Aluminium packaging finds its way through incineration – Metal transfer ratios higher than expected

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Molten aluminium and cans recovered from bottom ash

Over the past 20 years several studies have been carried out into the behaviour of metals during and after incineration in Waste-to-Energy (WtE) plants but little is known about one of the most well-known non-ferrous metals, aluminium. After iron, aluminium is the most abundant metallic component of incinerator bottom ash, originating largely from used aluminium packaging not collected separately. This fraction usually ends up in the remaining household waste fraction and is sent for incineration in most Western European countries. Today, most WtE plants extract non-ferrous metals from incinerator bottom ash (IBA) in quantities ranging from 0.5 to 3.0%, with aluminium being the largest component. The aluminium input into the incinerator is not exactly determined, for reasons outlined below.

Tests on the behaviour of aluminium during incineration

Several tests (Prof Buekens, Technical University Delft, and others) have been conducted in laboratories to measure the oxidation level of several types of aluminium packaging, using crucibles, ovens with different atmospheres, temperature cycles, and various additional waste pollutants. However, the authors acknowledge that such tests can only lead to qualitative results compared with the actual functioning of industrial WtE plants. For instance, the latest publication in *Waste Management* 31 (2011) by Hu, Bakker, de Heij (TU Delft) summarises qualitatively the key parameters impacting the transfer ratios of aluminium packaging from waste input to IBA: the main one is obviously the type of packaging and in particular its thickness, followed by the combustion temperature of the incinerator, the residence time and the composition of the total waste fraction incinerated.

With a melting point of 660 °C, aluminium can be found as molten particles in the IBA. Some larger and thicker aluminium packaging items can be even recognised as they (partially) keep their shape. This is mainly due to the heterogeneous nature of the incineration process, as a result of the somewhat 'colder' points in the furnace.

Aluminium does not burn during incineration but its surface oxidises partly into its oxide Al_2O_3, releasing a quantity of energy, 31.6 MJ/kg, equivalent to that resulting from the combustion of plastic, paper and even oil.

The outer alumina layer offers a major advantage as it prevents the aluminium substrate from further oxidation. This property is highly valued and widely used in some industrial processes, especially for the controlled voluntary deep oxidation (anodisation) applied to aluminium extrusions for windows and doors. Due to this surface treatment, these building products are well protected against weather influences and do not need any additional maintenance for a considerable period of time, thus reducing costs.

Aluminium metal transfer ratios measured in WtE plants

During 2011/12, the European Aluminium Association (EAA) was actively involved in two Italian tests regarding the behaviour of several aluminium packaging items at two different Italian incinerators. These tests were initiated by the Italian aluminium packaging recovery scheme Consorzio Imballaggi Alluminio (CiAl) and the Polytechnic University of Milan and the main results have already been published.

The results from the Italian project, combined with those of prior experiments in three other Western European countries, have shed some new light on the basic rationale behind the transfer ratios of aluminium from metal packaging. As a number of data were delivered in private communications, the five incinerators concerned in the four countries are named by a symbolic letter in Table 1.

With only five tests and more than 400 WtE plants in Europe, the results cannot be processed via a proper statistical analysis: each incinerator is different in size, waste input, operating parameters, etc. However, the converging results allow some very interesting conclusions to be drawn.

Objectives and methods

Mass flow analyses of total aluminium (as well as of other metals) during the incineration process are relatively easy to carry out and clearly demonstrate that only a very small quantity of the metal is found in the fly ash, less than 5% of the total aluminium (Al).

Although the five tests were conducted independently, they were all aiming at measuring what percentage of the *metallic* Al content in the waste feed was subsequently found to be metallic in the IBA output, or, conversely, what was the oxidation rate of the metallic Al input for the different types of aluminium packaging concerned.

Most tests also calculated the total flow of Al atoms in any chemical form, from the aluminium packaging input to the fly ash and to the various grain size fractions of the IBA, in order to analyse the metallic Al / total Al ratio in different fractions and to define where to look for the metallic content.

The main challenge was to define the exact Al metal content in the waste feed, which to complicate matters also varied with time. Therefore, the method used consisted of adding controlled quantities of specific aluminium packaging items and measuring the changes in the Al metal content in the IBA resulting from the additions above the normal 'trend' in the IBA Al content. In Plant B, the synthetic waste contained no Al metal, and the test was conducted in the same manner. Plant E was the only plant in which the Al metal content in the waste feed was measured or calculated, and computations made on the total Al metal content in the input and output.

