from the nitrogen in the air (around 80%).

As already mentioned in the introduction, there are several constructional arrangements of burners and combustion devices. They differ not only in shape, but also in the arrangement of individual functional parts of the combustion equipment. The heat exchange surfaces are arranged in such a way as to ensure optimal heat transfer from the combustion process to the heat-carrying medium. The burner, which forms the basis of the combustion equipment, must meet not only technical but also emissions parameters. Mandatory environmental standards determine in particular the permitted content of emis-

sions in flue gas. Determining the amount of emissions is evaluated on the basis of officially approved methods and procedures for taking samples of flue gas in a device's chimney. Such sampling and measurement work is carried out at a workplace in the University of Zilina's Department of Power Engineering, using the furnace setup shown in Figure 5.

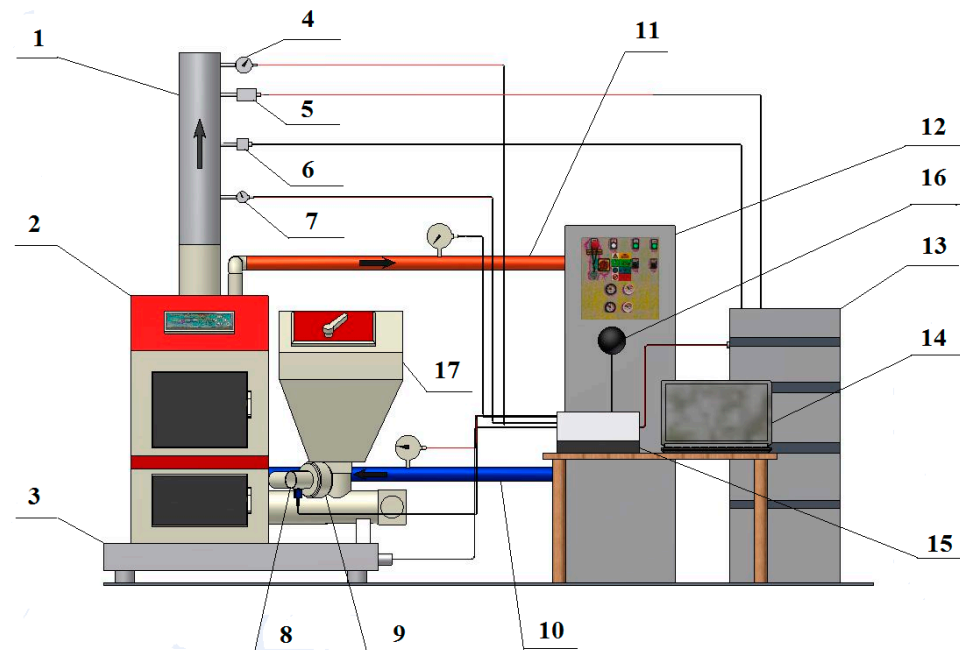


Figure 5. Furnace experiment setup. 1—chimney; 2—automatic pellet boiler; 2—weight; 3—chimney draft sensor; 4—PM probe (solid pollutants); 6—emissions probe; 7—thermometer for measuring flue gas; 8—anemometer; 9—fan; 10—supply pipe; 11—drainage pipe; 12—control center; 13—flue gas analyzer; 14—computer; 15—measuring station; 16—Vernon thermometer; 17—fuel tank.

This workplace allows the connection of any heat source up to 50 kW. The measurement takes place continuously, with computerized recording and evaluation of the measured quantities. The workplace was used for the measurement of emissions from two types of burners—retort and rotary. A standard burner from the Slovak furnaces manufacturer was chosen as the retort burner. This burner has a bottom fuel feed to the center of the burner and an air feed through the burner wall. The second burner chosen was our novel-design burner. This burner is rotary, with the chamber rotating in a rotary motion. The fuel is fed from above into the center of the combustion chamber. The air is led through the wall of the chamber. Both burners were gradually installed in the selected boiler at the workplace, and the performance and emission parameters of combustion in each of the burners were determined. In the case of automatic fuel supply to the boiler, the test must take place for at least 6 h at nominal and minimum heat output. During the tests at the nominal thermal output, the average value of the water outlet temperature must be between 70 and 90 °C, and the average temperature difference between the water outlet from the boiler and the water inlet to the boiler must be between 10 and 25 °C. For solid-fuel hot-water boilers up to 300 kW, the efficiency is officially determined according to the STN EN 303-5 standard. The main method of determining effectiveness is the so-called direct method, in which the efficiency is calculated from the measured heat output of the boiler and the energy input supplied by the fuel. The fuel is initially supplied horizontally by a screw feeder to the retort, where it changes direction of movement and is pushed vertically upwards into the combustion part of the burner. As the layer of new fuel approaches the combustion zone, it gradually heats up and begins to release volatile combustibles. The new fuel passes through the fuel base layer and, after mixing with the combustion air, ignites above the grate in the afterburning zone. The burnt residues are either blown away by the combustion air or pushed with new fuel onto the circular grate that is above the rotor.

