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## COMBUSTION OF PLYWOOD WASTE IN A LOW-POWER BOILER

*The article presents the results of experiments aimed at the identification of the influence of the share of phenol and amine resins in burnt fuel mixtures from wood waste along the basic parameters of the process of their thermal oxidation in a low-power boiler. Differences in the composition of combustion gases from the burning of waste from "virgin" wood and plywood manufactured using urea-formaldehyde (UF) and phenol-formaldehyde (PF) glues were observed.*

**Keywords:** wood waste, recycling of waste, combustion processes, bioenergy, biomass burning, emissions of combustion products

### Introduction

In the production process of wood-based panels the main product is accompanied by considerable amounts of various types of waste. It is estimated that the domestic industry produces a few million cubic meters of lignocellulosic waste a year. This waste includes: shreds, sawdust, wood dust, bark, final product waste [Szostak et al. 2004].

Industry practice has proved that one of the more rational ways of managing waste from the composite wood product industry is to burn it to produce the energy necessary for the technological process. Combustion means the thermal-oxidation disintegration of plastics used for the finishing of wood-based materials, much reduction of the volume of waste and use of its chemical energy [Baker 1991; Marutzky 1991a, 1991b, 1991c; Marutzky, Schriever 1986].

However, previous research has shown that during the thermal neutralisation of waste from the composite wood product industry, products of the combustion of bonding and finishing substances used with wood material, which are harmful to the environment, are emitted into the atmosphere. Among these substances, the most dangerous are nitrogen oxides ( $\text{NO}_x$ ) and carbon monoxide [Cichy 2004; Cichy, Prądyński 1995; Ladomerský et al. 1994; Marutzky 1991a; Schneider,

Deppe 1996; Schriever et al. 1983]. These are the substances found during every process of fuel combustion. They are products of the oxidation of both natural organic substances (wood) and synthetic organic substances (e.g. glue resins), as well as the oxidation of atmospheric nitrogen found in the air supplied to the hearth.

Research carried out in the Wood Technology Institute has shown that the content of nitrogen in composite wood product waste coming from Polish manufacturers ranged from 1.5 to 7.0%.

Researchers from German-speaking countries, mainly from Germany and Switzerland, have devoted much attention to the phenomena observed during the processes of the combustion of wood and wood-based materials. Nussbaumer in his papers [1991, 2003] compared the results of nitrogen oxide emission determinations with nitrogen content in the case of waste from particleboards glued with urea resin, and in the case of pine and beech burnt isothermally in laboratory conditions. Therefore, it would be useful to learn the mechanism of the reactions occurring inside the hearth and their bearing on the final composition of the combustion products (mainly  $\text{NO}_x$  and CO). Interesting information on the combustion of composite wood products manufactured using amine and phenol resins may be found in the publication by Marutzky [1991a]. The publication compares the results of the emission of basic toxic substances from the combustion of particleboards glued with “phenol” and “urea” resins (table 1).

**Table 1. Emissions of selected combustion gases during the combustion of wood and particleboards glued with amine and phenol resins**

*Tabela 1. Emisje wybranych gazów spalinowych w trakcie spalania drewna i płyt wiórowych zaklejanych żywicami aminowymi i fenolowymi [Marutzky 1991a]*

Fuel type <i>Rodzaj paliwa</i>	Emission volume <i>Wielkość emisji</i> [mg/MJ]		
	CO	Hydrocarbons <i>Węglowodory</i>	$\text{NO}_x$
Virgin wood <i>Surowe drewno</i>	3200	390	35
Particleboard “PF” <i>Płyta wiórowa „fenolowa”</i>	4500	450	45
Particleboard “UF” <i>Płyta wiórowa „mocznikowa”</i>	3100	350	140

The compared data shows that phenol particleboard combustion was accompanied by carbon monoxide emissions higher by approximately 30% compared with the other fuels. In the case of hydrocarbons, their content observed in the exhaust was approx. 22% higher than in the case of urea board and approx. 13% higher compared to phenol board. The emission volumes of nitrogen oxides were

different. In this case, the highest emissions were recorded during the combustion of “urea” board (140 mg/MJ) and the lowest during the “virgin” wood combustion (35 mg/MJ). The above demonstrates that the combustion of composite wood product waste containing both urea and phenol resins is accompanied by different in volume emissions of gaseous combustion products (mainly CO, NO<sub>x</sub>, and hydrocarbons).

For some time the Wood Technology Institute has conducted research aimed at the identification of the phenomena accompanying the processes of thermal utilisation of waste from composite wood products. In view of the fact that the issue of how to reduce the production of nitrogen oxides and carbon monoxide during thermal destruction of waste from composite wood products has not been fully solved yet, the Institute decided to continue its research at ¼ technical scale. Most known literature only touches upon the issues of particleboard waste combustion, while there is extremely little information on wood waste burdened with phenol resins as well as on co-burning of waste containing phenol and amine resins. Therefore it was decided to carry out research with this scope.

The aim of this research was to learn the influence of phenol and amine resins present in the burnt wood waste along the basic parameters of the process of thermal oxidation of this waste under the conditions found in a low-power laboratory hearth.