Commonly accepted analytical methods such as AAS (atomic absorption spectroscopy) or XRF (X-ray fluorescence) were used to measure the Al atoms. For the Al metal content, manual sorting or eddy current sorting was used for the coarser particles, complemented by the caustic soda attack for the rest, especially the finer particles. One particular plant with so-called 'dry extraction' for bottom ash used only cascades of eddy current machines, to sort out Al particles down to 1 mm.

	Incinerator A	Incinerator B	Incinerator C	Incinerator D	Incinerator E
Furnace capacity	4 t/h	7 t/h	9,5 t/h	7,5 t/h	4 t/h
Grate movement	Forward acting	Backward	Forward	Backward	Forward
Waste input	80% urban; 20% industrial	Synthetic without packs	Urban + 8% hospital	Urban + sewage sludge	Urban
Typical LHV kcal/kg	2,000-2,200	2,800	2,500-3,000	3,000	2,200-2,400
IBA extraction kg/t	Dry 171	Dry 200	Wet/chain 186 Moisture 18-24%	Wet/pusher 190 Moisture 11-15%	Wet 250 Moisture 20%
Fly ash kg/t	22	35	31	45	15 (without coarse)

Table 1: Incineration characteristics

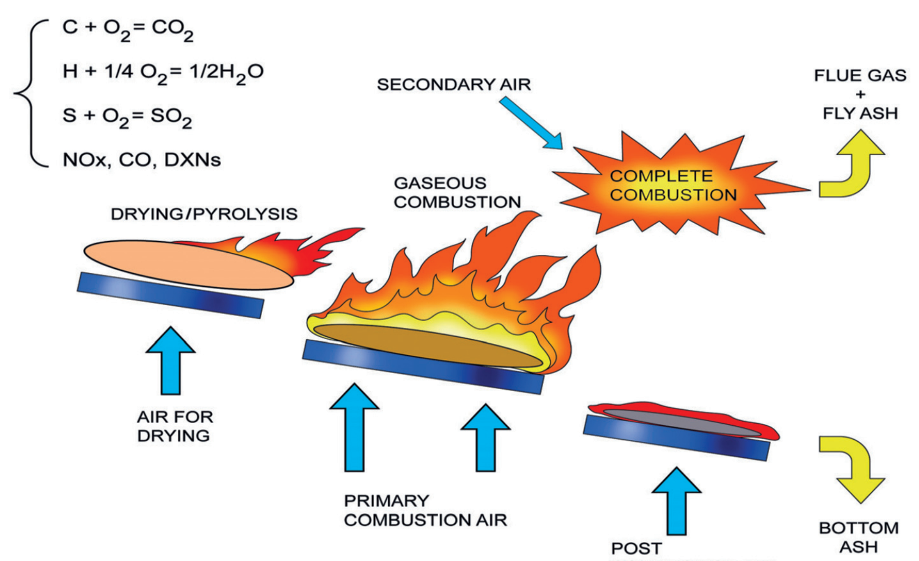

Fig. 1: Incineration process steps

Incinerator characteristics and process steps

Each incinerator is specific in many aspects, from the furnace size to the bottom ash extraction method, IBA ratio and type of input waste. The five incinerators investigated here are no exception and can be described according to the following main characteristics:

As expected, all plants show a low fly ash quantity, confirming the above mentioned statement regarding the minimum losses of Al metal content in the fly ash.

The main steps in the incineration process are shown in Fig. 1, based on a similar model used by Prof Buekens. Obviously modern incinerators as used in Western Europe have to meet the highest EU environmental and health and safety standards in terms of emission controls and incineration efficiency.

Types of aluminium packaging tested

The basic hypothesis is that the thinner the gauge of the aluminium packaging the higher the oxidation rate, as the depth of the oxide layer should be roughly the same under the same incineration procedure. The big question was: how much? Standard thickness ranges for the various aluminium packaging items vary a lot and can go from relatively high for rigid items, such as aerosol and beverage cans, to very low for very thin and laminated foil applications. Therefore, a wide and representative range of packaging items had to be used in controlled additions for the tests.

