Method for indication of municipal waste combustion in households by ash analysis

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Abstract

The practice of co-combustion of municipal waste in domestic small-scale combustion units is not only a problem of the Czech Republic. One way to prove that waste was burned in the domestic combustion unit is to analyze residues after incineration - ash. The aim of this study was to propose the method for indication of municipal waste combustion in households by ash analysis. 73 samples of ash were obtained from the combustion of different solid fuels (such as spruce wood, beech wood, wood pellets, lignite, lignite briquettes, black coal and Flot coal slurries), their mixtures with municipal waste (floor coverings, paper, PET briquettes, plastics and textile) and municipal wood waste (furniture chipboard and window frames) in household combustion units. The limit values of the parameters were determined for metals Sb, Cu, Pb, Sn, Zn, Ti and chlorides in our previous study (Horák et al. 2019). The method called Semafor (English translation: traffic light) is based on three criteria: i) proof of municipal waste combustion (proven), ii) combustion of municipal waste cannot be proven or excluded (suspected) and iii) no proof of municipal waste combustion (not proven). The aim of further study is to confirm the application of proposed method and to extend the available analyses in case of not unequivocally proved combustion of municipal waste such as plastics.

Keywords: solid fuel; municipal waste; combustion; ash; households

Introduction

To author´s knowledge, there are currently several methodologies for identifying waste combustion in domestic combustion units:

Swiss method (Umweltfachstellen 2015)

This methodology is proposed for proving the incineration of foreign admixtures with wood. The sampled ash is first visually inspected in the laboratory by separating through a sieve, finding "suspicious" residues, such as nails, screws, plastics, or aluminum foil, which is the reason for filling a complaint, and the sample is no longer analyzed analytically. Visually unobjectionable samples are judged from the point of view of the concentration of the elements: chromium, copper, lead, zinc and chlorine. From these five elements (Table 1), the percentage of the assessed value is calculated and added to the sum of the parameter. If the sum of the percentages of all elements is more than 500% and at least two elements lie above the assessed value, the ash sample is found to be contaminated by municipal waste.

Table 1. Limit values of indicators ($mg/kg_{dry\ matter}$) published in (Umweltfachstellen 2015).

Limit values of indicators [$mg/kg_{dry\ matter}$]	**Cr**	**Cu**	**Pb**	**Zn**	**Cl**
EMPA 2001 (Swiss method)	100	150	100	600	2,000
ZUDK 2008 (Swiss method)	150	400	100	800	2,000
ZUDK 2010 (Swiss method)	150	600	100	1,500	2,000

German standard (VDI 2016)

The content of firebox and firebox ash shall be visually inspected for the presence of foreign matter such as metallic residues (e.g. nails, screws) or plastics, textile, cardboard and paper scraps. If there are indications of unallowable fuels being used, this can be inspected by analyzing a composite sample of firebox residues. The reference values of heavy metals such as As, Pb, Cd, Cr, Cu, Ni, Zn, Cl and Ti are given in Table 2. They may be used for the

further assessment in the case of installations exclusively authorized for the operation of untreated wood.

Table 2. Reference values for pollutant concentrations of ash from the combustion of untreated wood in small firing installations ($mg/kg_{dry\ matter}$) published in the standard (VDI 2016).

Reference values for ash pollutant concentrations in mg/kg								
arsenic (As)	lead (Pb)	cadmium (Cd)	chromium (Cr)	copper (Cu)	nickel (Ni)	zinc (Zn)	chlorine (Cl)	titanium (Ti)
30	200	10	400	600	200	2000	2000	1000

IChPW method (IChPW 2017)

It is a methodology of the IChPW Research Institute (Instytut Chemicznej Przeróbki Węgla), Zabrze, Poland. The ash is judged by the concentration of majority element oxides by a procedure that is non-public and copyrighted, but software prepared based on this method was transferred to the self-government units of the Silesian Voivodeship. The result of the evaluation is that i) waste incineration was excluded ("OK" designation), ii) waste incineration was confirmed ("NOK") or iii) waste incineration was not confirmed ("Confirm"). Due to the protected evaluation process, no limit values are available.

Method of the University of Krakow (Politechnika Krakowska im. Tadeusza Kościuszki), Poland

In the ash, Zn, Pb, Hg, Sb, Sn, Cu, Cr, Ni, Cd, organically bound nitrogen, phenols and visually distinguishable plastics are analyzed and evaluated (Dragon 2015). The approach of this method is not known by us as it is non-public.

New legislation has been adopted in the Czech Republic (369/2016 2016) in which is written that the combustion of municipal waste in small-scale combustion units in households is forbidden. This paper refers to the method for indication of municipal waste combustion in households by ash analysis published as Communication of the Ministry of the Environment of the Czech Republic (MoE 2018). The aim of our study was to elaborate the method for determination of municipal waste combustion by ash analysis and to compare this method with existing and published methods. The tool was the reference values of ash from the combustion of solid fuels (biomass, lignite, black coal and unspecified fuel).

