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VARIATION OF THERMAL PARAMETERS AND POLLUTANT CONCENTRATIONS DURING ALDER LOGS THERMAL UTILIZATION IN THE HEATING BOILER

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SYNOPSIS. Thermal utilization investigations were carried out in the heating boiler of 25 kW heat power. The boiler was a part of a heat station and was working together with the water heat storage of 900 l capacity. During the experiments boiler water temperature frequently reached its maximum permitted value of 80°C and at this moment the fan supplying air to combustion stopped and started again when temperature went down below 75-76°C. Considerable variations of the boiler heat power and other parameters were observed. The boiler was preheated before investigations. Thermal utilization in the boiler took place in two steps: pyrolisis and wooden gas combustion in the nozzle. The following parameters were measured: temperature in the pyrolisis chamber, flame temperature in the nozzle, volume stream rate and temperature of boiler water, boiler heat power, concentrations of: oxygen, carbon monoxide, nitric oxide, nitrogen oxides and dust, and also air excess rate in flue gases. Heat efficiency and pollutant emission indicators were calculated. The pollutant concentration values, measured during the investigations, were below permitted values established in the Polish Regulations. The lowest value of carbon monoxide concentration was 362 mg/nm^3 (normalized to 6% oxygen concentration, dry gas): and was observed at the temperature 385°C in the pyrolisis chamber, 740°C in the flame in the nozzle, and at air excess rate 1.92 (measured in flue gases). Three measurements were performed. Two of them lasted approx. 2 h and the third one approx. 3 h. During these measurements 13.50, 17.75 and 16.70 kg of alder logs were combusted.

KEY WORDS: wood thermal utilization, pollutant emission

INTRODUCTION

The most important aim of thermal utilization is waste mass reduction with pollutant emission as low as possible. The boiler heat efficiency value is also very important from ecological point of view. If it is higher, the smaller amount of fuel can be combusted and lower pollutant emission is obtained. A lot of experiments of wooden waste thermal utilization were carried out all over the world, many of them in Germany (Marutzky 1991) and Slovakia (Ladomersky et al. 1993). Some experiments of this kind were also performed in Poland, (Prądzyński et al. 2000, Juszczak 2002). Also, there are known laboratory experiments of thermal utilization where waste combustion was not complete and a small mass of solid organic carbon (as a part of waste) was left on the grate in the combustion chamber (Yoshizawa et al. 1996) – to reduce carbon dioxide emission. Obviously, it would be better to improve the thermal utilization process and heat exchange in the boiler in order to obtain boiler heat efficiency as high as possible during waste combustion, but sometimes in industrial conditions it is not possible. Waste wood and wooden waste without chemical components as well as forestry and agricultural residues are called biomass and are accepted as fuel, according to the Polish Regulations (Rozporządzenie Ministra Środowiska 2003).

Nowadays thermal utilization of waste wood and wooden waste very often takes place in domestic heating boilers. In some modern boilers used in single--family houses, thermal utilization process is performed in two steps: pyrolisis and combustion of wooden gas. This type of boilers is especially good for wood logs combustion because the wooden gas obtained from logs in the boilers is of good quality. Logs are put in the pyrolisis chamber close to each other, so there is very little air between them and they are gasified instead of being burnt in flame. Only few domestic boilers in Poland have now automatic devices with oxygen probe located in flue gases stream behind a boiler. In this case, air volume stream rate used for thermal utilization process depends on oxygen concentration in flue gases. Price of boilers with such automatic devices is several times as higher than the standard ones. This is the reason why majority of domestic boilers in Poland work without any automatic devices. This results in high emissions of carbon monoxide and total organic carbon. There is a possibility to reduce the emission of these pollutants by manual regulation of air volume stream rate, according to observations of flame (temperature and colour), but it is very difficult to do it in a household environment. Observation of flame colour to detect carbon monoxide and nitrogen oxides emission reduction, has been recently applied in industry by Babcock & Wilcock. They used it with very good results for large power boilers (70% of carbon monoxide and 20% of nitrogen oxides emission reduction). Scanner and computer program called FLAME DOCTOR were used for collaboration with air supply system (Flymn et al. 2003).

In November 2005, during POLEKO, an International Fair held in Poznań, a small Italian boiler of 21 kW heat power with an optical device for flame height and colour monitoring was exhibited. It is widely known that if carbon monoxide emission is reduced, the emissions of other products of incomplete combustion (e.g. total organic carbon) are also reduced, therefore the emission of carbon monoxide can be regarded as a good indicator of combustion quality (Lundgren et al. 2004). There are Polish standards (PN-EN 303-5.2002) for permitted pollutant concentration values (carbon monoxide, total organic carbon, dust) in the flue gases from solid fuel burning boilers of heat power of 300 kW or below. Permitted values of pollutant concentrations depend on heat efficiency value declared by boiler producers. These values for manually supplied biomass boiler of 25 kW heat power are presented in Table 1.

