Hydrogen content and calorific value of municipal solid waste: innovative quality control strategies of waste fed to incinerators

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Abstract

The composition of municipal solid waste (MSW) influences the incineration process. The high heat value of some materials contained in the waste and their moisture content affects the capacity of the process. In particular, the plastics presence negatively affects the incineration process: an increase of calorific value means a reduction of the capacity of the incineration plant. The throughput of the incinerator can be limited for both purely mechanical reasons and by thermal and mechanical overload. The thermal stress can be calculated starting from the calorific value of the waste fed to the incinerator. In this paper, innovative measurements of calorific value and hydrogen content of MSW fed to incinerators have been carried out, in order to improve the technical operation of incineration plants. A calorimetric bomb was used for waste heat measurements and a neutron probe analysis was tested for hydrogen content determination in waste. Measurements have been carried out on different typologies of household waste products characteristics of four towns in the Netherlands. A special waste sample holder was designed and different detection architectures based on neutron sensing techniques were utilised to perform hydrogen content analysis. Starting from the results achieved in this study the possibility to regulate the heat value of the waste and its combustion in order to optimize the incineration process has been envisaged.

Keywords: incineration, calorific value, hydrogen content, municipal solid waste, neutron probe.

WIT Transactions on Ecology and the Environment, Vol 109,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WM080311

1 Introduction

In the last years, household consumption has become an important part of the production-consumption chain as it is the consumer who makes the final choice about which goods and services s/he consumes. Although environmental impact of each household is relatively small compared with that of production activities, millions of households in Europe are major contributors to environmental problems such as climate change, air pollution, water pollution, land use and waste [1]. The increase of household consumptions and wastes focused the general attention about optimization of the treatment systems of refusals and, at the same time, there was an increase of the interest about the recovery of matter and energy from the refusals [2].

Concerning energy recovery from the waste, new importance is given to incineration process: in the household waste it is possible to find a relevant percentage of material with high calorific value, like plastic, rubber, etc., that have influence on the plant capacity.

The increase of plastics in the municipal solid waste brought about an increase in the heat value of refuse: it is important to investigate on the plastics contribution in the incineration process, in particular the plastics influence on the calorific value of the waste and its effects in the incinerator efficiency [3].

The research of different technologies, in order to optimize the efficiency of the technical operation of an incinerator plant, is made focusing the attention mainly on two parameters:

- the high heat value of the refuse;
- the hydrogen content of the waste.

The possibility to determine the calorific value and hydrogen content of a municipal solid waste fed to incinerator is important to develop suitable regulation strategies addressed to increase the efficiency of the plant.

The purpose of this study is to test the feasibility of an innovative technology, based on neutron probe detection architecture, for the analysis of hydrogen content of the waste that is collected and delivered to an incineration plant.

The investigation about the hydrogen content is important considering the influence of water on the heat value of waste products. The indirect evaluation of water content is the basic idea around which this work is developed and finalised to optimize incineration efficiency.

The advantages of the neutron method are that it is non-destructive, non-contacting, rapid, repeated measurements can be performed and the measurement's results are representative of a large volume of sample.

The study was carried out in three steps: the first one is addressed to the preparation of four box-samples containing the household waste of four selected towns in the Netherlands; the second step is related to the calculation of heat value of all utilized waste materials, adopting a calorimetric bomb; the final and most important step is related to the analysis of the boxes with the neutron probe.

2 Materials and methods

In order to obtain a general analysis on the municipal solid waste in the Netherlands, four cities were chosen with different characteristics, as shown in Table 1. In Table 2 the composition of household waste of the selected towns is shown [4].

Table 1: Cities-sample data.

Municipality	***Description***	***n. Inhabitants***	***n. Household***	***Analysed Quantity (kg)***
Waddinxveen	Better neighbourhoods, often determined by children.	25653	9322	426
Arnhem	Apartments, town centres	133272	59410	289
Veendam	Elderly, lower middle class	28260	11269	1010
Heerenveen	Traditional rural areas (farmers)	38728	15667	668

Table 2: Composition of household waste of the selected towns.