Materials and methods

The detail description of used materials (solid fuels and municipal waste) and methods (combustion tests, methods of ash samples analysis) was published by Horák et al. (Horák et al. 2019). The description of 73 tests from the combustion tests performed in the Energy Research Center, Ostrava, Czech Republic and selected heavy metals Sb, Cu, Pb, Sn, Zn, Ti and chlorides are described in Table S1. The parameters were chosen according to analytical results and statistical evaluation summarized by Horák et al. (Horák et al. 2019).

Results and discussion

Assessment methods of ash analysis for the identification of waste incineration in domestic heating devices

The results of the analysis of selected ash samples from the combustion tests were evaluated by the methods described in Introduction and it was proved that the use of these methods is very limited for the conditions of the Czech Republic. The question of the applicability of the IChPW method, which needs to be validated for lignite from the Czech Republic, remains

open. These methods inspired the development of the final methodology for the indication of waste combustion by ash analysis.

The Swiss methodology was applied for 40 ash samples (Table S2). The methodology did not prove the identification of combustion of paper, plastics, PET briquettes and partly furniture chipboard.

German standard (VDI, 2016) does not show the methodology used for the evaluation of municipal waste combustion except of reference values for elements (Table 2). However, it can be expected that if the reference values are not exceeded, the municipal waste combustion was not proven (Table S3). The combustion of paper + dry beech and PET briquettes + dry beech was not proven.

Proposal of waste incineration methodology by analysis of ash sample collected at the operator

On the basis of the evaluation of the results, ash is indicated as: 1) ash from combustion of municipal waste, 2) suspicious ash, 3) ash, which failed to prove the combustion of municipal waste (which does not mean that the municipal waste was not burned, method did not prove it).

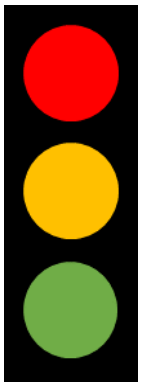

Fig. 1. The description of the applied method Semafor.

The assessment is made according to the type of declared fuel for 6 groups:

• biomass (e.g. wood, wood briquettes, wood pellets)

- lignite and lignite briquettes
- black coal
- lignite + biomass
- black coal + biomass
- unspecified fuel

Limit values of indicators

Limit values of indicators were set for each group of solid fuel. The calculation of the limit values was based on the analysis of ash from the combustion of solid fuels. The limit values of the indicators were determined for metals Sb, Cu, Pb, Sn, Zn, Ti and chlorides. It is assumed that for the indication of waste incineration it will be required to determine the concentration of Sb, Cu, Pb, Sn, Zn, and Cl^- in the ash sample always, whereas the determination of the "Ti" concentration will be required only in case of combustion of biomass.

The limit values of the individual monitored indicators were calculated from the maximum concentration of the particular substance in the results. Unusually, high concentrations (suspicious maxima) were excluded from the calculation of the limit value or were left out in the calculation on the basis of the examination (e.g. repeated analysis or assessment of possible contamination of the ash sample). The maximum concentration value of the relevant indicator was then increased by 30% (assumed maximum uncertainty of the analysis in the test laboratory) and rounded to the next highest divisible number of 5 for better clarity. This value is marked as the limit. This procedure was performed for each indicator.

The maximum values of the individual indicators are shown in graphs, which are presented separately for each group of declared fuels: biomass – Fig. S1, lignite and lignite briquettes – Fig. S2, black coal– Fig. S3.

142 The resulting limit values of the individual indicators of the Semafor method are shown in
143 Table 4.

144 Table 4. Limit values of indicators of the Semafor method (MoE 2018).

Limit values of indicators [mg/kg$_{dry\ matter}$]	**Sb**	**Cu**	**Pb**	**Sn**	**Ti**	**Zn**	**Cl**
Semafor (biomass)	10	390	55	10	1,835	3,070	1,690
Semafor (lignite)	5	300	35	5	x	375	2,015
Semafor (black coal)	10	130	75	10	x	145	1,690
Semafor (lignite + biomass)	10	390	55	10	x	3,070	2,015
Semafor (black coal + biomass)	10	390	75	10	x	3,070	1,690
Semafor (unspecified fuel)	10	390	75	10	x	3,070	2,015

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147 Calculation of exceedance index according to the equation:

148 $$exceedance\ index[\%] = \frac{measured\ concentration\ of\ the\ indicator\ [\frac{mg}{kg_{dry\ matter}}]}{limit\ value\ of\ the\ indicator\ [\frac{mg}{kg_{dry\ matter}}]} \cdot 100$$

149 Criteria of assessment of particular indicator:

150 • Allowed value – exceedance index of the indicator is lower or equal to 100%
151 • Significantly exceeded value – exceedance index of the indicator is higher than 200%
152 • Suspicious value – exceedance index of the indicator is higher than 100% and lower or
153 equal to 200%.