Combustion air is forced into the base layer of fuel from the sides in the upper part of the retort and passes through it. The oxygen not used for the burning of the solid part is already so preheated that it is easily involved in the oxidation of the volatile part of the fuel in the afterburning space of the combustion chamber. The fuel releases volatile combustibles in the heating zone even without air access. When the burner transitions to attenuation, the supply of combustion air stops and the base layer of fuel slowly moves down into the retort as it burns out. Therefore, after some time, it is necessary to move the fuel layer (and thus the base layer) a little higher with the screw dispenser. After re-entering the operating mode, all that is required is to restore the supply of combustion air and controlled refueling. Therefore, this type of burner is suitable for burning low-quality pellets with a large proportion of ash and a high tendency to sintering. The ash and any solids are pushed out of the combustion zone by the new fuel (base layer) and thus do not block the access of combustion air. The constant contact of the base layer with the newly transported pellets brings an increased risk of ignition of fuel in the fuel hopper. Technically, this problem can be effectively solved by cyclically moving the fuel during the deceleration period.

With a rotary burner, the burning fuel is continuously carried out of the burner by the circular movement of the combustion chamber.

The boiler is operated at rated power during the test so that its operation is as smooth as possible. The ambient air temperature must be between 15 and 30 °C, and the draft of the chimney must be set according to the type of test and according to the thermal output.

When measuring the nominal furnace output, the outlet temperature from the boiler, the inlet temperature to the boiler, and the water flow are measured and recorded. The heat output is determined using the calorimetric equation.

The tested hot-water boiler was placed on a weighing machine used to measure fuel consumption. The flue-gas outlet is connected to an isolated flue-gas measurement section with samples taken for measuring flue-gas temperature (chimney temperature), operating draft (chimney draft), flue-gas composition (carbon dioxide, oxygen, carbon monoxide, nitrogen oxide and other NO_x), and solids of dirt. A constant chimney draft is ensured by the exhaust fan, the speed of which is regulated by a frequency converter. The temperature of the flue gas is measured by a temperature sensor, which is located inside the probe for exhausting the flue gas. This probe must have three sampling holes with a diameter of 2.5 ± 0.5 mm, with one hole being located in the center of the flue pipe. The other two holes are located one quarter of the distance of the flue pipe diameter from the side walls of the flue-gas measuring section. A tube with an internal diameter of 6 mm is used to measure the static pressure.

Flue gas emissions were measured using an ABB AO 2020 flue gas and carbon analyzer, which was connected to the measurement center. Flue gas was collected using a flue-gas sampling probe. The measurement program was started after the boiler stabilized and the analyzers were switched on. All measured emissions were calculated to normal conditions—pressure 101,325 Pa, temperature 0 °C and 10% oxygen content in flue gas. The IPECON DT1 control unit was used to control the boiler, which consisted of a heating circuit and a cooling circuit. These two circuits were separated from each other by a heat exchanger. A control valve was also included, with the help of which the temperature difference between the inlet and outlet temperatures of the heat transfer medium was set.

These two temperatures were measured by paired resistance temperature sensors, which have the same measurement characteristics. The measured values were fed to the measuring center. The amount of heat-carrying medium entering the boiler was measured using a flow meter, the values of which were recorded using a measuring unit. Using the control system, the entire process was controlled automatically.

5. Results and Discussion

The results of measurements of the performance and emission parameters of the heat source for the different types of burners (average heat output (kW), thermal efficiency (%), CO production (mg.m⁻³), NO_x production (mg.m⁻³), organic gaseous carbon (OGC)

production ($\text{mg}\cdot\text{m}^{-3}$), and particulate matter (PM) production ($\text{mg}\cdot\text{m}^{-3}$) are shown in Table 1.

