The influence of geometry of primary air channels in standard retort burners on dust emission

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Abstract. The article presents the analysis of dust emissions from a low power boiler fired with various solid fuels. The boiler, presented for testing, met the emission conditions for boilers made in the third class in accordance with the PN-EN 303-5: 2012 standard. The solid fuel boiler was equipped with two different retort burners with automatic fuel supply. For the test were used a first generation retort burner with a fixed rim and the next were used second generation retort burner provided with a rotary rim. Both constructions differ in the geometrical model of the primary air supply system to the furnace. During the tests, the work of the burners was controlled using a microprocessor temperature controller. During the research, the rotation time of the screw supplying the fuel through the retort to the furnace was changed, as well as the rotational speed of the blast fan impeller responsible for supplying the combustion air. The purpose of the tests was to check whether the boiler will meet the highest environmental class regardless of the technical parameters of the burner and fuel used. The article describes the research methodology and analysis of the results obtained. The effect of the tests carried out is a comparison of average dust emission values depending on the fuel used and the work settings of a given burner. The test results are a prerequisite for further research work in terms of the impact of primary air supply on the emission of harmful substances.

Keywords: retort burners, dust emission, heating boilers, air channels

1 Introduction

In Poland, during the heating season, drastic deterioration of air quality is noticeable. The main cause of pollution is low emissions due to improperly conducted combustion process in heating solid fuel boilers appliances operating in individual heating. The increasing awareness of the public in the area of improving air quality means that more users choose devices that meet the highest emission standards. In many places, autonomous regulations aimed at combating smog have also been introduced. Another element related to the high

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emission of harmful substances during the heating season is the incineration of waste or poor quality fuel. Waste incineration and the use of cheap and bad quality fuels is a measure of the impoverishment of society. Dusts suspended in the air are dangerous to health due to their reactivity with other toxins. Breathing with dusty air has a negative effect on the upper respiratory tract and circulatory system. The people with frequent contact with dusty air can develop serious respiratory diseases, including cancer. The high dustiness of air during the heating period is a serious heating problem in the 21st century. There are many ways to reduce the amount of dust emitted. The basic ones are: the use of high quality fuel, the change of the burner to a low emission construction. From the burner designs offered on the market, we distinguish old and new type burners with an improved air supply system. The latest research issues are guided many times towards the use of fuels different from conventional fuels [1, 2, 3]. Natural gas and gases generated in the refining of crude oil are no longer the only ones that are used in the industry and the municipal and household sector. The above mentioned works are examples taken from the most renowned journals dealing with fuel research. Solid fuels, coal and lignite as well renewable fuels used in boilers as fuels are also the subject of research works of an increasing number of scientific and industrial workers. The growing requirements regarding the operation of solid fuel boilers lead to analyzes of the long term operation of boilers under variable load conditions [4] and to an increasing extent reach for numerical methods supporting the design of devices and the combustion process [5, 6]

In the experiment, two retort burners were used: first generation and second generation. Both burners are presented in figure 1. The first generation burners are the dominant structures in Polish heating. They are characterized by simple construction but also high level of emitted harmful substances. Second generation burners have been introduced for use recently. They are equipped with a rotating air delivery rim. They are characterized by a lower level of emitted harmful substances relative to the first generation retort. Second generation burners are already equipped with targeted air openings, however, the angle of air flow for them is 0 degrees which does not create a disturbed stream but only reproduces the air supply system from the first generation structure. In addition, they have a reduced positioning of the air holes. More information on the operation of retort burners can be found in publications [7, 8, 9, 10]. For both constructions, a structural analysis was carried out and the concentrations of emitted dusts were measured. The next stage of the research was fixing the overlay of air channel on the upper part of the burner and finding the optimal angle of the air outlet to the firing layer so as to obtain a reversible air stream. This operation was aimed at obtaining a uniform flame which would cause burning of dust escaping from the burner. The last stage was to rebuild the air rim for the old structure by applying air holes on its circumference with the predetermined optimal angle of air outflow. The final stage was to perform tests of the dust concentration in the flue gases for the improved structure.