			Waddinxveen		**Arnhem**		**Veendam**		**Heerenveen**	
Component	*Dry part (%)*	*Moisture content (%)*	*wet* (*wt %*)	*dry*	*wet* (*wt %*)	*dry*	*wet* (*wt %*)	*dry*	*wet* (*wt %*)	*dry*
GFT*:										
<3 mm	76									
(3-8) mm	68									
(8-20) mm	53									
>20 mm	55									
Tot (Ave)	63	37	40.75	25.67	41.27	26	48.4	30.49	34.87	21.97
Paper/Cardboard	71	29	31.63	22.46	32.45	23.04	24.16	17.15	24.55	17.43
Plastics	88	12	9.83	8.65	8.69	7.65	7.05	6.2	9.07	7.98
Glass	99	1	2.98	2.95	4.39	4.35	4.57	4.52	3.74	3.7
Ferrous metals	98	2	3.87	3.79	2.97	2.91	3.41	3.34	6.3	6.17
Non-ferrous metals	92	8	0.54	0.5	0.66	0.61	0.45	0.41	0.62	0.57
Textiles	83	17	2.99	2.48	1.49	1.24	1.67	1.39	3.47	2.88
Animal refuse	57	43	2.05	1.17	2.25	1.28	2.42	1.38	1.05	0.6
Ceramics	96	4	0.58	0.56	1.22	1.17	2.96	2.84	2.79	2.68
Carpeting/Mats	91	9	0.01	0.01	0	0	0.12	0.11	2.76	2.51
Leather/Rubbers	94	6	0.37	0.35	0.35	0.33	0.8	0.75	1.71	1.61
Wood	90	10	1.45	1.31	0.91	0.82	1.47	1.32	5.34	4.81
Bread	66	34	2.61	1.72	2.25	1.49	2.26	1.49	1.78	1.17
Special/Chemical waste	100	0	0.35	0.35	1.1	1.1	0.27	0.27	2.05	2.05
TOTAL			100.00	71.96	100.00	71.97	100.00	71.67	100.00	76.13
TOTAL MOISTURE CONTENT				28.04		28.03		28.33		23.97

*GFT: Groente-Fruit- en Tuinafval (Green fraction).

2.1 Waste sample boxes preparation

Four sample aluminium boxes with size of 40x40x50 cm and 1mm of thickness have been built in laboratory and filled of waste products assumed representatives of the real municipal solid wastes of the four selected cities.

Information on the quantity and on the typology of household waste was obtained by the past data concerning the municipal solid waste, produced in the towns. In order to achieve a good result, it was fundamental to reduce the materials size and to reproduce the proper density of the refuse in an incinerator plant. The boxes were also isolated with silicon gel: the decision of using silicon is an obvious choice both for the characteristics of this material, and because the presence of silicon does not interfere with the neutron probe based analyses.

The samples of refusals selected to fill the boxes are a mixing of plastics (PP, PS, PET, PE and PVC), paper/cardboard (newspaper, magazines, sanitary paper, carton paper, others), glass, ceramics, metals (aluminium, copper and steel), wood, textile (cotton and synthetic), leather, sand and rubber. The weight of all materials in every sample-box was about 25 kg.

The different typologies of waste were reduced in size (Figure 1) to make samples as similar as possible to the real refuse and to facilitate their mixing avoiding this way the creation of "inhomogeneous" samples.

Waste components have been preliminary mixed, the resulting "homogeneous" sample was placed in the aluminium box and compacted by an hydraulic press (Figure 2).

Figure 1: Waste materials after size reduction.

Figure 2: a: Hydraulic press at work, b: A box ready.

2.2 Waste heat value by calorimetric bomb

Calorimetric tests are usually utilised to determine the high heat value of coal, coke and petroleum products [5].

A bomb calorimeter test has been carried out using a SANYO Gallenkamp AutoBomb apparatus, at the Department of Applied Earth Sciences of the TU of Delft (the Netherlands). Samples of all different typologies of waste were compacted in tablets of 0.5 g in weight with nickel chromium firing wire inside. For every sample material (wood, leather, etc.) the temperature increase of water, caused from the heat developed from the combustion into the bomb, was recorded. With the temperatures that were obtained, it was possible to calculate the High Heat Value (HHV) for every waste material using a simple equation (1) that puts in relation the chosen intervals of temperatures (ΔT) and the weights of the samples (ws) used for the tests:

$$HHV = k * \left(\Delta T / ws \right) \tag{1}$$

being k [j/g] a constant related to the certified value of the quantity of energy evolved by combustion of benzoic acid (Standard Reference Material SRM 39j), when burned under the standard bomb conditions [6].

2.3 Hydrogen content by neutron probe analysis

Hydrogen measurements have been carried out by the DUNBID (Delft University Neutron Backscattering Imaging Detector), a particular apparatus (Figure 3a) used for the landmine research guarded at the IRI (Interfaculty Reactor Institute) of TU Delft, the Netherlands [7–9].

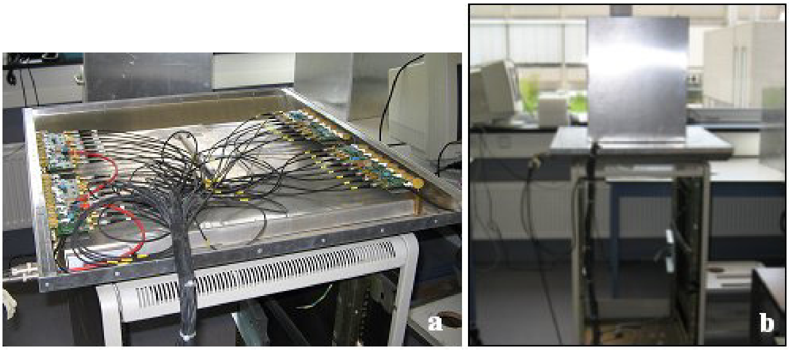

Figure 3: a) The DUNBID detector, b) Apparatus with a waste sample box on the top.