Table 1. Results of measurements of performance and emission parameters of heat source for different types of burners.

Burner Type	Measurement Number	Heat Output (kW)	Thermal Efficiency (%)	CO ($\text{mg}\cdot\text{m}^{-3}$)	NOx ($\text{mg}\cdot\text{m}^{-3}$)	OGC ($\text{mg}\cdot\text{m}^{-3}$)	PM ($\text{mg}\cdot\text{m}^{-3}$)
Rotary	1.	14.56	85.61	854.4	211.1	15.92	82.4
	2.	15.01	86.15	759.3	214.6	14.74	67.6
	3.	14.92	86.01	748.6	220.9	15.07	77.2
	Avg.	14.83	85.92	787.43	215.53	15.24	75.73
Retort	1.	13.52	87.88	918.3	196.3	18.41	47.9
	2.	13.13	87.12	1283.2	191	21.36	51.5
	3.	13.27	86.91	1301.6	187.3	19.62	57.6
	Avg.	13.31	87.3	1167.7	191.53	19.79	52.33

The average heat output of the rotary burner was higher than the heat output of the retort burner by approximately 1.5 kW, but the thermal efficiency of combustion was a little lower, namely by approximately 1%. This could be caused by our novel construction, which could be optimized for greater thermal efficiency in the future, but the achieved combustion efficiency values are close to those of other similar heat sources in a rotary burner [26]. Typical time courses of the heat output of the heat source in retort and rotary burners from our experiments are shown in Figure 6. The time course of the retort burner was more constant-stable and reached values of between 12.5 and 13.5 kW during the experiments. In contrast, the heat output of the rotary burner varied during the experiments, with values of between 11.5 and 16 kW. This variation was caused by the changing amounts of burial and burning wood pellets in the combustion space—at one moment there was little burning fuel and at the next more. It was manifested in the obvious fluctuations in the temperature of the flue gases, a change in the heat removed through the hot-water heat exchanger, and subsequently also in the production of emissions. This problem could be solved by changing the method of dosing fuel into the burner space—a more continuous supply of pellets in smaller and more frequent doses. The long response time between the change in heat output and the subsequent supply of fuel can also be a problem.

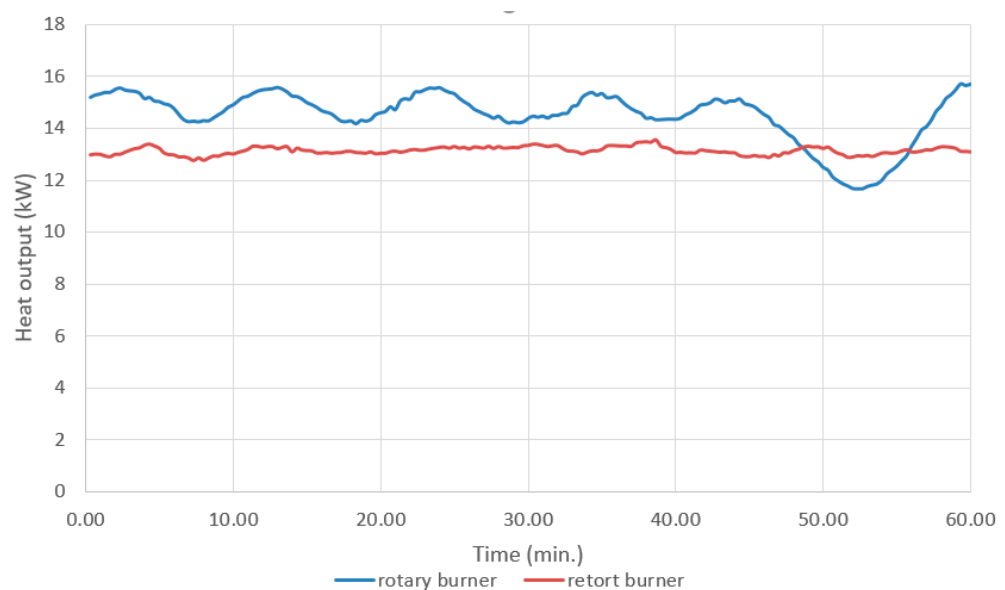


Figure 6. Typical time courses of heat output of heat source in different types burners from experiments.

