Gold from garbage

Delft technology reclaims valuable metals from incinerated domestic waste in an amsterdam test factory

Dutch garbage, including parts of gold and silver

Domestic waste contains large quantities of copper, aluminum, nickel, zinc and silver. Until now, only around 20% of this was reclaimable, and annually 45 million euro of copper and aluminum disappears into the ground. A new Delft technology and Amsterdam innovation separates bottom ash into valuable non-ferro metals and clean building materials.

Dap Hartmann

Households in the Netherlands collectively produce some 6 million tons of domestic waste in the 'gray fraction' (the garbage bags) per year. This amounts to 1,000 kilos per household per year. Of this, 80% is processed in waste energy plants; the rest is buried. Incineration makes a substantial contribution to the production of sustainable energy in the Netherlands. Moreover, a small country has a limited capacity for burying domestic waste, and incineration reduces the volume by 90%. The organic material in buried domestic waste produces methane (CH_4), a greenhouse gas that is 25 times more powerful than carbon dioxide (CO_2), which is released when these same carbon dioxide atoms are incinerated. In Europe, currently only 20% of the 220 million tons of domestic waste is incinerated annually. According to a recent European directive, in future that figure must rise to 70%.

Incineration reduces a ton of rubbish to approximately 200 kg of bottom ash and 25 kg of fly gas. Moreover, 25% of domestic waste's energy content is converted into sustainable electricity. Fly gas rises with the smoke gasses, and bottom ash – as the name suggests – remains on the bottom of the incinerator. When the incineration is complete, the bottom ash is filtered to 40 millimeters, and the large fraction is collected. A magnet removes the iron and steel. What remains is a pitch-black granular material. Until now, the bottom ash has had a negative economic value, but recently it has become a valuable metallic ore.

Attempts have been made to extract non-ferro metals from non-incinerated waste; for example, by VAGRON, in Groningen, but this was never successful, mainly because metal concentrations in un-incinerated waste are five times lower in weight and ten times lower in volume. The main problem is that metals are not present in pure forms. Copper wire has a plastic casing, a printed circuit board with copper tracks is 99% circuit board and 1% copper, and copper also only accounts for a small part of a battery. Incineration therefore is in fact a first separation step, because it separates the copper from the casings and carriers. The type of material

The pilot factory on the grounds of the municipal Afval Energie Bedrijf (AEB) in Amsterdam's harbor area.

Building materials, made from bottom ash, granules and sand – the granular fractions are delivered to cement producers, where it is converted into cement of a definitive granular structure. The finer fractions reclaimed from the bottom ash are recycled in the limesandstone industry (illustration below) The color is the only difference between this and traditionally manufactured chalksandstone. This reclamation technique can completely replace the sand from sand excavation projects.

The bottom ash that remains after the waste has been processed is in fact a new type of waste and, as such, presents a problem. Solution: AEB transforms the bottom ash into building material by removing the metal particles from the remaining ash. In partnership with TU Delft, an effective process for this has been developed: wet non-ferro separation of bottom ash. AEB and TU Delft have registered three international patents for this technological process.

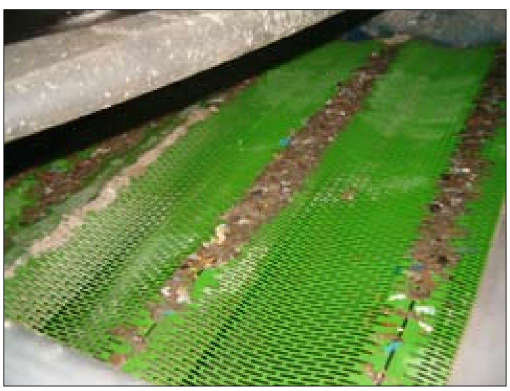
Afval Energie Bedrijf, Amsterdam Sources: 2005 AEB Annual Report

can also present problems. Much of the aluminum in domestic waste is in the form of aluminum foil, which is difficult to separate. Incineration however melts the aluminum foil down to fine, pure drops of aluminum, which is easy to separate.

Eddy current separator

Peter Rem, of the Resource Engineering section of Applied Earth Sciences (CEG Faculty), has developed a method for extracting five times as much non-ferro metals from bottom ash as was previously possible. No chemicals are used to do this: only elementary physics and ingenious mechanical constructions. Rem has developed and patented a 'wet eddy current separator', which is based on a 150-year old principle that no practical application has actually ever been found for.