It consists of a two dimensional position sensitive slow neutron detector. Currently, a 10 bar helium (^3He) gas detector is being used. The analyses on the boxes were made adopting a different positioning of the sensors in respect of the volume containing the waste products (Figure 3b). Such an approach was utilised in order to find the best detection architecture, because this apparatus has never been used on this kind of materials.

When the waste surface was irradiated with high-energy neutrons the number of low-energy neutrons which were scattered back from the waste formed a good indicator for a hydrogen rich anomaly. Positional information of the hydrogen-rich anomaly in the ground was obtained by forming a three dimensional image of the thermalised neutron radiation which emerges from the waste. The computer records the number of hydrogen atoms counts by the detector. Starting from these data, it was thus possible to reconstruct an image of the hydrogen-rich anomaly's disposition.

3 Experimental results

In Figure 4 a comparison between the results obtained from the calorimetric bomb tests for the different waste materials is shown. The greater values of HHV are those calculates for plastics (PS, PP and PE), confirming the expectations.

In Figure 5, the difference between temperature trends of the different materials has been better evidenced. Comparing the results showed in Figures 4 and 5, it is clear the correlation existing between materials HHV characteristics and corresponding trends of temperatures. Plastic wastes, as already underlined, are characterised by the highest HHV. From the results it is possible to obtain the global HHV of a determined quantity of refusal in order to facilitate the optimization of the incineration procedure.

Since the DUNBID detector is commonly utilized for other purposes, the tests for the measurements of the hydrogen content on the sample boxes have been carried out adopting different configurations, that is varying the position of the source and the detector for every box and adding water in different steps. The results of the tests are summarized in Figure 6.

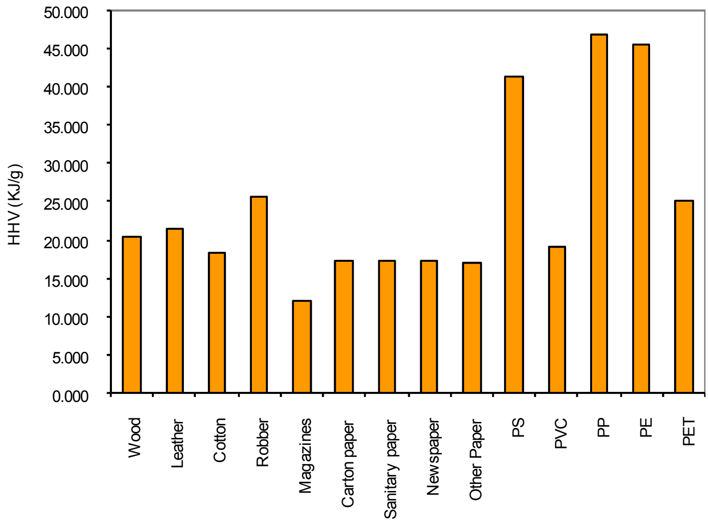

Figure 4: Comparison between the values of HHV of all waste materials.

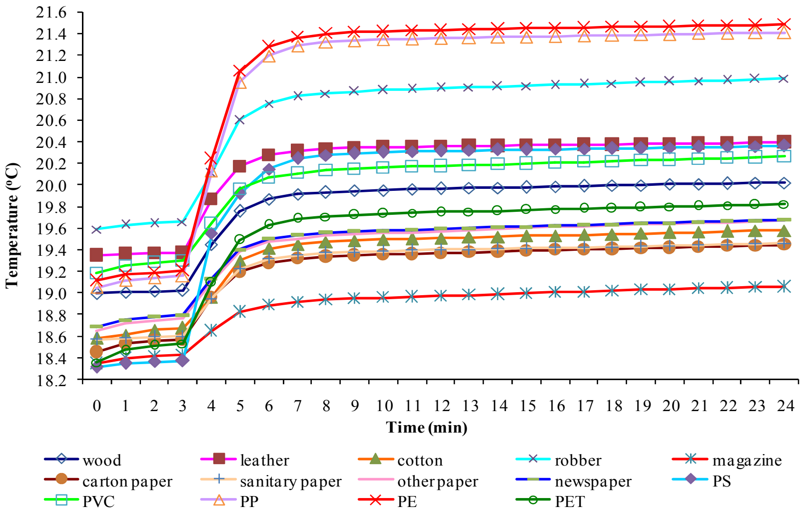

Figure 5: Comparison between trends of temperature of all waste materials.