Figure 7 shows the typical time courses of CO emissions from the same heat source in both rotary and retort burners during the experiments. The characteristics of these time courses are very similar to the time courses of the heat output—CO production from the retort burner was more stable, not changing much over time and reaching values of around 1000–1400 $\text{mg}\cdot\text{m}^{-3}_{10\% \text{ O}_2}$. CO production during use of the rotary burner was much more variable and reached values of from 100 to 5000 $\text{mg}\cdot\text{m}^{-3}_{10\% \text{ O}_2}$. This was related to variable fuel metering as well as uneven heat output. Paradoxically, the average CO production was lower for the rotary burner by approximately one third, namely by 380 $\text{mg}\cdot\text{m}^{-3}_{10\% \text{ O}_2}$. Our novel design for a rotary burner needs more optimization because similar wood pellet heat sources achieve production of CO emissions at the level of tens to hundreds $\text{mg}\cdot\text{m}^{-3}_{10\% \text{ O}_2}$ [27] and lower, being classified as Emission Class 5 according to the STN EN 303-5 standard and Commission Regulation (EU) 2015/1189—500 $\text{mg}\cdot\text{m}^{-3}_{10\% \text{ O}_2}$ for automatic heat sources for wood biomass.

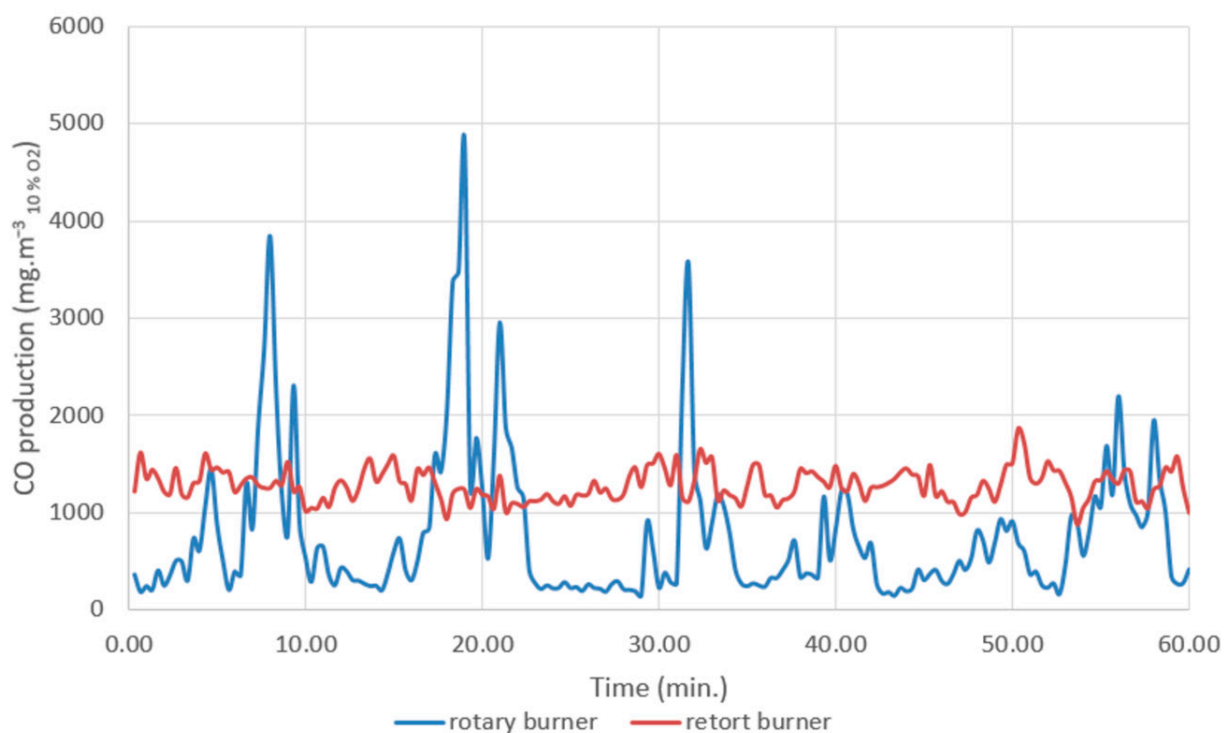


Figure 7. Typical time courses of CO emissions depending on the type of burner from experiments.