At the heart of a normal (dry) eddy current separator is a powerful magnet that revolves at extremely high speeds. The bottom ash falls past the magnet, creating eddy currents in the metal particles, which in turn generates an electromagnetic field. The metal particles temporarily become small magnets with a polarity opposed to that of the rotating magnet. While the other material falls unaffected downwards, the metal particles are deflected and land elsewhere. This dry eddy current has one major limitation though: a magnetic field of sufficient strength to deflect the particles out of the flow can only be created in metal fragments that are larger than approximately 5 mm.



Spanwelle-filter, with a continuously reforming flexible filter screen, which prevents clogging.

The metal particles in which eddy currents are created rotate at several hundred revolutions per minute. And a rotating body experiences an upward force or lift as a result of the asymmetric turbulences that arise behind it: this is known as the 'Magnus-effect' and it plays a crucial role in, for example, a wave, but there are in fact no industrial applications known for it. Peter Rem hoped that the Magnus-effect would sufficiently deflect the metal particles from the main flow in order to separate them properly. The predictability of this subtle effect was however strongly compromised by the influence of turbulence and air resistance. Over a drop of half a meter, the deflection rate amounted to just one centimeter, which is insufficient for practical separation. In order to slow the particles down, Rem let them fall into a container of water. The result was amazing: the deflection rate increased tenfold!

It is easy to demonstrate how the Magnus-effect works in water. Take a bucket of water and let a (metal) cylinder roll into it from a sloping surface. The Magnus-effect will cause the cylinder to move in a backwards direction in the water. Non-rotating material does not experience this effect and lands - due to its forward motion – in another place. The Magnus-effect also gives rotating, randomly shaped particles a sufficiently large enough deflection to make separation feasible in practice.

Test runs

Dry eddy current separators reclaim a half percent of non-ferro metal from the coarse fraction of bottom ash (larger than 10 mm). Approximately half of all bottom ash is contained in the fine fraction (0.5-10 mm). Up until now, the material flow has not been further processed, because it was impossible to separate non-ferro metals from it. But this can now be done using a wet eddy current separator. Owing to the large division of metal particles in the bottom ash, Peter Rem predicts that the fine fraction will consist of five times more copper and aluminum than the coarse fraction.

In March 2000, an article in the Dutch newspaper NRC Handelsblad about the wet eddy current separator reported on its potential application for reclaiming non-ferro metals from the fine fraction of bottom ash. This article prompted the Municipality of Amsterdam's Afval Energie Bedrijf (AEB) (Waste Energy Company) to call and discuss a possible partnership. AEB is a very large and innovative waste company, which last year produced 200,000 tons of bottom ash – nearly a quarter of the other eleven Dutch installations' production combined. The waste energy plant produces 530 GWh of electricity from this (approximately what the Netherlands uses in two days), as well as 140 TJ for usable heating. AEB is extremely positive regarding waste. Director Daan van der Linde does not regard waste as a final destination, but rather as a new beginning: "Waste is a raw material," is his motto.

The partnership between TU Delft and AEB began with a careful analysis of the composition of bottom ash. AEB delivered a half-ton of bottom ash to TU Delft's Resource Engineering section's laboratory, where the bottom ash was processed in the wet eddy current separator. The results were exactly as predicted: 3% of the bottom ash consisted of non-ferro metal, of which roughly half consisted of copper and the other half aluminum; 20% was found in the coarse fraction, and 80% in the fine fraction.

In addition to copper and aluminum, the bottom ash also contained rust-free steel (rfs: steel comprised of approximately 10% nickel and 20% chrome), lead, tin, zinc, silver and gold. How does all this actually end up in our domestic waste? There are copper wires from electrical equipment, aluminum foil from the kitchen, copper rings, rust-free steel screws, brass brackets, and so forth. There is 30,000 tons of non-ferro metals in the annual flow of 1 million tons of bottom ash in the Netherlands. In addition to copper and aluminum, this bottom ash contains 5,000 tons of rfs, 1,300 tons of zinc, and, not to be overlooked, 10 tons of silver (or approximately 10% of the demand for silver in the Netherlands). With a market price per ton of 2,500 for copper and 1,400 for aluminum, we are talking about approximately 60 million euro per year, of which currently 80% disappears into the ground.