Making a comparison of the results achieved from the different tests it appears that:

a. the DUNBID detector "sees" the inner hydrogen content of the different materials analyzed (without water addition): this means that the apparatus has its normal behaviour and that this kind of utilization could be interesting to develop;

b. the proposed detection architecture allows to count and record the increase of hydrogen number, due to the progressive water adding: this is important because it means that a dynamic analysis of the materials can be carried out, in order to control the process;

c. not every positions of source and detector allow to perform a correct detection of the hydrogen content. Results obtained for box 2A demonstrate that source and detector have to be placed on the same side. Adopting a different configuration, as that assumed for box 3A, where the source was embedded in the waste products and the detector on one side of the box, it is possible to verify that such a configuration produces a dispersion of the neutrons emitted and caused by a thickness of 8-10 cm of air, present between the waste surface and the edge of the box. In the tests carried out on 4A and 5A boxes where the detector was placed under the box, but not in direct contact, and the source was placed between the box and the detector, it is possible to compare the results obtained and to consider that this procedure of measurement is the most appropriated, in order to obtain the correct information about the hydrogen content.

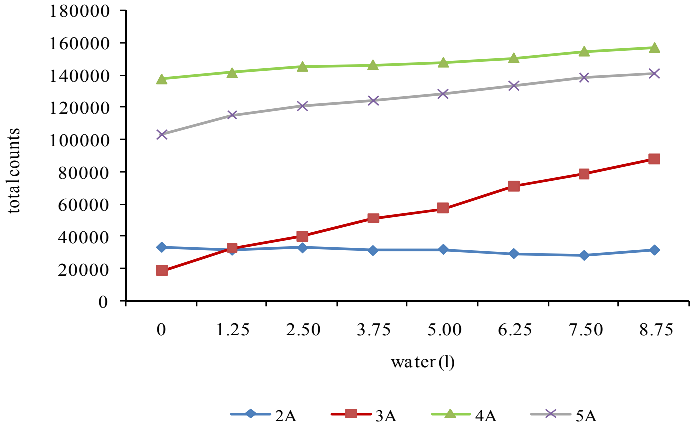

Figure 6: Comparison between trends of hydrogen counts obtained for the different testing conditions of the four waste sample boxes. 2A, 3A, 4A and 5A sample waste boxes are representative of the municipal solid waste collected in the municipality of Waddinxveen, Arnhem, Veendam and Heerenveen, respectively.

4 Conclusions

Main aim of this study was to investigate the possibility offered by an innovative utilization of two technologies not commonly considered in waste characterization, and specifically addressed to define new quality control strategies of wastes fed to an incineration process. Such techniques are the calorimetric bomb, for heat measurements of wastes, and the neutron probe, for the determination of waste products hydrogen content.

The first work-step was concerned on the preparation of the aluminium box-waste-samples, in order to reproduce four typologies of household waste, each representing one of four town in The Netherlands.

Thanks to the accuracy of the calorimetric bomb's analysis, it was possible to determine, in precise way, the heat value of the different selected typologies of wastes. Plastics showed the HHV. This methodology is very efficient, easy to apply and to repeat.

The investigation on the hydrogen content with the neutron probe showed the applicability of this technology to the household waste analysis. The experimental work demonstrated as the DUNBID detector, could be utilized, like a hydrogen sensor, on incineration systems. The study of the results led to suggest a possible guide-line concerning technical procedures that could be applied in the hydrogen research in an incineration process. Results showed that the thickness of the waste to be analyzed must be no more than 15-20 cm because the neutrons, in these conditions, can penetrate only this layer of material. Moreover, also the air layer between the detector and the waste must be no larger than 2–4 cm in order to avoid the neutron dispersion.

In this study results were obtained by analysing the hydrogen content only in the reconstructed sample of household waste. It would be interesting to perform the same analysis under the guide-lines deduced by this experience and with waste that really feeds the incinerators.

The use of such method is more profitable as many more information can be supplied on the amount and on the composition of refuse. In order to obtain more information concerning the waste feeds to the incinerator, it could be interesting to develop a research about the quality and the quantity of waste collected from different areas of a municipality. It could be fundamental in order to elaborate a work strategy to obtain most effective results by the incineration process.

The utilization of this technology, in order to control the moisture content and to measure the calorific value of the municipal solid waste in input, could improve the technical operation of the incineration plants. Quality control strategies based on this kind of sensors could give information both on the quantity of the hydrogen and on the position of hydrogen-rich anomaly inside the waste analysed. Finally, the neutron technique could be further developed and applied in order to develop reliable and robust control strategies addressed to optimise the incineration process, with effective technical and commercial results. The introduction of these technologies could also strongly contribute to change the general opinion on the environmental impact of incineration process and would improve the industrial development of these plants.

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