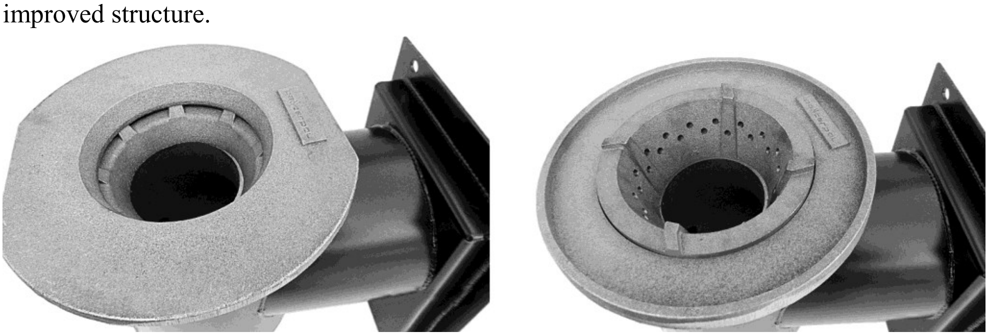

Fig. 1. An example of a first generation retort burner (left side) and a second generation retort burner (right side)

2 Aim

The purpose of the conducted research was to check whether the shape and geometry of the position of the air channels in the retort burner affects the concentration of emitted dusts and whether it is possible to reduce the emission of dust from the first generation burner by redesign the air rim to create a structure of airstream withdrawn.

3 Methods

Two retort burners were used to perform the experimental research: the first generation equipped with a fixed rim and the second generation equipped with a rotating rim. For both constructions, a structure analysis was carried out and then the concentrations of dust emitted by them were measured. The next step was to change the rim of the first generation of the burner to reduce dust emissions. To this end, a overlay of air channel was used to analysis of the speed of the out flowing air. The purpose of this part was to find the angle of the air holes in the standard rim that the air supplied to the layer create a structure of airstream withdrawn. The individual stages of research and the methods used in them are presented below.

3.1 Characteristics and test methods of the first generation retort burner

The first generation retort used for the study was a Pancerpol burner model PPS 25 kW Standard. This burner consists of a cast iron rim placed in a cast iron plate, the whole is placed on a cast iron retort.

The rim used in the burner consists of eight air holes whose geometry is semicircular in shape and the cross-section is trapezoidal. The supply of fuel to the air rim takes place through a cast iron knee set at an angle of 90°. The fuel outlet opening in the rim widens at an angle of approximately 30° in the direction of fuel out. The shaped hearth allows to slow the flow of fuel in the furnace. The task of the rim is the distribution of air supplied by the air chamber to the burning layer. The combustion process takes place on the surface of the plate. In order to test the dust emission level from the burner, it was placed in a Heiztechnik Q Eko 15 heating boiler. This boiler is equipped with an entrance dedicated to burners manufactured by Pancerpol. The view of the heating boiler with the test stand is presented in figure 2. The location of the air channels in the top part of the rim causes hypoxia of the firing layer. From the tests and observations carried out, air dosing system is imprecise because at the moment of fuel combustion below the level of openings some air does not participate in the combustion process and escapes directly to the convection parts of the boiler and then to the chimney. In addition, an excessive amount of air that does not participate in the combustion process contributes to raising some of the dust from the surface of the plate, which also affects the increased emission of this substance. These situations contribute to the hypoxia of the firing layer and increase of the level of harmful substances emitted. The first generation burner was used in the first phase of research to determine the level of dust output from the old type construction.

Fig. 2. View of the heating boiler with the test stand

3.2 Characteristics and test methods of the second generation retort burner

In the case of second generation retort burner studies, was used a Pancerpol PPSM 25 kW Duo burner. This burner, in comparison to the first generation burner, differs in the air rim used in it.

In the case of the second generation burner, the rim used enables rotation of the burning layer, which prevents sintering of the slag. Additionally, the longitudinal air holes were replaced with two rows of oval holes with a diameter of 6 mm. In addition, the location of the air supply holes has been changed, reducing their location to half the height of the rim. As in the case of the first generation retort, the air rim has a divergent shape with an inclination angle of approximately 30°. The dust emission level tests were also performed on the Heiztechnik Q Eko 15 boiler. In the case of the second generation of the burner, the level of emitted dust is significantly lower than in the case of the first generation. This is due to the multiplication of the points supplying the combustion air and the lower positioning of the holes, which allows better oxygenation of the burning layer. The observation of the geometric model of the second generation burner and the emission results obtained from it, allowed for further steps to transform the first generation rim structure so as to obtain similarly satisfactory emission results. The design of the air rim from the second generation hearth served as an inspiration to redesign the first generation air rim, using the concept of oval openings to further reduce the emission of harmful substances, efforts to orient the air holes. The second generation burner was used in the next phase of research to determine the level of dust emission from a new type of construction.