## Materials and methods

The research focused on the combustion process of waste from phenol and urea plywood under changeable temperatures in the experimental hearth. The variable factors in the experiment were:

- 1) mass share of particular types of waste in the total mass of the fuel burnt:
  - a) PF plywood – wood, in the following proportions: 100 – 50 – 25 – 0%,
  - b) PF plywood – amine plywood, in the following proportions: 100 – 50 – 25 – 0%,
- 2) the amount of air dosed – 50÷140 m<sup>3</sup>/h

The observed factors were:

- 1) combustion efficiency,
- 2) excess air ratio  $\lambda$ , and
- 3) composition of combustion gases:  
carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), hydrocarbons (C<sub>x</sub>H<sub>x</sub>) and oxygen (O<sub>2</sub>).

## Raw material for testing

Typical waste from exterior (PF) and interior (UF) plywood were used for testing. Shreds obtained from a factory were reduced to chips. Such prepared raw material (of a relative moisture content of approx. 15%) was stored at an ambient temperature. Virgin softwood chips of the same graining were used as the con-

trol sample. Prior to the tests, fuel mixtures of the assumed proportions were prepared.

### Methodology of laboratory work

The prepared raw material was subjected to elementary analysis concerning carbon, hydrogen, sulphur, and nitrogen content. The analysis was done using an EA 1108 analyzer by CARLO ERBA INSTRUMENTS. Quantity analyses were conducted using an internal standard, i.e. sulphanilic acid.

The base of the experimental station, where the combustion processes were investigated, was an AZSO-50 Automatic Waste Combustion Set, by Z.M. HA-MECH from Hajnówka (power output 50 kW), equipped with a heat storage tank. Detailed technical specifications of this boiler were presented in previous publications (Cichy 2004).

### Procedure of the combustion process investigation

- 1) Lighting the furnace until optimum combustion process parameters are reached,
- 2) period when stable process conditions are being reached (3 hours),
- 3) stabilisation of the process in assumed working conditions (around 1 hour),
- 4) combustion process analysis:
  - measurement of temperatures inside the hearth,
  - measurement of concentration of gaseous combustion products,
  - measurement of combustion parameters,
- 5) putting out fire in the hearth.

The analysis of the combustion gases was carried out using a LANCOM Series II portable analyzer with electrochemical cells, by LAND COMBUSTION, which facilitates measurements with the following scope:

$O_2$	0...25%	accuracy $\pm 1\%$	resolution $\pm 0.1\%$ ,
$CO_{low}$	0...2000 ppm	accuracy $\pm 4\%$	resolution $\pm 1$ ppm,
$CO_{high}$	0...40000 ppm		resolution $\pm 100$ ppm,
$NO$	0...1000 ppm	accuracy $\pm 4\%$	resolution $\pm 1$ ppm,
$NO_2$	0...100 ppm	accuracy $\pm 4\%$	resolution $\pm 1$ ppm,
$SO_2$	0...2000 ppm	accuracy $\pm 4\%$	resolution $\pm 1$ ppm,
$C_xH_x$	0...5%.		

The content of  $CO_2$  and  $NO_x$  was given based on calculations. Combustion efficiency was calculated in the same way by the software of the exhaust gas analyzer.

The values of emission obtained from the measurements were converted into 11% content of oxygen in the exhaust. The apparatus also facilitated comprehensive calculations of the power object efficiency, the temperature of combustion gases in the funnel, and ambient temperature.

## Results and discussion

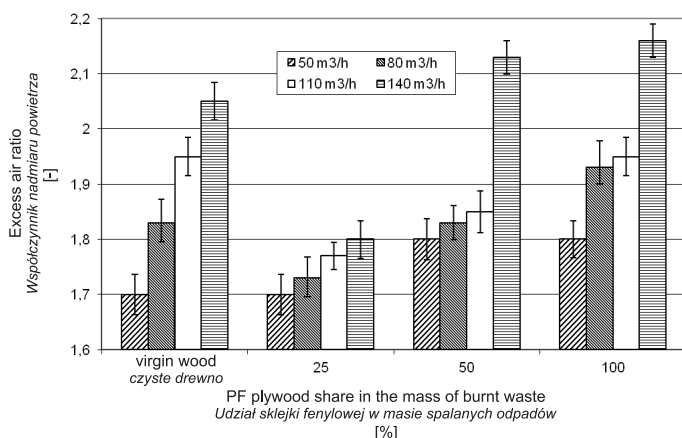
Table 2 presents a comparison of the results of elementary analyses employed to test the fuel materials.