Table 1. Permitted values of carbon monoxide, organic carbon and dust concentrations in flue gases from the 25 kW boiler, biomass manually supplied*

Heat efficiency η %	CO concentration mg/nm^3	Total organic carbon concentration mg/nm^3	Dust concentration mg/nm^3
$\eta \geqslant 75.4 = (67 + 6 \log 25)$	5 000 (6818)	150 (205)	150 (205)
$\eta \geqslant 65.4 = (57 + 6 \log 25)$	8 000 (10 909)	300 (409)	180 (245)
$\eta \geqslant 55.4 = (47 + 6 \log 25)$	25 000 (34 091)	2 000 (2 730)	200 (273)

*Normalized to 10% oxygen concentration, dry gas.

The values in parenthesis are concentrations normalized to 6% oxygen concentration in flue gases.

In order to obtain an ecological certificate, the nitrogen oxides concentration value, (calculated to nitrogen dioxide), must be below 400 mg/nm^3, dry gas – normalized to 10% oxygen concentration in flue gases (KUBICA 1999). It equals the value 545 mg/nm^3 – normalized to 6% oxygen concentration in flue gases.

THE AIM OF THE INVESTIGATIONS

The main aim of the experiments was to obtain the knowledge about alder log thermal utilization in a typical domestic biomass boiler of 25 kW heat power working unsteadily in the heat station together with a water heat storage. The boiler worked without any automatic device regulating volume stream rate of the air for combustion. In a case like that, the boiler water temperature frequently reaches maximum value permitted by the boiler producer and a fan supplying air to combustion stops. Considerable variation of pollutant concentrations and thermal boiler parameters are then observed. This often happens in domestic heating installations, because currently used boilers' heat power value frequently exceeds by far the maximum value qualified by a boiler's producer. It is very interesting to know this variation especially of carbon monoxide concentration, which in these conditions can be high. This type of boiler, observed in this experiment, is the cheapest one and very popular in Poland.

EXPERIMENTAL SET-UP, MEASURING PROGRAM AND EQUIPMENT

In the years 2004 and 2005 a heat station with two 25 kW biomass boilers working together with 900 l water heat storage and mixing and pumping device (pump and valves for boiler water mixing) was constructed at the Poznań University of Technology. The boiler (Fig. 1) used for the experiments was located in this heat station. The boiler was preheated before the experiments. Thermal utilization was performed in two steps: pyrolisis and wooden gas combustion in the nozzle located at the bottom of the pyrolisis chamber. In order to obtain good pyrolisis condition (high temperature in the pyrolisis chamber), boiler water flew through the boiler and mixing and piping device (Fig. 1) only when its temperature was above 62°C. Boiler water began to flow through the water heat storage when its temperature reached 72°C. Volume stream rate of air for combustion was regulated manually (flame colour and display of gas analyser were observed, but this regulation was not sufficiently accurate) by the use of choking valve. The fan stopped, when the temperature of boiler water rose above 80°C and started again when the boiler water temperature went down to 75-76°C. The air was supplied to the pyrolisis