3.3 Characteristics and test methods of the first generation retort burner with the use of a steering overlay

In order to improve the design of the first generation burner, an overlay with a notches in the shape of the blades was used. The use of the steering plate made it possible to examine the air outflow profile from the burner to change the angle of air outflow. The tests were carried out for the burner without overlay and with overlay. The tests without the overlay were intended to examine the normal profile of the velocity of the outgoing air from the rim. In the case of tests with a overlay, an optimal angle of the outgoing air was created to reversible air flow. The overlay was made of 0.5 mm thick steel sheet with eight notches in the shape of the letter L. The view of the overlay used is shown in figure 3.

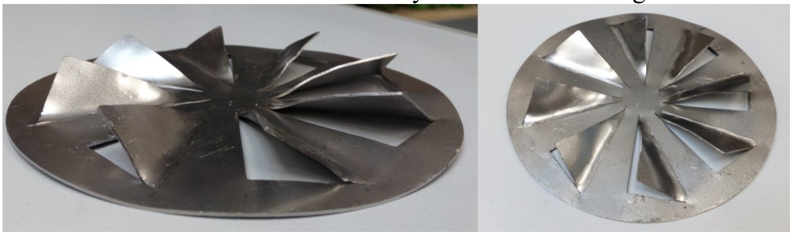

Fig. 3. View of the overlay used in tests

The base of the steering wheel was 30 mm long and the longer arm 50 mm. Steering plate was fixed permanently to the cast iron fireplace plate. Steering flaps were folded from $\alpha = 20°$ upwards every 10°. Air distribution tests were made across the length of the hearth plate. The final stage of the research was to achieve the optimal angle of outflow causing the maximum return of the air stream. The distribution of the outgoing air was measured by a micromanometer with a pitot probe for the fire plate divided into 11 sections. The method of division the hearth without a sheet is presented in figure 4.

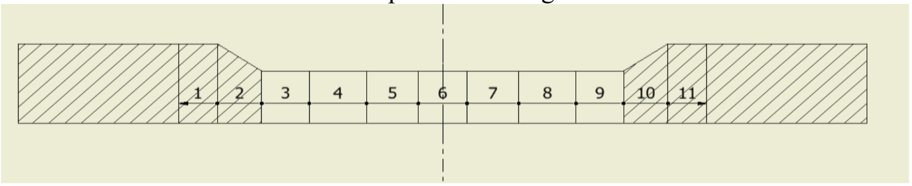

Fig. 4. View of the division of standard retort rim used in tests

For measurements with the steering overlay mounted, the cross section of the burner was divided into 17 sections in which the measurements were made. The method of division the burner with the used steering plate is presented in figure 5.