Typical time courses of NO_x emissions from experiments on the retort and rotary burners are shown in Figure 8. Similar to the previous cases, the course of NO_x production is more variable when using a rotary burner. The average measured NO_x production values for the rotary burner were approximately 12.5% higher than the measured values for the retort burner. These slightly higher values could be due to the higher temperature in the combustion chamber due to the higher amount of supplied air, which was partially preheated. These values do not deviate from the usual values for similar heat sources [26,27]. The measured average values of NO_x are bordering on or just above the required limit set by Commission Regulation (EU) 2015/1189—200 $\text{mg}\cdot\text{m}^{-3}_{10\% \text{ O}_2}$ for automatic heat sources for wood biomass. This higher NO_x concentration needs to be solved in our novel design for a rotary burner by construction modification to achieve a lower combustion temperature in the combustion area of the burner.

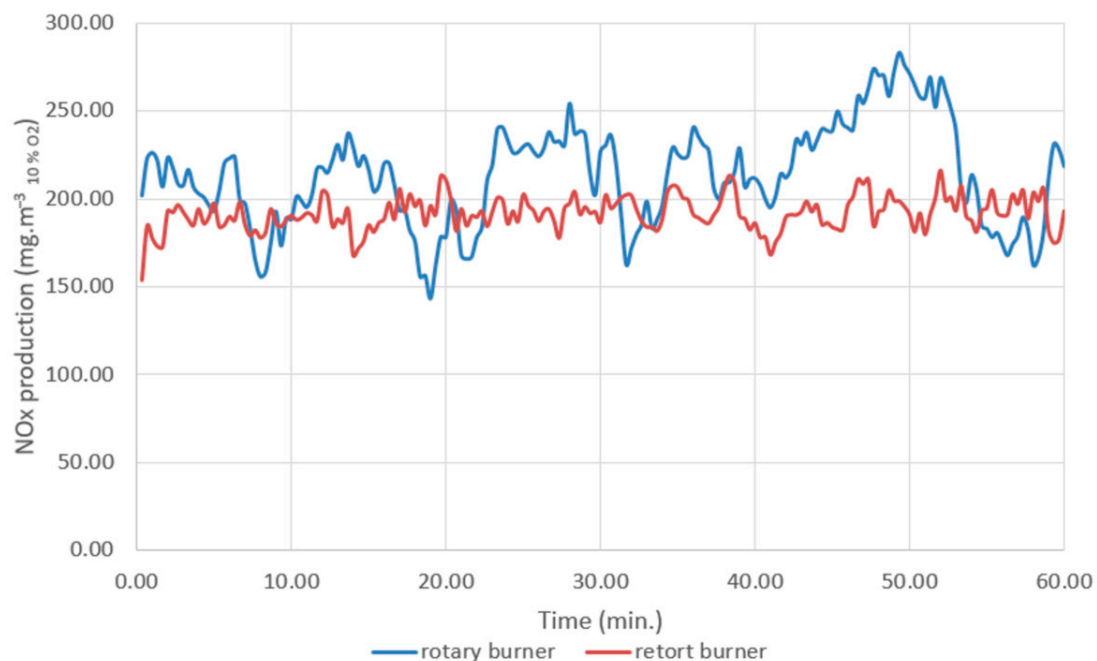


Figure 8. Typical time courses of NOx emissions depending on the type of burner from experiments.

The rotary burner produced 23% lower average OGC production in comparison with the retort burner, which could be due to the higher amount and better redistribution of combustion air, similar to the reasons suggested above for the lower CO emissions production. Average PM production during the experiments was almost 45% higher for the rotary burner in comparison with the average PM production for the retort burner. All these measured values for OGC and PM correspond with those for similar heat sources [26,27], but the PM production needs to be lower to fit the limits for Emission Class 5 of the STN EN 303-5 standard and Commission Regulation (EU) 2015/1189— $40 \text{ mg.m}^{-3}_{10\% \text{ O}_2}$ for automatic heat sources for wood biomass. This could be achieved by further optimization of the burner operation process, especially by construction modification of the combustion air supply.