**Table 2. Elementary composition of fuels used in the experiment**  
*Tabela 2. Skład elementarny paliw użytych w eksperymencie*

Waste type <i>Rodzaj odpadów</i>	Content of elements <i>Zawartość pierwiastków</i> [%]			
	C	H	N	S
Virgin wood <i>Surowe drewno</i>	49.54	6.38	0.42	< 0.01
Plywood waste (UF) <i>Odpady sklejk (mocznikowej)</i>	45.62	7.65	8.41	< 0.01
Plywood waste (PF) <i>Odpady sklejk (fenolowej)</i>	49.72	7.06	0.63	< 0.01

The analysed wood waste did not contain sulphur (within the apparatus determination capacity). Therefore, sulphur dioxide emission was not analysed in the following tests. The content of nitrogen in the “phenol” plywood was 0.63% and was similar to the content of this element in the “virgin” wood. The share of amine resin in the amine plywood contributed to a relatively high content of nitrogen (8.41%) in the fuel obtained from this plywood waste. The content of other analysed elements (carbon and hydrogen) changed to a small extent (hydrogen 6.38–7.65%; carbon 45.62–49.72%), which was connected with the diverse proportions of wood to glue resin.

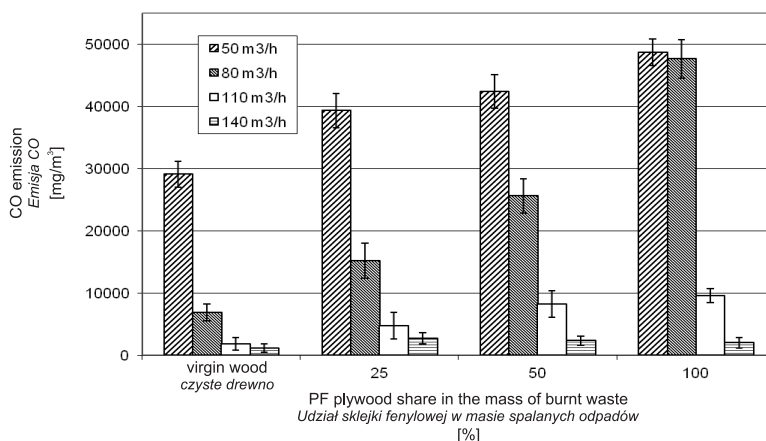
The diagrams (fig. 1–5) present the changes of the individual parameters of the combustion process and emission of the analysed combustion products. Each measuring point shown in the diagrams of emission and combustion parameters (apart from temperature) was an arithmetic mean of approximately fifty elements. Figure 1 presents the values of excess air ratio  $\lambda$  which change depending on the share of PF plywood in the fuel burnt. The data shows that  $\lambda$  ratio ranged from 1.70 to 2.16. The lowest values (1.70–1.80) were recorded for all fuel types at the air dosing velocity of 50 m<sup>3</sup>/h and the highest (2.05–2.16) at the velocity of 140 m<sup>3</sup>/h. The small differences between the individual types of the fuel burnt seemed to have been caused by small disturbances in the operation of the low-power hearth.



**Fig. 1. Changes of excess air ratio ( $\lambda$ ) depending on the share of PF plywood in the fuel burnt**

*Rys. 1. Zmiany współczynnika  $\lambda$  w zależności od udziału sklejk fenolowej w spalanej paliwie*

Figure 2 presents the changes in carbon monoxide content in the combustion gases produced during the combustion of wood fuels with various shares of PF plywood. The presented data indicates that carbon monoxide emission ranged from 1.13 to 48.74 g/m<sup>3</sup>. According to the data, the highest level was reached when the “phenol” plywood was burnt at the air dosing velocity of 50 m<sup>3</sup>/h, while the lowest level was recorded when the “virgin” wood was burnt at the air dosing velocity of 140 m<sup>3</sup>/h. As should have been expected, CO content in the exhaust dropped as the amount of air supplied to the hearth rose.



**Fig. 2. Carbon monoxide emission changes depending on the content of PF plywood in the fuel burnt**

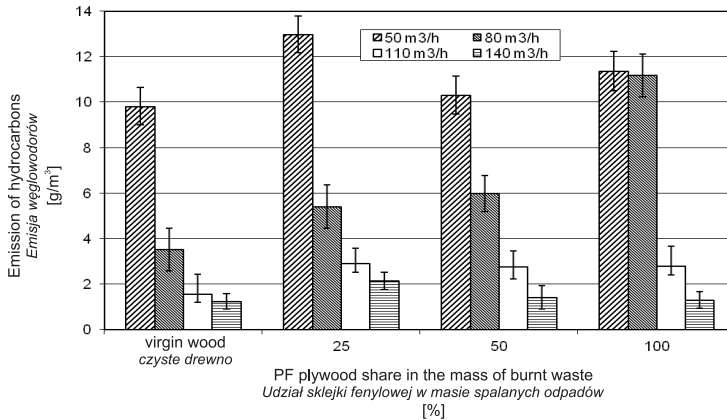
*Rys. 2. Zmiany emisji tlenku węgla w zależności od udziału sklejk fenolowej w spalanej paliwie*

In the case of the “virgin” wood, this drop was almost thirtyfold (from 29.101 to 1.130 g/m<sup>3</sup>), in the case of the fuel with a 25 percent share of PF plywood, over fourteenfold (from 39.350 to 2.750 g/m<sup>3</sup>), in the case of the 50% share of PF plywood, the fall was 17.9:1 (from 42.444 to 2.369 g/m<sup>3</sup>), while in the case of fuel containing 100% PF plywood it was 23.6:1 (from 48.738 to 2.062 g/m<sup>3</sup>). Non-linear changes, intensifying especially when the share of phenol resin in the burnt fuel increased, were probably caused by the oxidation and reduction reactions occurring in the hearth between the nitrogen oxides and carbon compounds (C, CO, C<sub>x</sub>H<sub>y</sub>). Such reactions are described in literature [Marutzky 1991a; Nussbaumer 1991, 2003] and confirmed by the author’s own research [Cichy 2004].