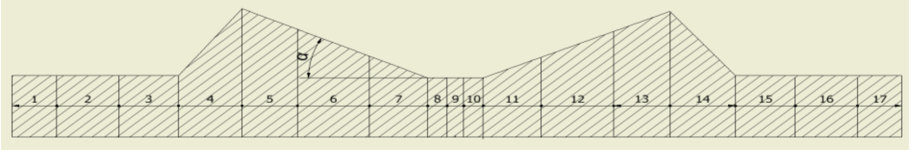

Fig. 5. View of the division of overlay used in tests

3.4 Other methods used in tests

The test methods used for testing are described in the standard PN-EN 303-5:2012. The lignite fuel was used to the tests. Fuel was stabilized before the tests under the same laboratory conditions. The obtained test results were compared with the currently applicable regulations regarding the emission of dust from boilers. According to the standard, the emission of dust from boilers with automatic feeding of fuels made in the fifth class should not be greater than 40 mg/m^3 with 10% oxygen content in the exhaust gas. The studies assume that the arithmetic mean of dust emissions from the entire test cycle should not exceed this value. In each test cycle, constant and uniform parameters of boiler operation were maintained, while during the measurements the boiler operation settings were not interfered with. Extended information on exploitation and testing of boilers can be found in [11, 12]. The flow temperature was kept on average between 75°C to 80°C and on the return on average between 60°C to 65°C; the temperature difference was around 15°C. During the research, the same environmental conditions prevailed. The burner operation was controlled by means of a microprocessor control system. This solution enabled a smooth change of the fuel supply and air settings in the burner, so as to obtain the same operating parameters in each test. A gravimetric dust meter was used to measure selected emission parameters of exhaust gases. The gas intake lance was mounted in the measuring chimney, and the selected exhaust parameters unrelated to the dust measurement were measured and recorded using the appropriate recording program. The emission value in the test cycle was determined as the arithmetic mean of individual measurements throughout the cycle. Each research cycle lasted about 2 hours. The parameters collected were converted into values in mg/m^3 at 10% O_2 content in the flue gases, which is in line with the PN-EN 303-5:2012 standard.

The research laboratory was equipped with a system of heat exchangers used to extract the heat generated during the tests. In the probes placed in the chimney, thermocouples for measuring the exhaust temperature were installed. The final exhaust temperature was determined as the arithmetic mean of five measuring thermocouples. The thermal power of the boiler was determined by means of a system consisting of four heat exchangers connected in series, the rated heat output of each exchanger was 50 kW. In addition, an electromagnetic flow meter and thermocouples were used to measure the temperature of water on the supply and return from the boiler. In addition to the estimation of the thermal power delivered by the heating water, the mass flow of the water leaving the exchangers was measured using a scale. During each of the research cycles, after obtaining the required thermal parameters, the device operation was stabilized and measurements and analysis of dust pollution were made.

4 Results

4.1 Test results of the air speed profile

The tests of the air speed profile for the burner in the producer's version have been carried out for the rotational speed of the blast fan rotor in the range from 0-100% with a 20% step. The resulting distribution is presented in figure 6.

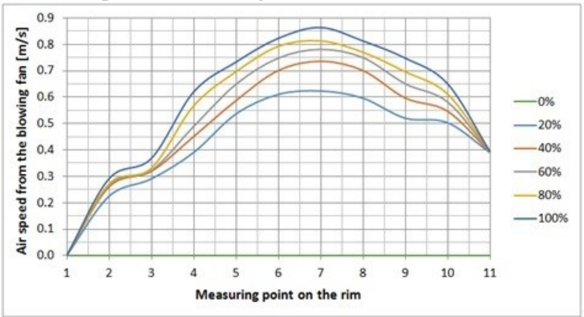

Fig. 6. View of the air velocity relative to the rotational speed of the fan

From the obtained results it can be seen that the highest air velocity is obtained for 100% of the fan setting and gives the speed of c = 0.85 m/s. In addition, the peak of the characteristic is shifted from point number 6 to point number 7 closer to the right side. Between points 1 and 4 you can see lower velocities of air outflow in relation to their symmetry for points 8 to 11. The reason for air downturn may be the retort knee located at this point, which causes the air flow to stop. This study showed that the burner construction itself is inaccurate and some of the layer above the retort knee may have air shortages due to the reduced air flow velocity.

Tests for the burner with the steering pad used were carried out for steering angle angles from α = 20° to 60° every 10° and changing the rotor speed from 20% to 50% every 10%. The mileages are show in figure 7.