154 Criteria of assessment of ash samples:

155 RED = Proof of municipal waste combustion

156 • Two or more significantly exceeded value (minimally two exceedance indexes are
157 higher than 200%)

158 ORANGE = Combustion of municipal waste cannot be proven or excluded

159 • Two or more suspicious values (minimally two exceedance indexes are higher than
160 100% and lower or equal to 200%) or one significantly exceeded value (one
161 exceedance index is higher than 200%)

162 GREEN = No proof of municipal waste combustion

- All allowed value (all exceedance indexes are lower or equal to 100%) or maximally one suspicious value (one exceedance index is higher than 100% and lower or equal to 200%).

The proposed method was used to evaluate the ashes from the combustion of municipal waste by the Semafor method, Tables 5 (28 samples) and Table S4 (73 samples).

Table 5. The evaluation of identification of municipal waste combustion by Semafor method.

Sample	Fuel	Semafor method
1	furniture chipboard	proven
3	textile + B1	proven
5	textile + L2	proven
8	window frames	proven
9	floor covering + B1	proven
10	textile + dry beech	proven
11	floor covering + L1	proven
12	floor covering + dry beech	proven
13	paper + B1	not proven
14	paper + dry beech	suspicious
15	paper + L2	not proven
16	PET briquettes + dry beech	suspicious
17	PET briquettes + L2	suspicious
18	plastics + dry beech	proven
19	plastics + B1	suspicious
20	plastics + dry beech	proven
21	plastics + L2	suspicious
22	paper + dry beech	not proven
23	plastics + dry beech	suspicious
24	furniture chipboard	proven
25	PET briquettes + dry beech	suspicious
26	window frames	proven
29	floor covering + dry beech	proven
31	paper + dry beech	not proven
33	textile + dry beech	proven
35	window frames	proven
46	furniture chipboard	suspicious
73	furniture chipboard	proven

171 The application of the method Semafor showed that red was 16 samples, orange was 8
172 samples and green was 4 samples (Table 6).
173
174 Table 6. The summary of applied Semafor method.

	green	orange	red
floor coverings	0	0	4
furniture chipboard	0	1	3
paper	4	1	0
PET briquettes	0	3	0
plastics	0	3	2
textile	0	0	4
window frames	0	0	3

175
176
177 The proposed method could:
178 • clearly prove the combustion of floor coverings, textiles and window frames,
179 • very successfully prove the combustion of furniture chipboard,
180 • indicate the combustion of PET briquettes and plastics,
181 • not prove the combustion of paper.
182
183 The comparison of Semafor method, Swiss method and German standard is shown in Table
184 S5. Swiss method and German standard were evaluated only for municipal waste combusted
185 with wood. From the results, it can be concluded: i) Semafor and Swiss methodologies clearly
186 prove the combustion of floor coverings, textiles and window frames, ii) the combustion of
187 furniture chipboard were successfully proven by Semafor and indicated by Swiss method (2
188 combustions were proven, 2 combustions were not proven); iii) the combustion of PET
189 briquettes and plastics were indicated by Semafor method, not proven by Swiss method and
190 German standard (herein, only PET briquettes evaluated); iv) the combustion of paper was not
191 proven by any of applied methods. To prove the combustion of PET briquettes and plastics

and paper, more combustion tests with the specification of the Semafor method will be the aim of further study.

The Semafor method was applied for solid fuels for which the method did not prove the combustion of contaminated fuels (Table S4).

Conclusions

Total number of 73 ash samples were analyzed within the research on the identification of combustion of unsuitable fuels in household boilers and stoves. There were 45 ash samples of solid fuels and 28 ash samples of municipal waste. Samples of ash were obtained from the combustion of seven solid fuels, their mixtures with municipal waste (five) and municipal wood waste (two) in household combustion units. Limit values of seven indicators (Sb, Cu, Pb, Sn, Zn, Ti and Cl^-) were set for each group of solid fuel (biomass, lignite, black coal and unspecified fuel). The new created method called Semafor was applied for 73 combustion tests and compared with other methodologies. The Semafor method was applied for solid fuels for which the method did not prove the combustion of contaminated fuels. Sixteen ash samples from the combustion of municipal waste were proved, eight ash samples were suspicious and four ash samples were not proved. The proposed Semafor method could: i) clearly prove the combustion of floor coverings, textiles and window frames; ii) very successfully prove the combustion of furniture chipboard; iii) indicate the combustion of PET briquettes and plastics; and iv) not prove the combustion of paper.

Declarations

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and materials: All analysed data during this study are included in this published article and its supplementary information files.

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Authors' contributions: JH: Conceptualization, Supervision, Funding acquisition, LK: Writing – Original Draft, Visualization, MD: Methodology, Project administration, SB: Validation, Investigation, FH: Writing – Original Draft, Formal analysis, JK: Validation, Investigation, KK: Methodology, JR: Formal analysis, OM: Visualization, MG: Resources.

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