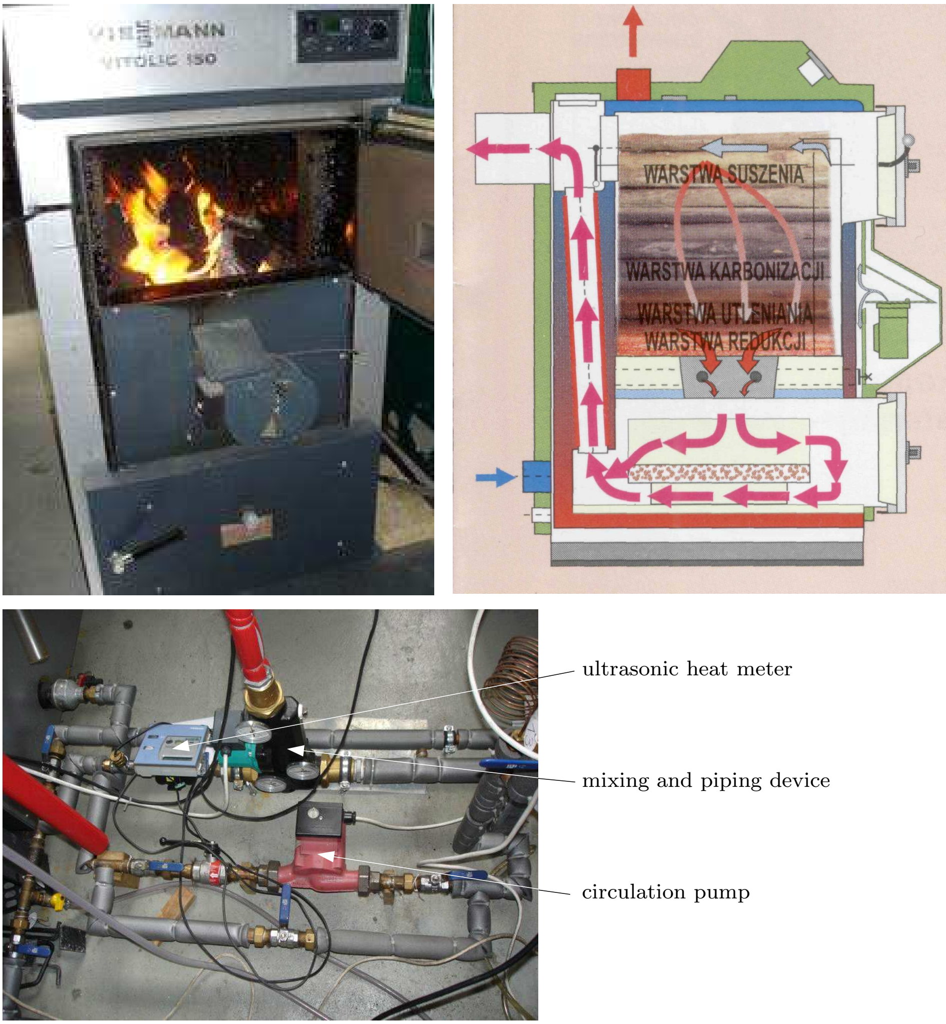

Fig. 1. Boiler of 25 kW heat power, where wooden gas obtained in pyrolisis process is combusted in the nozzle; scheme of the boiler; ultrasonic heat meter, mixing and piping device, circulation pump

chamber and to the nozzle with the help of one fan. A gas analyser with electrochemical cells was used for measuring the following parameters of flue gases in the stack: temperature, air excess rate, oxygen, nitric oxide, nitrogen oxides and carbon monoxide concentrations. Pollutant concentrations were normalized to 6% oxygen concentration in flue gases by gas analyser. Dust concentration was measured by a gravimetrical dust meter with izokinetical probe sampling. The flue gas humidity was measured using two thermometers: dry and wet (Asmann hygrometer) and pollutant concentrations were calculated for dry gas. The temperatures in the pyrolisis chamber and in the nozzle were measured by two radiation shielded thermocouples PtRhPt. The ultrasonic heat meter (Fig. 1) measured a volume stream rate and the temperature of the boiler water as well as heat quantity obtained by the boiler water (for boiler heat efficiency calculation) and present heat power. Pressure losses of water in the boiler was measured using u-pipe filled with water. All described parameters (except dust concentration), were measured continuously. Experiment was conducted with help of an assistance of a student (Kałużna 2005). Heat efficiency was calculated dividing heat quantity obtained by the boiler water through alder log mass multiplied by the calorific value of the logs. Obtained parameter values were presented in the Table 1 and Figure 2 (measurement 1) to present parameter variations and correlations between them. Boiler water was cooled in the heat exchanger with fan. It was located on the roof of the heat station near the insulated steel stack (200 mm inner diameter and 8.5 m high). Boiler water can be also cooled in central heating installation placed in single-family house, DREWBUD type (wooden construction). This house is situated about 35 m from the heat station. Three measurements were performed during investigations and 13.50, 17.75 and 16.70 kg of alder logs were used.

Parameters were measured with accuracy: boiler water temperature – 1°C, temperature in the pyrolisis chamber and in the nozzle – 5°C, temperature of flue gases in the stack – 1°C, boiler water volume stream rate: 0.001 m^3/h, boiler heat power – 0.1 kW, oxygen and carbon oxide concentration – 0.2%, nitric oxide, nitrogen dioxide, nitrogen dioxides, carbon monoxide concentrations – 10 ppm + 5% of measured value, dust concentration – 5 mg/m^3, fuel mass – 10 g, dust mass in dust meter: 1 mg, air excess rate – 0.01.

MATERIALS

Alder logs were obtained from city tree trimming in Poznań performed by urban services. Logs were dried for approx. one year inside a heat station. The biomass moisture content (water mass divided by dry wood mass) and calorific value (measured at The Wood Technology Institute in Poznań, Winiarska St.) were: 15% and 15 386 kJ/kg, respectively. Generally, wood contains about 0.1% of nitrogen and about 50% of carbon (Orłowski and Dobrzański 1976).