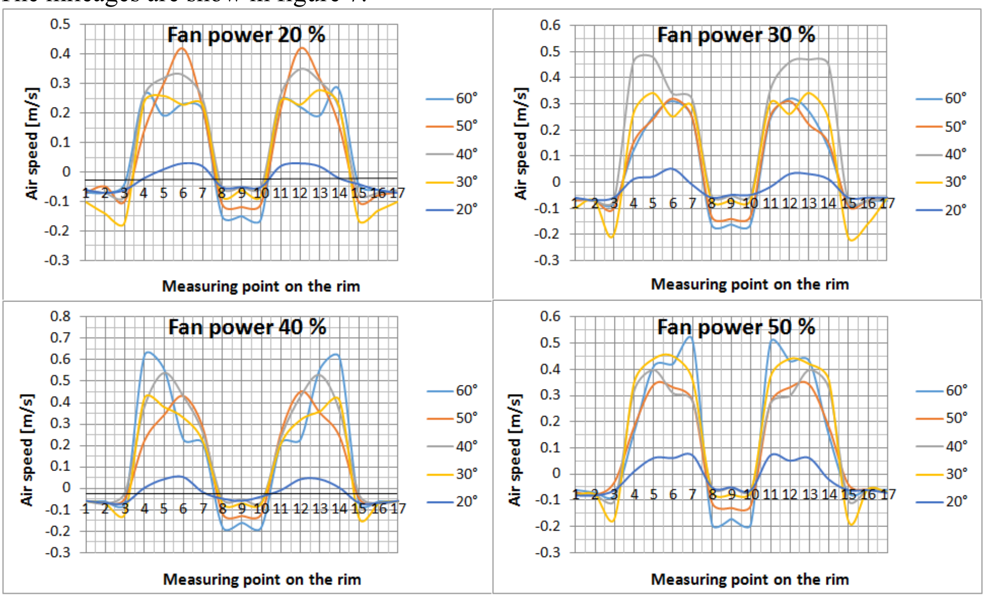

Fig. 7. View on the course of dynamic pressure at a given measuring point in relation to the deflection angle of the steering flaps in the overlay

From the obtained characteristics, we can see that regardless of the rotor speed level, the largest withdrawal of the air stream was obtained for an air outlet angle of 60°. Therefore, holes were made in the corrected rim at this angle. It has been assumed that the diameter of the holes will be the same as in the second generation burner, it will be around 6 mm. Vertical orientation of air channels are 60° and the additional horizontal deviation is 30°. The angle of horizontal deviation resulted from the complement of the angle of the side of the steering wheel to the base forming the air outlet. Collected data from the used steering wheel were to reproduce the obtained results from the research carried out with the steering overlay as much as possible.

4.2 The results of the tests of the concentration of dust in the exhaust

During the tests of individual constructions, it was tried to maintain the same thermal conditions of the burner as well as the boiler and use the same air supply settings (rotational speed of the fan) and the amount of fuel fed to the boiler.

The first element subjected to dust emission tests was the first generation retort burner without structural changes. The course of emission of harmful substances that was obtained can be treated as input data regarding the amount of dust emitted. The boiler was subjected to four test sessions of 30 minutes each, which gives a total of 2 hours measurements. From the obtained results a common course of emitted dusts was carried out to the measured oxygen level in the flue gas. The arithmetic mean of dust pollination was 199 mg/m^3. The obtained result significantly differs from the assumptions of the standard for boilers made in the fifth class. The obtained average exceeds the standard's assumption almost five times. Such a high emission of harmful substances shows that the first generation burners used in boilers do not meet the requirements of low emission constructions in any aspect and they should be subjected to a comprehensive verification of construction parameters and steps should be taken to modernize them. The results obtained also confirmed the correctness of the measures taken to redevelop the burner part. The obtained course for the first generation burner is presented in Figure 8.