6. Conclusions

In the process of designing a new combustion device, it is always necessary to start from the fuel combustion requirements. Burning wood pellets does not cause combustion problems such as melting of ash and formation of deposits. When burning low-quality fuels, such as straw pellets, it is necessary to make structural adjustments to prevent ash melting. Burners which allow the burning of such low-quality fuels have been designed. However, these are mostly large devices. Because of this, a new burner was designed. In order for the newly designed burner to meet all requirements, particular emphasis was placed on the distribution of combustion air.

Our novel-designed rotary burner achieved higher heat output and similar thermal efficiency of combustion than a traditional retort burner commonly available on the market. One of the main indicators of combustion quality is the amount of CO emissions. The measurement of CO emissions for two different burner types showed that their highest production was measured when the highest heat output of the heat source was reached. The main difference between the retort and the rotary burner was caused by the imperfect and constant mixing of the burning fuel in the rotary burner. In the retort burner, the fuel is burned gradually, in a static layer, which contributed to significantly lower NOx ($24 \text{ mg.m}^{-3}_{10\% \text{ O}_2}$ lower) and PM emissions ($23 \text{ mg.m}^{-3}_{10\% \text{ O}_2}$ lower). On the other hand, lower CO (32.5% lower) and OGC (23% lower) production was achieved in the novel-design rotary burner.

Due to these issues, our proposed new design incorporates air-control and setup mechanisms that should lower emissions and provide acceptable burning quality. After these modifications and construction adjustments, it is hoped that this novel design for a rotary burner will meet the requirements of Emission Class 5 of the STN EN 303-5 standard and Commission Regulation (EU) 2015/1189 and thus burden the environment to a minimum. It is also necessary to focus on the optimization of the combustion of lower-quality types of biofuels, especially those with a lower ash-melting temperature. This is an area in which our novel-designed burner should outperform other burners, but one which requires a much greater amount of analysis and experimentation.

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References

- Nielsen, C. Utilisation of straw and similar agricultural residues. *Biomass Bioenergy* **1995**, *9*, 315–323. [CrossRef]
- Voytenko, Y.; Peck, P. Organisational frameworks for straw-based energy systems in Sweden and Denmark. *Biomass Bioenergy* **2012**, *38*, 34–48. [CrossRef]
- Alsos, G.; Lunggren, E.; Pettersen, L.T. Farm-based entrepreneurs: What triggers the start-up of new business activities? *Small Bus. Enterp. Dev.* **2003**, *10*, 435–443. [CrossRef]
- Simmons, B. Straw in Skane: The Imminent Development of the Skane Straw Market Triggered by the Ortofta Biomass Boiler. Master's Thesis, Department of Economic History Economic Growth, Innovation and Spatial Dynamics, Lund University, Lund, Sweden, 2008.
- Perea-Moreno, M.A.; Sameron-Manzano, E.; Perea-Moreno, A.J. Biomass as Renewable Energy: Worldwide Research Trends. *Sustainability* **2019**, *11*, 863. [CrossRef]
- Gradziuk, P.; Gradziuk, B.; Trociewicz, A.; Jendrzewski, B. Potential of Straw for Energy Purposes in Poland—Forecasts Based on Trend and Causal Models. *Energies* **2020**, *13*, 5054. [CrossRef]
- Mzurkiewicz, J.; Marczuk, A.; Pochwatka, P.; Kujawa, S. Maize straw as a valuable energetic material for biogas plant feeding. *Materials* **2019**, *12*, 3848. [CrossRef] [PubMed]
- Smil, V. Crop residues: Agriculture's largest harvest. *Bioscience* **1999**, *49*, 299–308. [CrossRef]
- Edwards, R.A.H.; Šúri, M.; Huld, T.A.; Dallemand, J.F. GIS-Based Assessment of Cereal Straw Energy Resource in the European Union. Available online: <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.550.9051&rep=rep1&type=pdf> (accessed on 2 February 2021).
- Elbersen, B.; Startisky, I.; Hengeveld, G.; Schelhaas, M.; Nae, H.; Böttcher, H. Biomass role in achieving the Climate Change & Renewables EU policy targets. Demand and Supply dynamics under the perspective of stakeholders. In *Atlas of EU Potentials; ALTERRA*: Copenhagen, Denmark, 2011. Available online: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/biomass_futures_atlas_of_technical_and_economic_biomass_potential_en.pdf (accessed on 2 February 2021).
- Mahmoud, M.M.; Ratib, M.K.; Raglend, J.; Swaminathan, J.; Aly, M.M.; Abdel-Rahim, A.M.M. Application of Grey Wolf Optimization for PMSG-Based WECS under Different Operating Conditions: Performance Assessment. In Proceedings of the 2021 Innovations in Power and Advanced Computing Technologies (i-PACT), Kuala Lumpur, Malaysia, 27–29 November 2021; pp. 1–7.
- Moliner, C.; Bove, D.; Arato, E. Co-Incineration of Rice Straw-Wood Pellets: A Sustainable Strategy for the Valorisation of Rice Waste. *Energies* **2020**, *13*, 5750. [CrossRef]
- Nosek, R.; Werle, S.; Borsukiewicz, A.; Zelazna, A.; Łagód, G. Investigation of Pellet Properties Produced from a Mix of Straw and Paper Sludge. *Appl. Sci.* **2020**, *10*, 5450. [CrossRef]
- Chungen, Y. Development in biomass preparation for suspension firing towards higher biomass shares and better boiler performance and fuel rangeability. *Energy* **2020**, *196*, 117129.