RESULTS

The main results of three investigations are presented in Table 2 and measurement 1 is presented additionally in Figure 2.

For pollutant indicator estimation (for the whole measurement period) the pollutant mass was calculated by multiplication pollutant concentration medium value and the flue gas volume value. The Rosin formula (Orłowski and Dobrzański 1976):

$$0.89\frac{Q}{4200} + 1.65 + (\lambda - 1) \cdot \left(1.01\frac{Q}{4200} + 0.5\right) \text{ nm}^3/\text{kg} \tag{7}$$

was used for flue gas volume calculation. Air excess rate medium value λ and fuel calorific value Q were measured.

DISCUSSION

The measurement began when boiler water temperature reached 71-76°C. The boiler heat power changed frequently because of an unsteady combustion (pyrolisis chamber temperature, flame temperature in the nozzle and oxygen concentration were changing at that time considerably). Looking at Figure 2 it is possible to notice, that in most cases the boiler heat power value and also NO and NO_x concentrations were low if the values of temperature in pyrolisis chamber and in the flame in the nozzle were low and carbon monoxide concentration values were high. The big changes of boiler heat power and other parameters appeared when boiler water temperature rose above the permitted 80°C and fan stopped. Temperature in the pyrolisis chamber and in the flame in the nozzle went down in this case as well as the boiler heat power. When the boiler temperature reached 75-76°C, the fan started again and boiler heat power rose. Selected most important thermal utilization parameter values were collected in Table 2. Medium values (in the measurement period) did not describe thermal utilization parameter variation, therefore one experiment was presented in Figure 2. Minimum carbon monoxide concentration value (362 mg/nm^3, dry gas) was obtained (measurement 2), when the temperature in the pyrolisis chamber was 385°C, in the nozzle about 740°C and air excess rate value was 1.92. Relatively low values of carbon monoxide concentration were obtained when pyrolisis chamber temperature was above 280°C and flame temperature in the nozzle above 600°C, even if air excess rate (measured in flue gases) was above 4.0 (measurement 3).

Table 2. Alder log thermal utilization parameters in the boiler of 25 kW heat power*

Thermal utilization parameters	Unit	Measurement 1	Measurement 2	Measurement 3
1	2	3	4	5
Wood mass	kg	13.50	17.75	16.70
Measurement time	min	138	135	210
Boiler water temperature – supply	°C	71-81 76 77 72 72	76-83 80 81 80 79	74-83 78 80 74 80
Boiler water temperature – return	°C	59-70 66 64 59 69	57-68 64 64 67 59	54-70 64 65 70 66
Boiler water volume stream rate	m^3/h	1.208-1.299 1.237 1.271 1.277 1.231	1.297-1.347 1.298 1.332 1.326 1.324	1.228-1.290 1.254 1.226 1.271 1.226
Boiler heat power	MW	1.9-33.5 13.3 13.9 4.1 2.9	16.5-39.0 24.1 25.1 19.6 31.2	4.7-38.4 20.0 21.8 4.7 20.1
Boiler heat efficiency	%	55.3	71.0	64.6
Pressure losses of water in the boiler	Pa	4 810-5 240 5065 5003 5239 5219	5 445-5 590 5519 5474 5445 5474	4 810-5 150 4961 4758 5150 4758
Pyrolysis chamber temperature	°C	170-375 263 355 190 260	260-465 371 385 280 395	155-440 318 300 165 275
Flame temperature in the nozzle	°C	450-685 574 660 220 630	500-850 728 740 590 780	250-825 629 640 250 670

Table 2 – cont.

1	2	3	4	5
Oxygen concentration	%	8.0-13.4 10.8 8.2 13.2 11.5	7.1-13.3 9.8 10.0 11.6 6.9	16.0-19.5 16.8 16.3 19.5 16.1
CO concentration	mg/nm^3	2166-9615 6564 2166 9615 7895	362-7102 2755 362 7102 3654	1086-20409 7003 1086 20409 4136
NO concentration	mg/nm^3	63-223 140 223 96 63	115-207 166 189 134 115	130-255 180 153 131 130
NOx concentration	mg/nm^3	99-360 225 360 157 99	187-333 268 304 215 187	213-412 292 251 224 213
Dust concentration	mg/nm^3	42.0	21.4	154.2
Air excess rate in flue gases λ	–	1.62-2.77 2.15 1.65 2.73 2.24	1.49-2.78 2.00 1.92 2.26 1.49	3.96-13.98 5.97 4.44 13.98 4.63
Flue gases temperature	°C	69-142 95 100 85 120	113-155 137 144 117 151	86-161 126 121 86 121
CO emission indicator	g/kg g/MJ	56.120 3.630	26.978 1.745	64.839 4.193
NO emission indicator	g/kg g/MJ	1.151 0.074	1.622 0.105	1.673 0.108
NO_x emission indicator	g/kg g/MJ	1.854 0.123	2.622 0.170	2.699 0.175
Dust emission indicator	g/kg g/MJ	0.364 0.024	0.211 0.014	1.425 0.092