Figure 3 presents the changes in hydrocarbon emission depending on the share of PF plywood in the fuel burnt at changing amounts of air supplied to the hearth. For this group of compounds, relations similar to those recorded in the case of carbon monoxide were observed, i.e. increased amounts of air dosed to the hearth resulted in a decrease in C<sub>x</sub>H<sub>y</sub> content in the combustion gases. However, the proportions observed between the extreme values were lower. In the case of the “virgin” wood, the proportion was 7.9:1; for fuel with a 25% share of PF plywood, 6.1:1; when the content of PF plywood was 50%, the proportion was 7.3:1; and in the case of 100% PF plywood, 8.8:1. A very distinct increase in hydrocarbon emission at a rising share of phenol resin in the fuel was observed when the air was dosed at a rate of 80 m<sup>3</sup>/h. In other cases, less or greater departures from this rule were observed. This phenomenon might have been caused by the hereinbefore described reactions of oxidation and reduction occurring in the reaction zone of the hearth. For all the analysed fuels, a distinct fall in hydrocarbon content in the combustion gases was observed as the amount of air dosed to the hearth rose. When the air dosing velocity changed from 50 to 80 m<sup>3</sup>/h, the emission of C<sub>x</sub>H<sub>y</sub> decreased over twofold for all the analysed fuels, apart from the PF plywood without any additions of “virgin” wood. A similar situation was observed when the air velocity was increased to 110 m<sup>3</sup>/h. A further increase in the supplied air resulted in only an insignificant fall in hydrocarbon content in the exhaust.

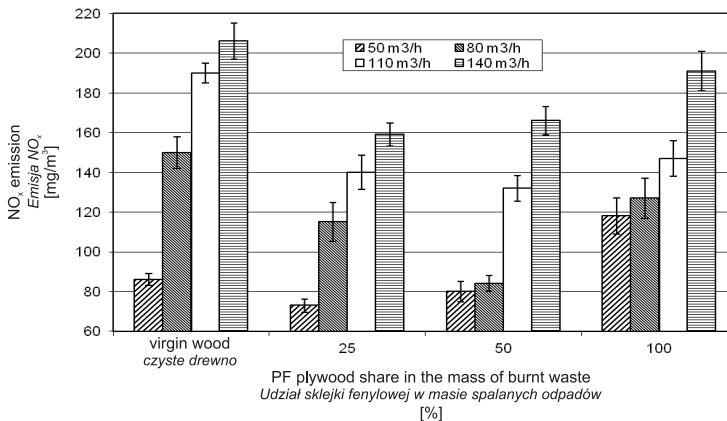
Figure 4 depicts the changes in the emission of nitrogen oxides depending on the share of PF plywood in the fuel burnt and under the conditions of changeable amounts of air supplied to the hearth. The presented data indicates that the highest emissions of NO<sub>x</sub> were recorded when the amount of air dosed to the hearth was the highest (140 m<sup>3</sup>/h) for all fuel types. The highest value of nitrogen oxides was determined in the exhaust produced on the combustion of the “virgin” wood (206 mg/m<sup>3</sup>). The combustion of fuels containing phenol resins were accompanied by slightly lower emissions of NO<sub>x</sub> (159–191 mg/m<sup>3</sup>). A reduction in the amount of air dosed to the hearth from 140 to 50 m<sup>3</sup>/h caused a fall in the emission of these substances, while the biggest differences were observed during the combustion of the “virgin” wood (206–86 mg/m<sup>3</sup>/h), and the smallest were recorded for the PF plywood without any share of “virgin” wood (191–118 m<sup>3</sup>/h). The observed chan-

ges in the content of nitrogen oxides should be connected with the hereinbefore discussed reactions of oxidation and reduction occurring in the hearth and resulting in a distinct reduction in  $\text{NO}_x$  emission when the content of carbon monoxide and hydrocarbons was high.