Relatively high transfer ratios for foil

The tests which measured both metallic Al and total Al in the fly ash and in the incineration bottom ash (IBA) showed that the transfer ratios are more coherent for the IBA than for the fly ash, most likely due to the different operating conditions. However, the main results provide a relatively consistent picture, confirming to a large extent what could already be assumed on the basis of the thickness levels of the packaging items used.

While the Al metal / total Al ratio in fly ash is just above 50% for beverage cans and trays, with more diverging results of 34 to 87% for foil, the ratio in the IBA is more coherent, with 83 to 94% for aerosol and beverage cans and trays and 41 to 53% for plain and laminated foil.

Thanks to the well-known protective effect of alumina, it is not such a big surprise to discover that the thicker gauge aluminium packaging items exhibit higher transfer ratios. However, it should be noted that this is not the case for steel cans which were simultaneously tested in plant B. Their transfer ratio was about 40% only, due to the fact that iron oxides and does not form a closed layer like alumina, permitting further oxidation of the steel substrate.

The surprise comes from the relatively high transfer ratio for the various types of foil, as our initial hypothesis should have shown zero or negligible transfer ratios. What are the main reasons for this?

The most likely explanation

The high transfer ratios of thin gauge aluminium foil from waste input to bottom ash can be explained as the result of the combination of two phenomena happening during the incineration process.

In the phase below the melting point of aluminium the oxidation is limited due to the

Aluminium packaging used		Thickness levels (in microns)		Comments
Rigid	Aerosol can	900 µ	High	Bottom of a high pressure aerosol can
	Beverage can	90 µ	High	Thickness of the wall of a beverage can
Semi-rigid	Foil container	50-150 µ	Medium	Menu tray, as representative example
Flexible	Plain foil	8-40 µ	Low	
	Laminated foil	6-7 µ	Low	

Table 2: Aluminium packaging items tested

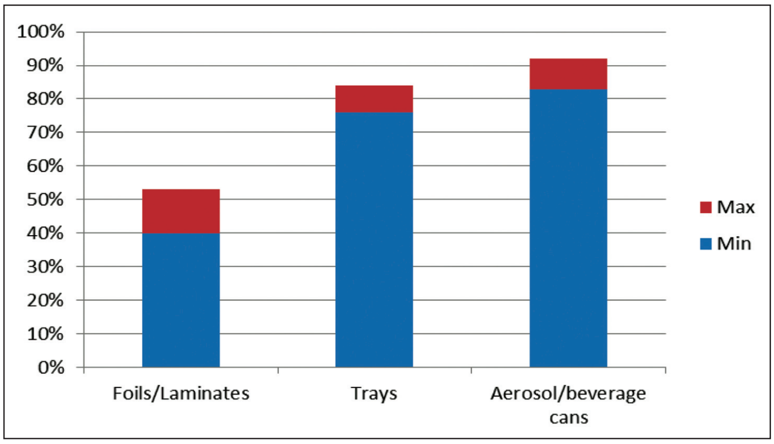

Fig. 2: Ranges of Al metal transfer ratios into IBA per aluminium packaging item

protective influence of alumina. Once molten, the liquid metal tends to form a small sphere as a result of surface tension, thus reducing drastically the surface exposed to oxidation, which is almost halted. The following example demonstrates this. A square piece of household foil 100 x 100 mm with a thickness of 17 µ has a total surface area of 20,007 mm^2, a volume of 170 mm^3 and weighs 0.459 g (assuming a density of 2.7 x 10^{-3} g/mm^3 for solid Al). When molten (with its changed density of 2.375 x 10^{-3} g/mm^3) its volume as a sphere becomes 193 mm^3, corresponding to a diameter of 7.17 mm with a surface of 162 mm^2, that is less than 1% of surface area of the foil!

This explanation is supported by the test in plant E, which shows that household foil heavily compacted into balls from the start results in higher transfer ratios than beverage cans and menu trays.

Once again, steel packaging does not benefit from this phenomenon as steel does not melt during incineration.