*When more than one value per cell is presented they stand for: range of values, medium value, value for the lowest CO concentration, value for the highest CO concentration, value for the lowest NO and NO_x concentrations. Pollutant concentrations were normalized to 6% oxygen concentration in flue gases, dry gas.

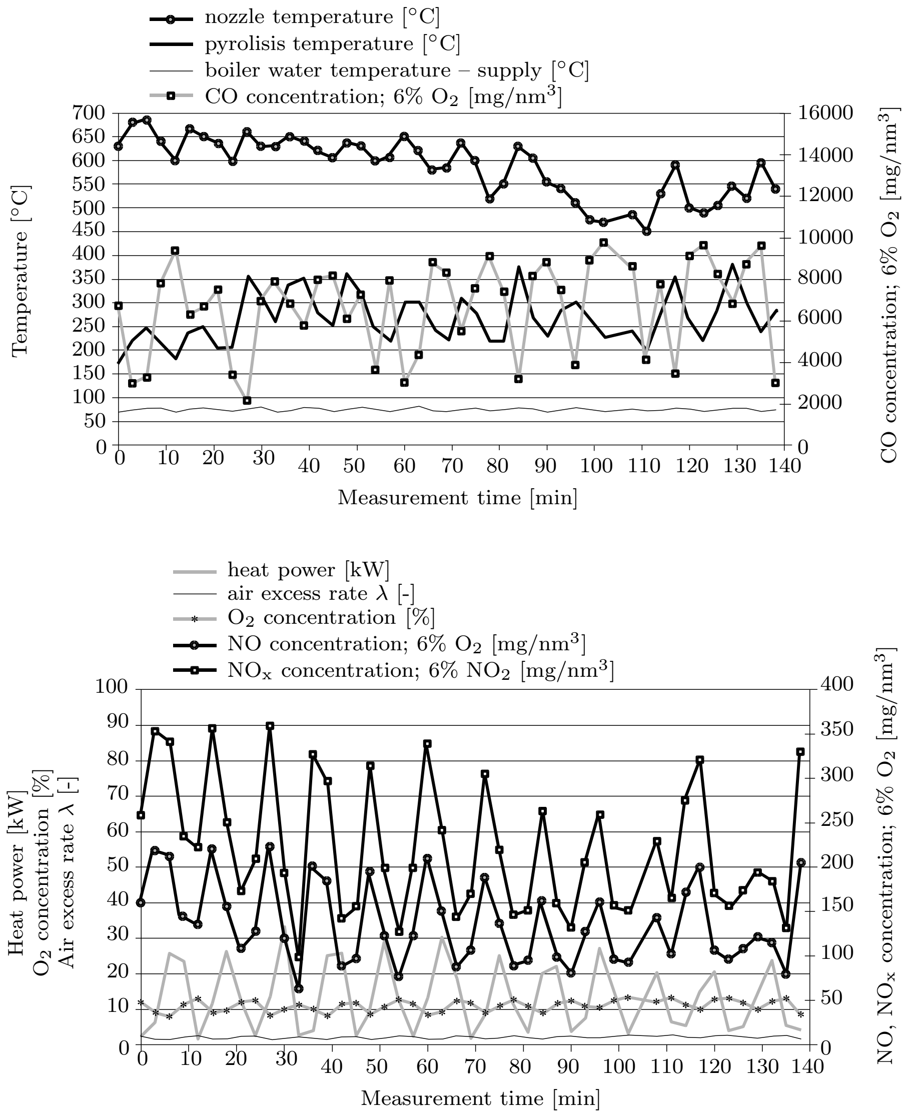

Fig. 2. Variation of selected parameters of alder log thermal utilization in the 25 kW heat power boiler – measurement 1

CONCLUSIONS

Thermal utilization of alder logs in 25 kW heating boiler was possible with small nitrogen oxides and dust concentrations (without exceeding these pollutant concentration values allowed by the Polish Regulations) even if the boiler was working unsteadily. Carbon monoxide concentration value was not low, because of unsteady boiler work but also below the value permitted in the Polish Regulations.

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