**Fig. 3. Changes in the emission of hydrocarbons depending on the content of PF plywood in the fuel burnt**

*Rys. 3. Zmiany emisji węglowodorów w zależności od udziału sklejk fenolowej w spalanej paliwie*



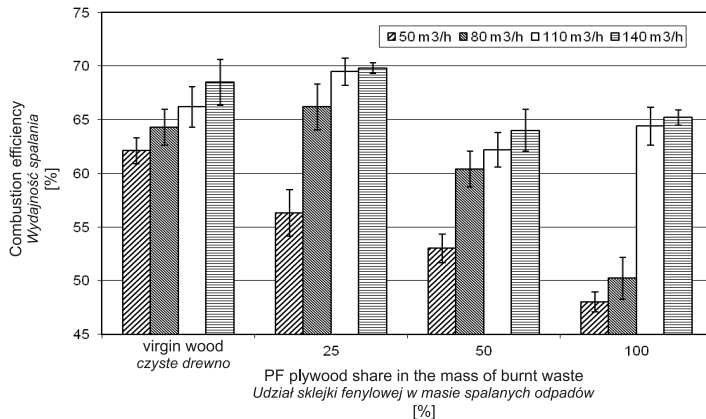
**Fig. 4. Changes in the emission of nitrogen oxides depending on the content of PF plywood in the fuel burnt**

*Rys. 4. Zmiany emisji tlenków azotu w zależności od udziału sklejk fenolowej w spalanej paliwie*

Figure 5 depicts the changes in combustion efficiency depending on the share of PF plywood in the fuel burnt. The presented data shows that combustion efficiency ranged from 48.0 to 69.8%. The lowest values of efficiency were recorded at the highest level of emission of carbon monoxide and hydrocarbons,



which was related to the manner of determination of this parameter. The highest efficiency (64.0–69.8%) was reached at low values of the emission of CO (1.13–2.75 g/m<sup>3</sup>) and C<sub>x</sub>H<sub>y</sub> (1.24–2.14 g/m<sup>3</sup>), and high values of NO<sub>x</sub> emission (159–206 mg/m<sup>3</sup>).

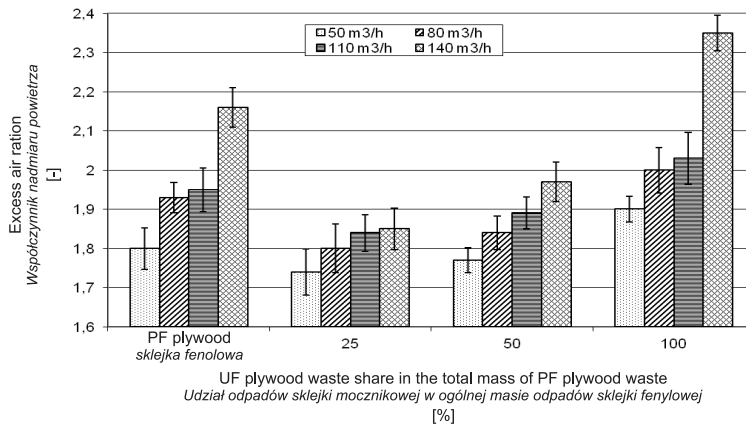


**Fig. 5. Changes in combustion efficiency depending on the content of PF plywood in the fuel burnt**

*Rys. 5. Zmiany sprawności spalania w zależności od udziału sklejk fenolowej w spalanej paliwie*

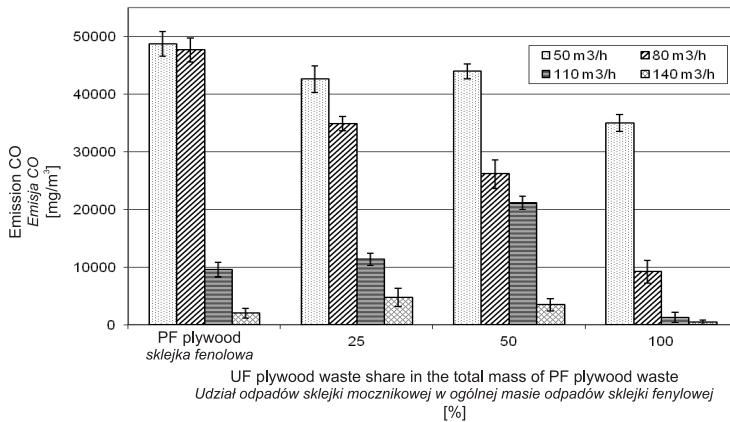
The following diagrams (fig. 6–10) show the results of the second part of the experiment in which the PF plywood waste was co-burnt with the UF plywood waste according to the assumed weight proportions. Figure 6 depicts the changes of excess air ratio  $\lambda$  for changing amounts of air dosed to the hearth, depending on the share of the UF plywood in the total mass of the PF plywood. In the cases discussed,  $\lambda$  ratio had similar values ranging from 1.74 to 2.35. The insignificant differences between these values mainly resulted from the nature of the low-power hearth operation, and not from the fuel properties. In comparison with the first variant of the experiment (fuel: PF plywood – “virgin” wood) the obtained values of  $\lambda$  ratio also differed to a small extent.