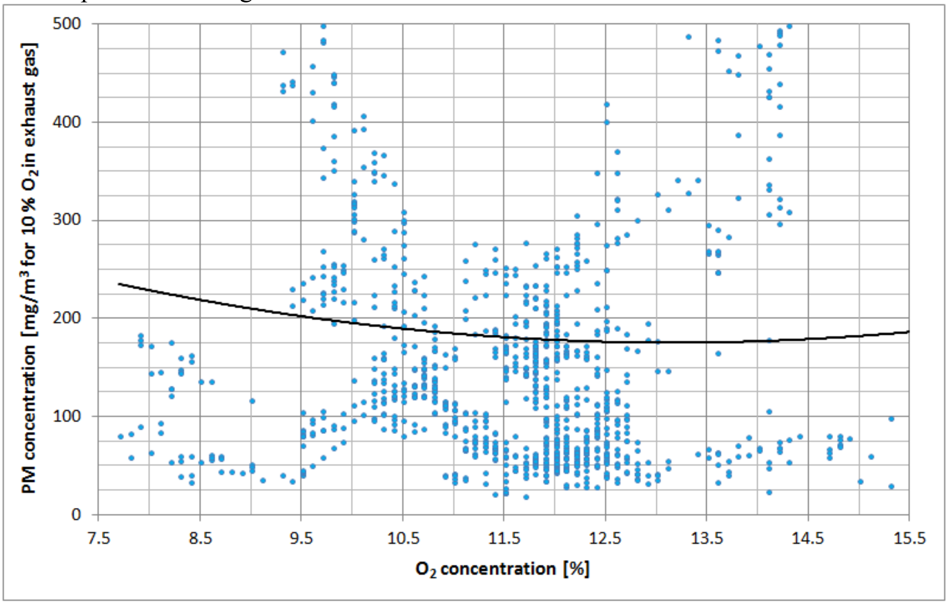

Fig. 8. The course of dust pollination in relation to the oxygen content for first generation retort burner with old rim

Another tested construction was a second generation retort burner. The entire research cycle as well as the methodology of the conducted research was identical to that of the first generation burner. The application of convergent research methods allowed to exclude the influence of external factors on the obtained results. Similar settings of the burner operation were also used to obtain similar operating conditions. From the obtained results and the literature study [13]. We can see that the burner equipped with a rotating rim has significantly better operating parameters relative to the first generation burner. The arithmetic mean of the concentration of emitted dust is 74 mg/m^3. The obtained result confirmed the correctness of the steps taken to redesign the first generation burner. It has been shown that the use of cylindrical holes gives better burner performance relative to trapezoidal hemispherical holes. The obtained course for the second generation burner is presented in Figure 9.

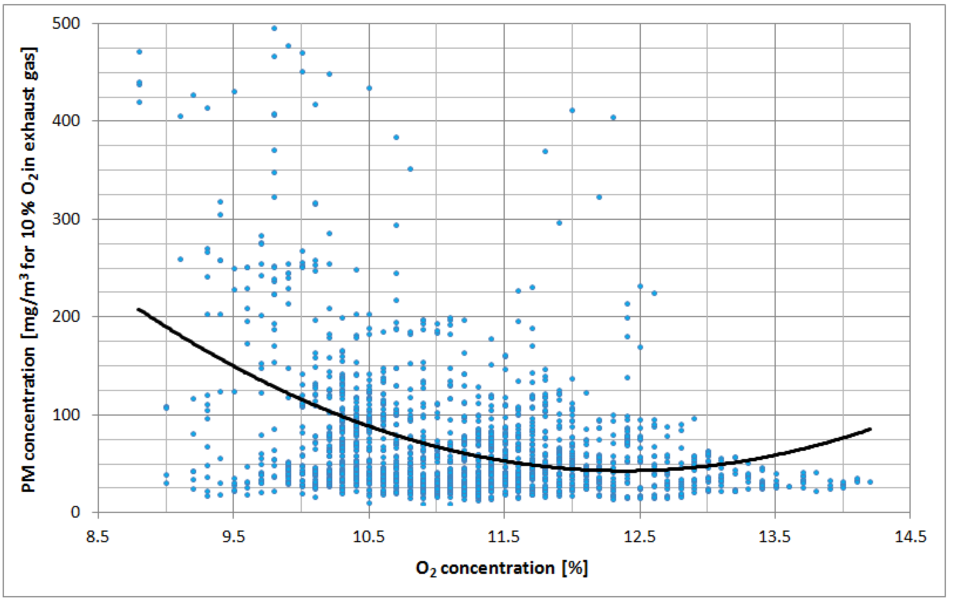

Fig. 9. The course of dust pollination in relation to the oxygen content for second generation retort burner

The last stage of the research was to conduct a flue gas analysis for the rim with improved construction. The old air holes were blinded with high temperature silicone. As a result, the air was sent to the burner only through previously prepared openings. As before, 4 measurement sessions were carried out of 30 minutes each, and the results obtained were presented in Figure 10.