The next question the AEB addressed to TU Delft concerned the possibility of designing a continuous process for processing the bottom ash, so that the costs would not outweigh the profits. To determine this, a test facility was built on the AEB site. Peter Rem: "If I think back, it is really is unbelievable. On Friday we took our equipment from the lab and drove to Amsterdam, and on the following Tuesday we were processing 20 tons of bottom ash per hour there. We worked for three days and processed a total of 120 tons of bottom ash."

The results of this experiment were carefully analyzed and published in a scientific journal. The non-ferro metal extraction remained constant at around three percent. It was also established that the remaining flow was free of non-ferro metals, and therefore could be used as clean building material. A fantastic result, especially given the simplicity of the test facility. It was therefore decided to start the third phase: the setting up of a pilot plant that could process 50 tons of bottom ash (approximately two full truckloads) per hour. For this, all that was learned in previous experiments was used to design larger capacity separators. By late 2003, the pilot plant was operational.

Pilot plant

After graduating from Ostrava University of Technology in the Czech Republic, Lenka Muchová began conducting research at Corus, where she analyzed the environmental–aspects of the soot and sludge in the furnaces. When the pilot plant in Amsterdam was ready, she began her doctoral research under the supervision of resource engineering technologist Dr. Peter Rem. Muchová's research focused on optimizing the bottom ash processing, the quality control of the end product and the commercial applications of this. From the beginning to the end of the chain, every step in the process had a role to play. One of the questions that Muchová tried to answer was what influence the composition of the bottom ash had on the various separation steps in the chain. This could determine whether the process could be successfully applied elsewhere in the world, where perhaps domestic waste has a very different composition than the waste in the Netherlands. For optimizing the recycling process, it is vital to know exactly what the bottom ash consists of. To determine this, Muchová very carefully analyzed the contents of three different fractions (coarse, fine and sand); collectively, these fractions ultimately comprise 70-80% of the end product.

Problem solving

The wet eddy current separator is only one apparatus in the entire bottom ash processing chain. There is also a density separator – another example of elementary physics and mechanical engineering ingenuity. When you place a piece of cooper and a piece of aluminum in a bucket of water at the same time, the copper sinks to the bottom first. Copper is heavier than aluminum and therefore sinks faster. So much for the elementary physics. The question now is: how to design a machine that can exploit this fact to separate copper and aluminum. In a laboratory experiment, Peter Rem figured out how to separate a single batch. He placed a mixture of light and heavy particles in the water. In order to observe the effect well, these two fractions were of different colors. As soon as the heavier fraction had sunk to the bottom, a sort of luxaflex formed above it. The lighter fraction then collected on the luxaflex. Extremely ingenious, very simple, but unsuitable for a continuous supply of material.

Fine granules for use in limesandstone, asphalt and cement.

Fijne metaaldeeltjes uit huishoudelijk afval: smelt van zware non-ferro fractie uit bodemas

Rem therefore devised a separator that converted the difference in time into a difference in distance. This separator consisted of a cylindrical vat, in which a turbine revolved around a central axis. The blades created compartments that could be extracted as individual batches. The blade revolved slowly, which allowed the compartments behind to be filled with material that entered the separator at a fixed point. When looked at from above, the cylinder resembled the face of a clock, with each compartment being filled at 12 o'clock. The heavier fraction in the compartment sunk faster than the lighter fraction. The circulation speed was so consistent that the heavier fraction reached the bottom at 6 o'clock, the lighter fraction at 9 o'clock. The heavy and light fractions were removed at the 6 o'clock and 9 'o'clock outlets, respectively. And at 12 o 'clock the compartments were filled again for the following round. Thus, a very refined, continuous separation occurs based on density.

A consequence of working on an installation that a company will actually use is that every problem that arises must be solved. "No' is not an option, because then the factory would have to shut down. It is nice to work on solving such problems, but it can be very stressful, because solutions must be found. Fortunately, the bottom ash team is extremely innovative. The solutions are continuously refined and they are never considered as mere stopgaps. Often, such solutions can then be patented. People are extremely critical, however, because patents cost a lot of time and money. If there is no other direct (commercial) application available, then one does not patent it, except insofar as it is necessary for protecting the intellectual property of the project as a whole.