Figure 7 depicts the changes in carbon monoxide emission at changeable amounts of air dosed to the hearth. The compared data indicates that the carbon monoxide content ranged from 0.493 to 48.738 g/m<sup>3</sup>, while the lowest values were observed for the UF plywood at the air dosing rate of 140 m<sup>3</sup>/h, and the highest for the mixture with a 100 percent share of PF plywood. When air was dosed to the hearth with the velocity of 50 m<sup>3</sup>/h, the recorded carbon monoxide content in the exhaust was almost the same (48.738–42.612 g/m<sup>3</sup>), except for the UF plywood, in which case this value was slightly different (34.997 g/m<sup>3</sup>). When air was dosed at the rate of 80 m<sup>3</sup>/h, a distinct downward trend in CO emission was observed as the share of the UF plywood in the burnt fuel rose (47.662–9.206 g/m<sup>3</sup>). For the other amounts of air supplied, the level of CO emission was more diverse.



**Fig. 6. Changes of excess air ratio ( $\lambda$ ) depending on the share of UF plywood in the total mass of PF plywood in the fuel burnt**

*Rys. 6. Zmiany współczynnika  $\lambda$  w zależności od udziału sklejkı mocznikowej w ogólnej masie sklejkı fenolowej w spalonym paliwie*

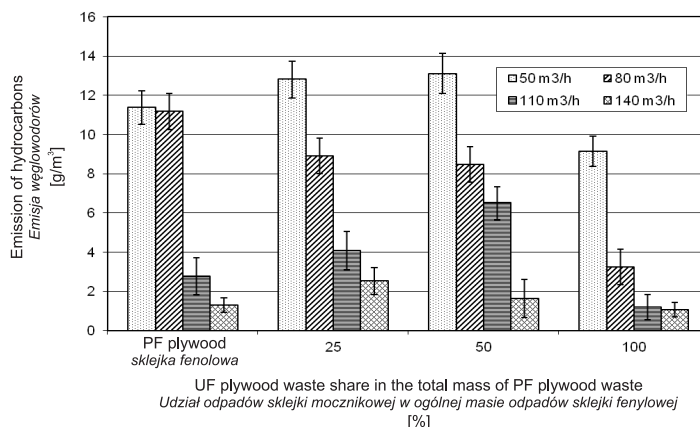


**Fig. 7. Carbon monoxide emission changes depending on the share of UF plywood in the total mass of PF plywood in the fuel burnt**

*Rys. 7. Zmiany emisji tlenku węgla w zależności od udziału sklejkı mocznikowej w ogólnej masie sklejkı fenolowej w spalonym paliwie*

Figure 8 depicts the changes in the emission of hydrocarbons during the combustion of the analysed fuel types resulting from changing amounts of air supplied. The presented data shows that  $C_xH_y$  emission ranged from 1.06 to 13,10  $g/m^3$ . Its highest values were recorded when air was dosed at the velocity of 50  $m^3/h$  (9.14–13.10  $g/m^3$ ), and the lowest at the air dosing velocity of 140  $m^3/h$  (1.06–2.51  $g/m^3$ ). Although the combustion of the UF plywood produced lower values of hydrocarbon emission compared with the combustion of the PF plywood, the fuel mixtures containing 25 and 50 percent of UF plywood were cha-

racterised by the highest content of  $C_xH_y$  in the exhaust (2.51–12.80  $g/m^3$  and 1.63–13.10  $g/m^3$  respectively). Despite this, the differences between individual types of the analysed fuels were insignificant. The most important factor causing a decrease in the emission of hydrocarbons was an increase in the amount of air supplied to the hearth. In the case of a 100 percent share of UF plywood, an increase in the amount of supplied air from 50 to 80  $g/m^3$  caused a 65 percent fall in the content of  $C_xH_y$  in the exhaust. When air was supplied at the rate of 110  $m^3/h$ , a 63 percent drop in emission was recorded. A further increase in the amount of air supplied was no longer so important (drop in emission 11%). In the case of the PF plywood, the increase in the air amount from 50 to 80  $g/m^3$  caused insignificant changes (drop in  $C_xH_y$  emission 1.7%). Only at the air velocity of 110  $g/m^3$  was the drop in emission 75%. The combustion of the fuel mixtures was accompanied by the emission of hydrocarbons at an amount and at a level similar to that in the case of the UF plywood.

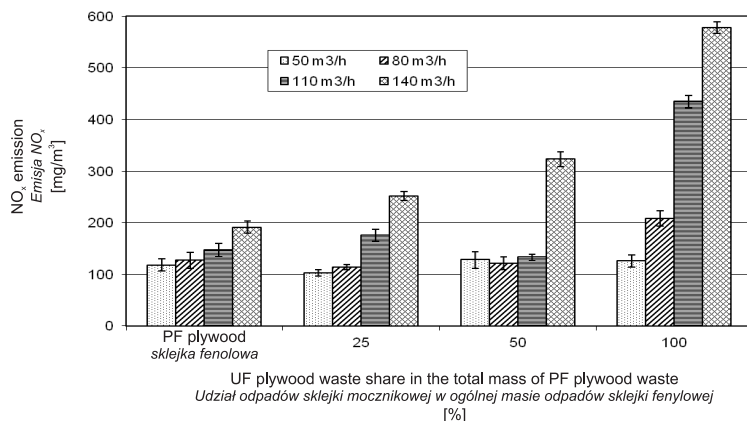


**Fig. 8. Changes in the emission of hydrocarbons depending on the content of UF plywood in the total mass of PF plywood in the fuel burnt**

