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CHARACTERISTICS OF THE COMBUSTION PROCESS OF WOODWORK WASTE IN THE INSTALLATION OF THERMAL TREATMENT OF MUNICIPAL SOLID WASTE (TPOK)

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ABSTRACT

The article presents tests concerning efficiency of combustion process in a layer by defining quantitative evaluation indicators (localization of reaction (flame) front, ignition rate, mass loss rate, thermal load of the grate). Wood wastes of various grain size were subject of tests. Obtained results for pure wood and paper have also been presented for comparison. Experimental tests were carried out on laboratory scale. The advantage of such tests is large saving of costs which would have to be incurred for tests performed on a real object. Received values of the quantitative indexes may be used by shifting them from the devices in laboratory scale into industrial devices. They help in selecting technical parameters for the systems. Furthermore, they help to avoid errors of input data at the stage of realization of the new or modernized project of the incineration plant.

The results show that the tested wood waste were similar regarding their physicochemical properties. The differences can be observed in heating values (14.30-19.91 $MJ \cdot kg^{-1}$). The rate of ignition for all investigated materials is high (0.021-0.063 $kg \cdot (m^{-2}s^{-1})$). Values of SZ and SUM are similar which suggests that the probability of unburned fraction of waste remaining at the end of grate of TPOK installation is low. The ratio SZ/SUM is between 0.79 and 1.49, higher than 1.0, which means that SZ > SUM. It seems to be right as the rate of mass decrement is lower than the rate of ignition.

KEYWORDS: Waste, physicochemical properties, combustion, quantitative evaluation indicators.

INTRODUCTION

In 2017 in Poland 7 installations for thermal utilization of municipal waste (TPOK) are exploited and several more will be built in a short time. According the state waste utilization strategy (KPGO) also the installations for RDF incineration and co-firing will be built. This fact changes the strategy of waste utilization in Poland (TPO). The incineration installations must be able to adapt their technical and thermal requirements to the changing parameters of the waste material like morphology, place of generation, time of the year etc. This is the reason why the investigations helping the optimization of parameters of the installation (like resident time on the grate, thermal and mechanical load of the grate, capacity of the grate) can reduce the risk of malfunctioning and improving the efficiency of the process. The basic information leading to the optimization of the process give quantitative coefficients describing combustion process. They are: the rate of combustion reaction front, the rate of mass decrement and the thermal load of the grate (Bleckwehl et. al. 2004, 2005a, Yang 2004, Risholm-Sundman and Vestin 2005, Cichy 2012, Jaworski 2012, Lin and Ma 2012, Czop et. al. 2015, Cyranka et. al. 2016). These coefficient were determined in a laboratory scale and they can be transferred to the commercial scale of incineration installation (TPOK). They are the kind of criterions allowing transferring the effects between various scales of process, from laboratory scale (discrete, transient process) to the real industrial scale with continuous and stable regimes of combustion. The knowledge of such coefficients substantially helps in designing process and optimization of exploitation of combustion chamber of the waste incineration installation equipped with the moving grate (Kolb et. al. 2003, Bleckwehl et. al. 2005b, Jaworski and Kolb 2007, Jaworski 2012, Xia et. al. 2014, Kajda-Szcześniak and Jaworski, 2016).

Quantitative coefficients describing combustion process

The first of analyzed coefficients is the rate of combustion reaction front. It is the rate of combustion front in the waste layer on the grate in the direction perpendicular to the grate. For all types of grates (moving, reciprocating, drum etc.) the material transport can be defined as longitudinal dispersion described as the results of research applying the marker technique. The transverse dispersion of material on the grate is only about 5% of total material flow on the grate. Having placed the temperature sensors across the height of waste layer in the distances Δx_{FR} (m) one can define the maximum rate of temperature rise in the element as Eq. 1 (Jaworski and Borzęcki 2009, Zhang et. al. 2010, Jaworski 2012):

$$\frac{\Delta\vartheta}{\Delta t} = \left(\frac{\Delta\vartheta}{\Delta t}\right)_{max} \tag{1}$$

This defines the localization of reaction (flame) front. Having the time Δt (s) - Fig. 1 and distance Δx (m) between the maximum temperatures in adjoining temperature sensors the rate of reaction front can be calculated Eq. 2 (Jaworski 2012):

$$u_{FR} = \frac{\Delta x_{FR}}{\Delta t}\left[\frac{m}{s}\right] \tag{2}$$

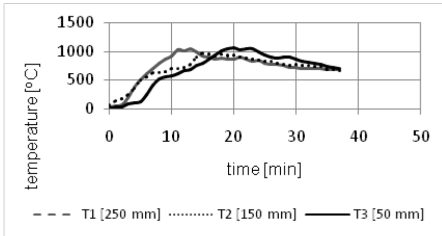

Fig. 1: The temperature changes in the layer of waste furniture in the time. The temperature is 700°C; fraction 20 – 50 mm.