15. Mladenovic, R.; Dakic, D.; Eric, A.; Mladenovic, M.; Paprika, M.; Repic, B. The boiler concept for combustion of large soya straw bales. *Energy* **2009**, *34*, 715–723. [\[CrossRef\]](#)
16. Perez-Jeldre, R.; Cornejo, P.; Flores, M.; Gordon, A.; García, X. A modeling approach to co-firing biomass/coal blends in pulverized coal utility boilers: Synergistic effects and emissions profiles. *Energy* **2017**, *120*, 663–674. [\[CrossRef\]](#)
17. Cai, Y.; Tay, K.; Zheng, Z.; Yang, W.; Wang, H.; Zeng, G.; Li, Z.Z.; Boon, K.; Subbaiah, P. Modeling of ash formation and deposition processes in coal and biomass fired boilers: A comprehensive review. *Appl. Energy* **2018**, *230*, 1447–1544. [\[CrossRef\]](#)
18. Wang, D.; Liu, L.; Yuan, Y.; Yang, H.; Zhou, Y.; Duan, R. Design and key heating power parameters of a newly-developed household biomass briquette heating boiler. *Renew. Energy* **2019**, *147*, 1371–1379. [\[CrossRef\]](#)
19. Brzeski, M. The Unit for Supplying Air to the Combustion Chamber of Pellet Burner. WO Patent 2016/056930 A2, 14 April 2016.
20. Jia, G.; Li, L.; Zhang, D.M. Effect Analysis on Combustion and Emission Characteristics of a Rotary Burner Fueled by Biomass Pellet Fuel. *J. Chem.* **2020**, *2020*, 3618382. [\[CrossRef\]](#)
21. Jansky, J. *Steam Boilers*; SNTL: Praha, Czech Republic, 1954; p. 296.
22. Setnicka, F. *Thermal Engineering for Wood Engineers*; ALFA: Bratislava, Slovakia, 1981; p. 432.
23. Trnobraský, K. Analysis of wood waste burning process. *Wood* **1976**, *31*, 237–240.
24. Mahmoud, M.M.; Khalid Ratib, M.; Aly, M.M.; Abdel-Rahim, A.M.M. Wind-driven permanent magnet synchronous generators connected to a power grid: Existing perspective and future aspects. *Wind. Eng.* **2022**, *46*, 189–199. [\[CrossRef\]](#)
25. Rotary Kiln Burner. Korea Patent KR101426660 B1, 5 August 2014.
26. Horvat, I.; Dović, D.; Filipović, P. Numerical and experimental methods in development of the novel biomass combustion system concept for wood and agro pellets. *Energy* **2021**, *231*, 120929. [\[CrossRef\]](#)
27. Pełka, G.; Jach-Nocoń, M.; Paprocki, M.; Jachimowski, A.; Luboń, W.; Nocoń, A.; Wygoda, M.; Wyczęsany, P.; Pachytel, P.; Mirowski, T. Comparison of Emissions and Efficiency of Two Types of Burners When Burning Wood Pellets from Different Suppliers. *Energies* **2023**, *16*, 1695. [\[CrossRef\]](#)

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