*Rys. 8. Zmiany emisji węglowodorów w zależności od udziału sklejkі mocznikowej w ogólnej masie sklejkі fenolowej w spalonym paliwie*

Figure 9 presents the changes in the emission of nitrogen oxides, depending on the share of the UF plywood in the total mass of the PF plywood, during the combustion at a changing amount of air dosed to the hearth. As should have been expected, the highest emissions of  $NO_x$  were observed during the combustion of the mixture with a 100 percent share of UF plywood (126–578  $mg/m^3$ ), and the lowest during combustion of the PF plywood (118–191  $mg/m^3$ ). When air was supplied to the hearth's reaction zone at a rate of 140  $m^3/h$ , a distinct influence of the nitrogen content in the fuel (0.42–8.41%) on the value of the  $NO_x$  emission (191–578  $mg/m^3$ ) was observed. At a dosing velocity of 50  $m^3/h$ , this influence was almost imperceptible (103–128  $mg/m^3$ ). At the air velocities of 80 and 110  $m^3/h$ , the addition of the UF plywood to the PF plywood which was being

burnt did not cause such distinct changes. As a matter of fact, in the case of the fuel with a 25 percent addition of UF plywood, a gradual increase in  $\text{NO}_x$  content in the exhaust was observed, but compared to the 100 percent PF plywood, the increase was small. On the other hand, in the case of the fuel with a 50 percent share of UF plywood, the emissions of nitrogen oxides remained at an almost equal level.



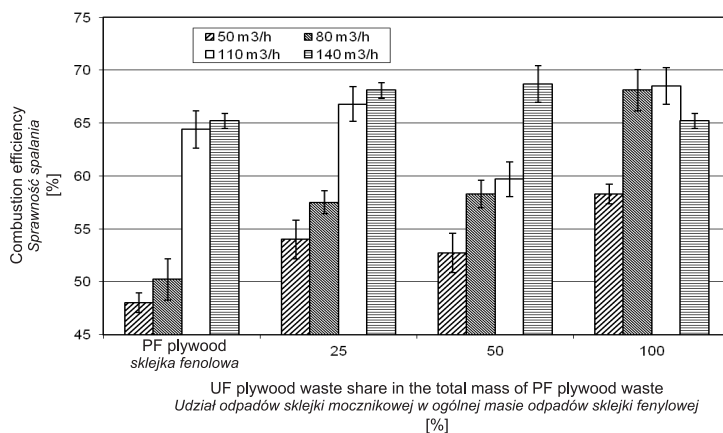
**Fig. 9. Changes in the emission of nitrogen oxides depending on the share of UF plywood in the total mass of PF plywood in the fuel burnt**

*Rys. 9. Zmiany emisji tlenków azotu w zależności od udziału sklejki mocznikowej w ogólnej masie sklejki fenolowej w spalonym paliwie*

Figure 14 depicts the changes in combustion efficiency depending on the share of the UF plywood in the total mass of the PF plywood burnt with changing amounts of air dosed to the hearth. The presented data indicates that the combustion efficiency of the analysed fuels ranged from 48.0 to 68.7%, where the lowest values were observed for the 100 percent PF plywood at the air dosing rate of 50 m<sup>3</sup>/h, and the highest for the PF plywood with a 50 percent share of UF plywood at the air dosing rate of 140 m<sup>3</sup>/h. In general, for all the analysed fuels, the combustion efficiency values rose as the amount of air dosed increased. Only for the 100 percent UF plywood was a drop in the analysed parameter observed at an air velocity of 140 m<sup>3</sup>/h.

Finally, the results of analyses from the first (PF plywood – wood) and the second (PF plywood – UF plywood) part of the experiment were compared.

The values of excess air ratio  $\lambda$  (fig. 1 and 6) did not differ much from one another. In the case of the PF plywood co-burnt with the “virgin” wood, the ratio ranged from 1.40 to 2.16, while in the case of the UF plywood co-burnt with the PF plywood, it ranged from 1.74 to 2.35.



**Fig. 10. Changes of combustion efficiency depending on the share of UF plywood in the total mass of PF plywood in the fuel burnt**

*Rys. 10. Zmiany sprawności spalania w zależności od udziału sklejkki mocznikowej w ogólnej masie sklejkki fenolowej w spalonym paliwie*

Differences were observed when the values of the carbon monoxide emission during the combustion of the analysed materials were compared (fig. 2 and 7). The combustion of the fuels containing urea resins resulted in lower emissions of this compound than in the case of the combustion of the PF plywood with additions of “virgin” wood. In the case of the phenol fuels, large falls in the CO emission caused by the increase in the amount of air supplied to the hearth were observed as well. In the case of the fuels with a share of urea resins, this fall was not so distinct.

The differences in the emission of hydrocarbons recorded during the co-burning of waste from the PF plywood and the “virgin” wood and the PF plywood and the UF plywood were similar to the differences observed in the case of the CO emissions (fig. 3 and 8). In the first variant of the experiment (PF plywood – wood), large falls in the  $C_xH_y$  emission, which were caused by the increasing amounts of air dosed to the hearth, were observed as well, while in the second variant (PF plywood – UF plywood), these falls were not so intensive.