The ignition rate (SZ) is defined as mass of fuel ignited in unit time for the unit area Eq. 3 (Jaworski 2012):

$$SZ = u_{FR} \cdot \rho_n \left[\frac{kg}{m^2 s} \right] \tag{3}$$

ρ_n – bulk density ($kg \cdot m^{-3}$).

Basing on this coefficient the mass rate of waste ignited on the grate for the unit area m^2 of the grate can be calculated.

The next analyzed coefficient is the rate of mass decrement (SUM) on the grate. It defines the mass reduction in unit time per unit area of the grate Eq. 4 (Jaworski 2012):

$$SUM = \frac{\Delta m_{fuel}}{A_R} \left[\frac{kg}{m^2 s} \right] \tag{4}$$

Δm_{fuel} – the rate of fuel reduction ($kg \cdot s^{-1}$],
A_R – area of the grate (m^2).

SUM coefficient depends strongly on the time of process, the highest value is observed in the first phase of combustion as can be seen on Fig. 2. The time of this phase is the base for calculation of mass decrement rate.

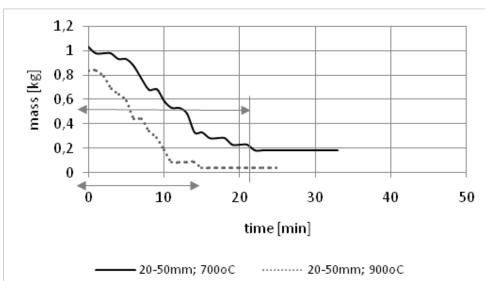

Fig. 2: Decrement of mass of woodwork waste in time of combustion.

The thermal load (OCR, Eq. 5.) is important factor for exploitation of grate in waste incineration systems. Thermal load shows the amount of energy released during oxidation of fuel in a unit time for given grate area – this can determine the intensity of cooling of the grate bars (Jaworski 2012).

$$OCR = SUM \cdot W_d \left[\frac{kW}{m^2} \right] \quad (5)$$

W_d – lower heating value of fuel ($kJ \cdot kg^{-1}$).

The monitoring of OCR can help in solving problems in grate exploitation for example during the thermal overload of the grate.

MATERIAL AND METHOD

Investigated material

The combustion process coefficients were determined for following materials:

- Waste hardboard from used furniture (OSM) - the fraction below 20 mm.
- Waste hardboard from used furniture (OSM) - the fraction 20 - 50 mm.
- Waste construction woodwork (door) (OSD), fraction below 20 mm (hardboard MDF plus honeycomb cardboard filling).
- Waste construction woodwork (door) (OSD), fraction 20 - 50 mm (hardboard MDF plus honeycomb cardboard filling).

As the first step the thermal parameters of the material was measured: moisture content, combustible, ash, volatiles, ignition temperature, Lower Heating Value) – Tab. 1.

Tab. 1: Thermal parameters and elemental composition of investigated materials.

Parameter	OSM	OSD
Total moisture content (% mass)	7.40	5.54
Combustible parts (% mass)	99.28	99.15
Ash content (% mass)	0.72	0.85
Volatiles (% mass)	73.69	74.08
Higher Heating Value (MJ.kg-1)	20.93	15.24
Lower Heating Value (MJ.kg-1)	19.91	14.30
Ignition temperature (°C)	188	209
Carbon (% mass)	41.93	50.06
Hydrogen (% mass)	3.69	3.56
Oxygen (% mass)	36.84	29.04
Nitrogen (% mass)	8.91	10.43
Sulphur (% mass)	0.21	0.26
Chlorium (% mass)]	0.30	0.26

All waste materials have similar properties: low moisture, low ash content and high combustible and volatile parts. The differences can be observed in heating values (LHV). For comparison the properties of wood and paper were measured.

Experimental stand

The schematic of the experimental installations shown on Fig. 3.