Conclusions

The scope and the size of the five tests were limited but the results are converging to a large extent. This allows us to draw the following conclusions:

- Minimum transfer ratios for aluminium foil are at least 40% and for aluminium cans around 90%
- Minimum transfer ratios for mixed aluminium packs (from flexible to semi-rigid and rigid) in a typical situation are between 50-75%, depending on the foil share in the mixed fraction
- The grain sizes of metallic Al in the IBA varies, depending on the operational parameters of each plant – the metallic Al was found in all grain sizes, also in the fractions below 5 mm and even below 1 mm.

Therefore, the optimum processing of the IBA of each incinerator requires an individually arranged combination of eddy current separators and/or other advanced sorting technologies, which opens the door to higher extraction levels even for the small grain sizes.

The sorting technologies available range from suspension magnets and magnetic drums, to first remove all ferrous materials, to advanced eddy current separators and inductive sensoring equipment for NF metals extraction. Their number and position in the sorting plant can be adapted as a function of the chosen process scenario.

These scenarios largely depend on the capacity of the bottom ash treatment plant and thus on the expected return on investment. Obviously this requires some serious capital expenditures but based on the high average scrap value of the sorted ferrous and non-ferrous metals from the bottom ash and the savings in landfill costs it is to be expected that the use of these advanced technologies will have a relatively short pay-back time. However, this is beyond the scope of this article and deserves a separate analysis.

Potential recovery

The preferred recovery solution for aluminium packaging is via separate collection and sorting of the rigid and semi-rigid items such as cans and foil containers. Well managed recovery schemes can reach recycling percentages of 80% or more. Also smaller items such as closures are usually covered by existing packaging recovery schemes and some even allow for thin plain foil to be added. However, as these schemes differ from country to country and taking into account that usually the thinner aluminium (laminated) foil is ending up in the household waste fraction, it is strongly recommended to keep all options open, including the aluminium recovery from the bottom ash at the incinerators. In addition, the oxidised aluminium contributes to energy recovery in the form of electricity generation or district heating. Consequently, taking 2006 as the reference year, it has been calculated that on average there should be 2.3% metallic Al in European bottom ash, resulting in an impressive tonnage of 'hidden' aluminium equivalent to the size of a modern smelter that is waiting for recovery!

Only a small part of this 'dormant' quantity is being recovered today. However, due in part to the pressure of more stringent EU legislation, targeting the phasing out of landfills and promoting the energy valorisation of waste in more efficient WtE plants, incineration of waste will increase significantly in the next decade. This should result in two to three times more aluminium being recovered from bottom ash in 2020 (with 2006 as reference year), offering some important economic and environmental benefits to Europe in terms of raw materials savings.

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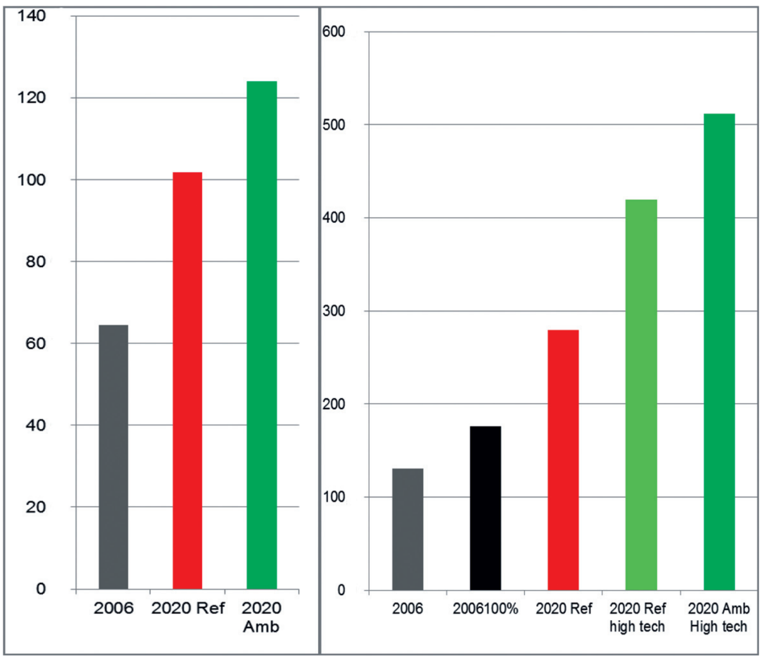

Fig. 3: Trends in incineration and remaining potential for non-ferrous metals extraction

a) Trends in incineration (Mt) b) Remaining potential for non-ferrous metals extraction (kt)