On comparing the levels of the content of nitrogen oxides for the first and the second variant of the experiment (fig. 4 and 9), it was observed that they did not differ significantly in the case of “phenol” fuels and fuels from the “virgin” wood. On the other hand, significant differences were recorded when the PF plywood, which caused a higher emission of carbon monoxide and hydrocarbons on burning, was added to the UF plywood, which was already being burnt and which caused a high  $NO_x$  emission. The combustion of the “sheer” UF plywood at the air dosing velocity of 140 m<sup>3</sup>/h resulted in emissions of  $NO_x$  2.8 times higher than in the case of the “virgin” wood combustion, and 3-fold higher if compared with the “phenol” fuel. A 50% addition of the “phenol” fuel to the UF plywood resulted

in a 1.8-fold drop in the  $\text{NO}_x$  content in the exhaust. When the share of the PF plywood in the fuel burnt (in the total mass of UF plywood) was 75%, the  $\text{NO}_x$  content in the exhaust dropped by 2.3-fold, compared with the 100 percent PF plywood (at the air dosing rate of  $140 \text{ m}^3/\text{h}$ ).

No significant differences between the values of combustion efficiency for both variants of the experiment were observed (fig. 5 and 10). This parameter was slightly lower for the combustion of the PF plywood. In the case of the UF plywood and the “virgin” wood, the combustion efficiency was at similar levels.

## Conclusions

This research on the processes of the combustion of wood waste containing phenol and amine resins provided information on the phenomena occurring under the conditions of the experimental hearth. The obtained results allow the formulation of the following statements:

- the values of excess air ratio  $\lambda$  and combustion efficiency under the assumed conditions of the combustion of the analysed wood fuels did not suggest significant differences in the course of the combustion process for the analysed fuels,
- the combustion of wood fuels containing phenol glue resins was accompanied by a higher content of carbon monoxide and hydrocarbons in the combustion gases compared with the fuels containing urea resins and with the “virgin” wood,
- increasing the amount of air dosed during the combustion of the PF plywood caused a significant fall in the emission of carbon monoxide and hydrocarbons compared with the fuels containing urea resins, which were burnt in the same way,
- on the combustion of the UF plywood and the air dosing velocity of  $140 \text{ m}^3/\text{h}$ , the content of nitrogen oxides in the combustion gases was observed to be approximately three times higher compared with the “virgin” wood and the PF plywood,
- the addition of the PF plywood to the UF plywood, burnt at the air dosing rate of  $140 \text{ m}^3/\text{h}$ , caused a 1.8-fold fall in  $\text{NO}_x$  emission when the share of the UF plywood was 50% and a 2.3-fold fall when this share was 25%.

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## SPALANIE ODPADÓW SKLEJKOWYCH W URZĄDZENIU ENERGETYCZNYM MAŁEJ MOCY

### Streszczenie

Zbadano wpływ udziału żywic fenolowych i aminowych w spalanych mieszkach odpadów drzewnych na kształtowanie się podstawowych parametrów procesu ich spalania w urządzeniu kotłowym małej mocy. Badania prowadzono na laboratoryjnym stanowisku badawczym składającym się z paleniska retortowego o mocy 50 kW odpowiednio oprzyrządowanego. Ocenę składu gazów spalinowych prowadzono przy pomocy przenośnego analizatora spalin wyposażonego w cele elektrochemiczne. Materiałem badawczym były

odpady sklejki wodoodpornej (zaklejanej klejem fenolowym – PF), suchotrwałej (zaklejanej klejem mocznikowym – UF) oraz odpady „czystego” drewna. W trakcie eksperymentu zmieniano ilości dozowanego do paleniska powietrza w zakresie 50–140 m<sup>3</sup>.

Stwierdzono, że spalaniu paliw drzewnych zawierających fenolowe żywice klejowe towarzyszyła wyższa zawartość tlenu węgla i węglowodorów, w porównaniu z paliwami zawierającymi żywice mocznikowe i „czyste” drewno. Zwiększanie ilości dozowanego powietrza przy spalaniu sklejki fenolowej powodowało znaczący spadek emisji tlenu węgla i węglowodorów w porównaniu z paliwami zawierającymi żywice mocznikowe, spalany w ten sam sposób. Przy spalaniu sklejki mocznikowej i dozowaniu powietrza z prędkością 140 m<sup>3</sup>/h stwierdzono około trzy razy wyższą zawartość tlenków azotu w gazach spalinowych w porównaniu z „czystym” drewnem i sklejką fenolową. Dodatek sklejki fenolowej do spalanej sklejki mocznikowej przy dozowaniu powietrza do paleniska z prędkością 140 m<sup>3</sup>/h spowodował znaczący spadek emisji NO<sub>x</sub>.

**Słowa kluczowe:** odpady drzewne, utylizacja odpadów, procesy spalania, bioenergia, spalanie biomasy, emisje produktów spalania