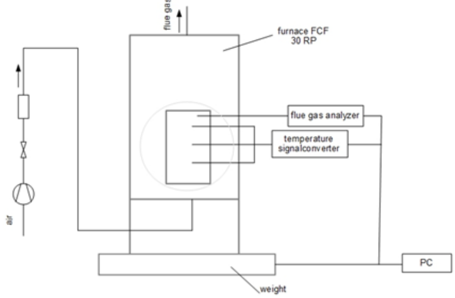

Fig. 3: Schematic of the testing stand for the assessment of the fuel combustion process (Jaworski 2012)

The main element of the stand is electric oven type FCF 30 RP of the power 5 kW. The other elements are the fan for combustion air supply and outlet gases channel. The most important element is the grate-crucible presented in Fig. 4. The crucible is built for waste combustion in a layer of maximum thickness 300 mm. Along the height of the crucible the temperature probes are placed in a distances 50/150/250 mm from the grate level. The flue gas composition is measured by a gas analyzer. The additional element is a platform scale for determining the mass decrement during combustion process.

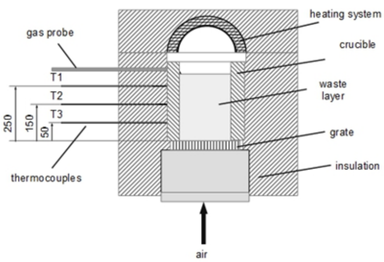

Fig. 4: The grate-crucible for waste combustion with measuring equipment. (made by Kajda-Szcześniak).

The investigation

The investigations were performed with the waste layer of a thickness 300 mm. Following parameters were measured: temperature of the material in three points: 50/150/250 mm above the grate, the gas composition and mass decrement of the material. Measurements were made for three temperatures of the process: 700/800/900°C and for the waste composition as shown in Tab. 2. The values were recorded using an electrical measuring device with a constant time interval of 1 minute. The amount of air for combustion was determined from the elemental composition of waste and was kept between 11 – 19 $m^3 \cdot h^{-1}$. The time of experiment was estimated iterative according to some repeated tests leading to the satisfactory similar values of air excess ratio λ (Tab. 2).

RESULTS AND DISCUSSION

The results of investigations determined on the basis of measurements are presented in Tab. 2. They are the quantitative coefficients of combustion process for waste furniture woodwork (OSM) and construction woodwork (OSD): the rate of reaction front, the rate of ignition front, the rate of mass decrement and the thermal load of the grate. The latter was determined for two sizes of waste particles (<20mm and 20-50mm) and for three temperatures of the process (700/800/900°C). For comparison paper and wood were combusted only for temperature 850°C. In Tab. 2 also the time of combustion process, average air excess ratio and bulk density of the samples are given.

Tab. 2: The quantitative coefficients of combustion process for waste furniture woodwork (OSM) and construction woodwork (OSD).

The waste type	Process temp. T	Combustion time t	Airexcess λ	Bulk density ρn	Rate of reaction front uFR	Rate of ignition SZ	Rate of mass decrement SUM	Thermal load of the grate OCR	SZ/SUM
	(°C)	(s)	-	($kg \cdot m^{-3}$)	($m \cdot s^{-1}$)	($kg \cdot m^{-2}s$)	($kg \cdot m^{-2}s$)	($kW \cdot m^{-2}$)	-
1	2	3	4	5	6	7	8	9	10
Waste furniture woodwork fraction < 20 mm	700	1980	3.38	271	0.000098	0.02656	0.02683	534.19	0.99
	800	1920	3.87	271	0.000128	0.03474	0.03472	691.32	1.00
	900	1860	3.39	271	0.000138	0.03740	0.035282	702.47	1.06
Waste furniture woodwork fraction 20 - 50 mm	700	1320	1.63	196	0.000277	0.05292	0.04261	848.44	1.24
	800	1020	1.44	196	0.000277	0.05292	0.04901	975.98	1.08
	900	960	1.82	196	0.000277	0.05444	0.05859	1166.60	0.92
Waste construction woodwork fraction< 20 mm	700	2640	2.35	203.5	0.000104	0.02119	0.021307	304.69	0.99
	800	2400	2.33	203.5	0.000111	0.02261	0.02474	353.77	0.91
	900	2400	2.56	203.5	0.000111	0.02261	0.02864	409.64	0.79
Waste construction woodwork fraction 20 - 50 mm	700	960	2.77	114	0.000555	0.06333	0.04232	605.14	1.49
	800	960	2.34	114	0.000555	0.06333	0.04557	651.69	1.38
	900	720	2.10	114	0.000555	0.06333	0.05642	806.81	1.12
Waste wood	850	1080	2.92	170	0.000277	0.04722	0.04051	526.63	1.16
Paper	850	720	4.78	36	0.000416	0.01500	0.01736	295.97	0.86

Fig. 5 shows the comparison of the rate of ignition and the rate of burning mass decrement expressed in ($kg \cdot s \cdot m^{-2}$) for all investigated materials. It can be seen the relatively small differences between the values of these coefficients. In Tab. 2 column 10 the ratio SZ/SUM is presented – the values are between 0.79 and 1.49. The ratio >1.0 means that SZ > SUM which seems to be normal as the rate of mass decrement is lower than the rate of ignition. The ratio SZ/SUM < 1.0 is for the case of combustion of waste type OSD (fraction<20 mm) and paper. It can be explained by the relatively high ignition temperature and high volatilization rate which influences the mass decrement. This effect can be also explained by the small size of waste particles which supports the volatilization process rather than combustion of char.