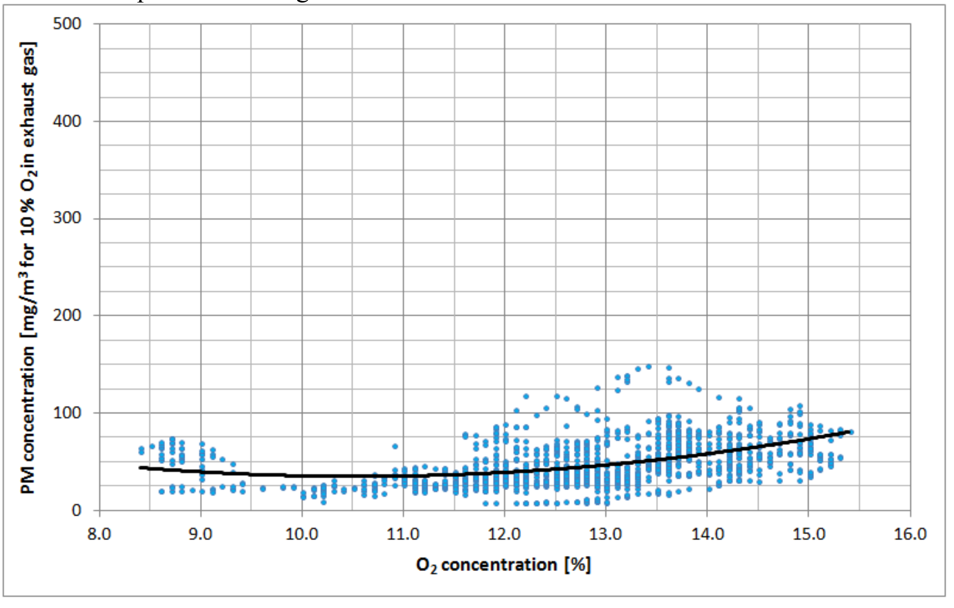

Fig. 10. The course of dust pollination in relation to the oxygen content for first generation retort burner with new rim

The arithmetic mean of the dust concentration tests in combustion gases is 47 mg/m^3. This result is very satisfactory because thanks to the shape change and the location of the air channels, we managed to improve the emission result more than 4 times while maintaining uniform settings of the burner operation. This result shows that the design offered by the manufacturer is incorrect and that it can be adjusted so that obtained emissions from the boiler meet the highest standards. In addition, we managed to obtain a lower dust concentration compared to the second generation of burner, which gives the premise to improve the structure of burners in terms of thermal and emission.

From the obtained results, we see significant dust emission for both the oxygen level below 10% and above for first generation burner. In the case of an improved structure, the amount of dust emitted increases with increasing oxygen concentration above 10%. This may indicate that the old type design has oxygen deficiencies in both low values and high oxygen contents in the exhaust. This may result from the escape of a certain amount of air that is not managed in the combustion process. In the case of a new type of construction, an increase in the concentration of dusts with increasing oxygen concentration will be associated with an excessive amount of air in the combustion reaction which will cause sub cooling of the flame ends and the formation of soot. While conducting the combustion process for a revised structure, the amount of combustion air should be carefully selected without creating a significant excess because the layer is well mixed with the air, which results in good layer oxygenation.

5 Conclusions

The research problem of the experiment was to show the relationship between the geometric shape and the location of the retort burner's air channels on the emission of harmful substances in the form of dust. The actions taken consisted in determining the concentration of emitted dust from the structures available in individual heating and re-designing individual elements of the old type of burner so as to lower their level. The actions taken and the methodology chosen have proved to be correct. The researchers experience as well as the mechanical and thermodynamic approach to the construction resulted in a lower concentration of emitted dust substances. The results obtained and the actions taken are a prerequisite for further research to further refine the design. The empirical and active studies have shown that the structures available on the market are imperfect and can be improved. The main possibilities of correction of burners lie on the side of the structure of gangue elements that are responsible for thermal and emission properties. In addition, the steps taken and the selected methodology for estimating the position and geometric orientation of the air ducts showed a simple method of redesign the mechanical construction of the burner. All these aspects influenced the receipt of favorable results from the newly modeled structure. Unfortunately, from the tests of the improved design of the burner, it was not possible to obtain emissions at the level of 40 mg/m^3 of dust pollination, but the obtained result at the level of 47 mg/m^3 was close to the requirements. Taking into account the measurement error of the apparatus declared by the manufacturer at the level of about 10 mg/m^3, it can be assumed that the construction at very accurate measurements and additionally adjusted for tests would have a mean result significantly lower than the requirements of the standard. This can be proved by dust emission results obtained on the corrected burner from 8-40 mg/m^3 about 65% of the results. The undertaken activities and research proved to be accurate as well as the applied research methods. The conducted research resulted in a positive result and all the objectives were positively implemented.

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