An example of such a problem was when the density separator's discharge clogged up. Lenka Muchová: "This was caused by copper wires that were often as much as 20 cm long. They slide normally through the filter, but then got stuck in density separator's outlet. The other material then got clogged up behind it, causing the discharge to stop. To solve this problem, we devised a special device that selectively removed these troublesome wires from the inflow. This wire separator made use of the specific shape that differentiated these wires from other materials. You often encounter this: a specific deviation creates a problem, and then you use the same deviation for devising a solution."

Cement

After all the non-ferro metals were removed from the bottom ash, a residue flow remained that could be used as clean building material, for example for building roads, or for constructing sound barriers. This offers great advantages to the current situation, in which bottom ash must be covered well (with layers of clay and plastic) to prevent it from seeping into the ground water. In addition to the risk of seepage, the presence of aluminum in the bottom ash also presents a problem. Aluminum corrodes over time, and therefore expands rapidly. This is the reason for the typical cauliflower-like formations one often sees on road surfaces.

Clean bottom ash can also serve as a base for limesandstone, for use in cement and asphalt. By pure coincidence, the sand fraction adhered to the regulations (bulk distribution, degree of impurity) in place for its use in limesandstone and cement. This was very fortuitous indeed, because located just a stone's throw away from AEB is the Recycling Maatschappij Steenkorrel, a cement production company. If they could use the reclaimed sand from the bottom ash for producing cement, this would save twice the transport costs: AEB would not have to export sand, and Steenkorrel would not have to import sand. Using the clean bottom ash for cement production provided a more secure outlet for its use than for construction projects. Moreover, additional areas of application ensure greater independence for the contracting parties. With financial support provided by Novem, the technical properties of this cement are currently being studied.

'Zero emission'

Peter Rem is extremely pleased with the partnership with AEB, even if it has influenced his normal way of working: "Indeed, your freedom is more restricted. I'm used to publishing everything I discover, and in this way sharing my knowledge with the rest of the world. This is more difficult here. Some things must just remain secret, in order to keep ahead of the competition. We patent as many clever solutions as possible. Extremely ingenious solutions have been found for the ancillary problems we've encountered. But unfortunately, I can't tell you everything about them. Without the partnership with AEB, so many of these great things would have never been realized. I prefer to see a complete plant, with its density separator, wet eddy current separator and all the other excellent equipment reclaiming tons of copper and aluminum from bottom ash, than our laboratory set up of three years ago. It's then that you realize that we have really come a long way."

Thanks to the new processing process, bottom ash has found a valuable new use. Unfortunately, there currently remains a sludge fraction in which approximately 4% of the bottom ash ends up. Consequently, bottom ash processing is not yet a 'zero-emission process'. This sludge is dried and then buried. Research is being done to determine how this sludge fraction can also be processed, so that the dream will be fully realized: 100% recycling of incinerated domestic waste.

In future, reclaiming non-ferro metals from bottom ash will be of even greater importance. The grade of cooper in bottom ash is approximately two times higher than that found in the richest natural ore. Extracting copper from natural ore is a very expensive and environmentally damaging process, because copper ore does not contain metallic copper, but rather copper sulfide. Reclaiming metallic copper from bottom ash however is simple: all you need is a rotating magnet and a bucket of water. Copper is becoming increasingly scarce, thanks in no small part to the rapid growth of the Chinese economy. There is certainly a lot of copper contained in the earth's crust, but only a small quantity of it can be efficiently mined. It is has been whispered that there are insufficient supplies available for every Chinese person to build a house like we have, with the approximately 30 kilos of copper used for our pipes and electrical wiring. This is a startling thought. The price of copper is currently around 2,500 euro per ton – nearly double its price two years ago. For one ton of nickel you must pay 10,000 euro, and silver costs 200 euro per kilo. What the prices will be in five years, ten years and twenty-five years, nobody knows. But it is unlikely they will fall.

New installation

AEB is currently working hard to enlarge the pilot plant, which has already been operational for a year.