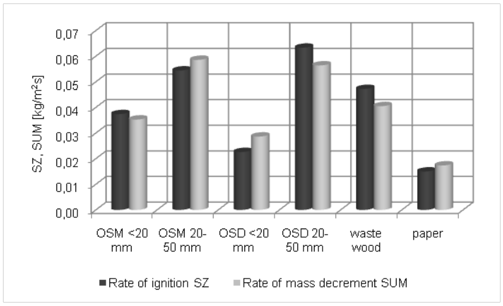

Fig. 5: The comparison of the rate of ignition and the rate of burning mass decrement.

Having the value of SUM one can calculate the length of combustion zone in industrial installation for given fuel capacity and grate area. This coefficient shows the relation between the ignition and real mass reduction of fuel. For fuels with the ignition rate much greater than the mass reduction rate (as it is for investigated materials) there is the risk of having the unburned material at the end of the grate.

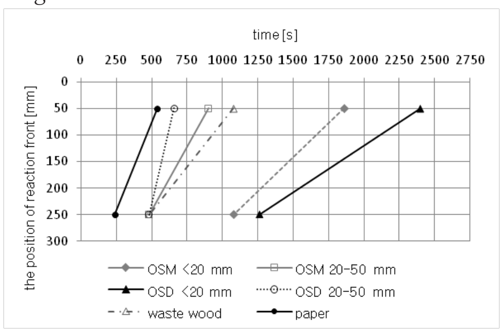

Fig. 6: Relation between the position of reaction front and reaction time – the first temperature extremum time in the waste layer was taken into account.

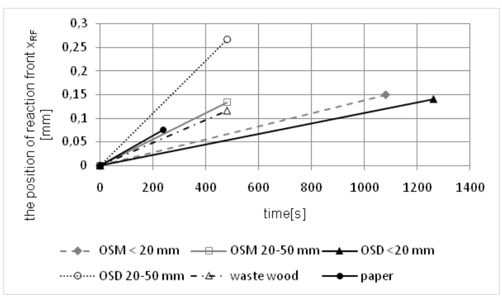

Fig. 7: Relation between the position of reaction front and reaction time – the first temperature extremum time in the waste layer was not taken into account.

Fig. 6. shows the relation between the position of reaction front and reaction time with allowance for the first temperature extremum time in the 250 mm thermocouple in the waste layer (Fig. 1). Fig. 7 shows similar relation but without taking the first temperature extremum in

the waste layer. One can see various inclinations of the lines representing the reaction front – the greater the angle the greater the rate of reaction front.

Presented results of investigations of mass reduction show that the combustion process of the fraction <20 mm is longer for both materials and was over 40 min while for the fraction 20 – 50 mm it was below 30 min. The time of full process depends mainly on the aging of material and consequently on the bulk density of material. The greater granulation and lower bulk density the combustion process becomes more intensive. The highest mass reduction rate for all materials was observed in the first phase of combustion process. In the final phase of combustion the stabilization of mass of waste was observed which signals the end of the process. The determination of mass reduction during combustion process is the base for calculation the mass decrement coefficient and thermal load of the grate.

CONCLUSIONS

The rate of ignition for all investigated materials is high and values of SZ and SUM are similar which suggests that the probability of remaining the unburned fraction of waste at the end of grate of TPOK installation is low. The practical solution for materials with high ignition rate (big SZ) is increasing the mass rate per grate unit area to keep the ignition front. The opposite for the materials with low ignition rates – reduction of mass rate suggests the use of hot air for combustion which helps drying the waste material.

The influence of the size of particles, process temperature and bulk density of waste material on the quantitative coefficients describing combustion process was presented in previous chapter. The presented laboratory method of determining the quantitative coefficients describing combustion process is quite precise what was shown in (Jaworski 2012). But the disadvantage of this method is the fact, that there is no mixing of material burned on the unmoving grate which is the rule on the moving or drum grates. The influence of mixing process on the rate of reaction front, ignition front and mass reduction should be the aim of future investigations leading to more adequate modelling of the real process in laboratory scale.

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