Sounds of coins

In addition to copper sprockets, brass coat rack hooks, cooper wire and rust-free steel screws, bottom ash also contains clinking coins. Dr. Peter Berkhout, head of the testing facilities at Applied Earth Sciences (CEG Faculty), conducted research to determine how many coins end up in our domestic waste. Based on a setting of 20 mm, Berkhout filtered a test sample of 45 tons of bottom ash (two full truckloads), in which most of the iron and steel had already been removed. The fraction that is larger than 20 mm accounts for approximately 5% (2.25 tons) of the total, and this fraction contained nearly all types of coins, except for 1 and 2 euro cent coins, 10 cent coins, Dutch guilder coins and other small coins. A dry eddy current separator removed the non-ferro metals, which Berkhout then sorted by hand. He washed all the coins, which were only recognisable as blackened discs, in a spin-tumbler, using sand and soap.

Part of a complete collection of coins that Peter Berkhout removed from a 'sample' of Amsterdam bottom ash: removing domestic waste-coins, including coins from the Netherlands, Belgium and Germany.


FMAX / Sam Rentmeester

Peter Berkhout found 69 euro coins, of which two were €2 euro coins and six €1 euro coins, with a total value of €21.55. The old Dutch guilder coins are magnetic, if smaller than 20 mm - except for the 5 cent coins, of which 104 of these were found in the bottom ash. Because 5 cent euro coins are lightly magnetic, only nine of these coins were found. The rest had already been removed by the magnet.

In addition to Dutch coins, the bottom ash also contained a considerable number of coins from countries located in the region of the Netherlands, but also coins from more distant countries, like New Zealand, Thailand, China, Brazil and South Africa. You could compile some very interesting statistics from this information, and, for example, make correlations based on the distance from the Netherlands or the annual number of travellers to these destinations. Finally, 34 coins recovered were for use in the metro, coffee machines and gaming machines, as well as some coins that Berkhout could not identify.

The coins extracted from the non-ferro fraction had a total value of approximately €50 euro. Every ton of bottom ash therefore contains one euro in coins, of which half is in the form of euro coins. The question now is whether it is worth it to build a special separator for removing these coins from the non-ferro fraction, because, as a non-ferro scrap metal, the €2 euro coin only has a value of 1 euro cent. In the non-ferro fraction of the millions of tons of bottom ash that we produce in the Netherlands, there is expected to be approximately one million euro in coins.

To get a complete picture of this found small change, you must also consider the coins deriving from the magnetic fraction. It is not really worth it to do this for the moderate processing recovery of these coins. In the days when the Dutch guilder was the currency in the Netherlands, it would indeed have been profitable, because 10 cent coins, quarters, guilder coins and 2.50 guilder coins were all ferro-magnetic. But for the euro coins, the magnetic can only recover the coins of 1, 2 and 5 cents, which is not exactly a goldmine. You can certainly say that the change to the euro is good for the recycling of bottom ash.

AEB plans to build an installation that can process 300,000 tons per year. This new installation will be capable of processing all of AEB's bottom ash. Experiments in processing bottom ash from other countries will be done to determine if the waste has different properties. The results could help determine how the separator installation will be constructed, and thus maximize the profits of the end product.

Sustainable processing of bottom ash has the wind in its sails. As recently as 2002, the Dutch government planned to ban the use of 'out-of-category' bottom ash as a building material. But through the discovery of a good alternative, people have come to see the economic importance – the situation however must remain 'workable'. Now that AEB and TU Delft have convincingly shown that bottom ash is completely recyclable, new alternatives have emerged. The market for this innovative technology is much larger than just the Netherlands. The annual mountain of domestic waste produced in Europe costs 220 million per ton, of which 70% must ultimately be incinerated. This means that annually 30 million tons of bottom ash is produced – or around 100 times what AEB produces per year. If the composition of all this bottom ash is comparable to that in the Netherlands, then 500,00 tons of copper and 500,000 tons of aluminum can be reclaimed annually, with a total value of 2 billion euro. AEB and TU Delft will certainly reap some of the rewards.


FMAX / Sam Rentmeester

Iron that was separated from other waste is sent via AEB to the scrap yard – for recycling. The reclaimed non-ferro and extra-ferro metals, including rust-free steel (RVS), are sent to companies that use metal, such as aluminum and copper forges.


FMAX / Sam Rentmeester

Fine heavy non-ferro metals removed from the bottom ash include copper, zinc, lead and smaller quantities of rust-free steel, tin, silver and gold.