Excuse me Sir, but you appear to be full of lead

*Customs X-ray detection system separates waste*

In Nederland wordt jaarlijks ongeveer 500.000 ton verpakkingsglas gebruikt, waarvan zo'n 380.000 ton na gebruik wordt ingezameld. Daarvan is ruim 90 procent geschikt voor hergebruik.
Waste separation has never been easy, but the increasing need to recycle materials has made it an economic necessity to rid useful components of any undesirable or even harmful ingredients. Just a handful of pottery shards in a mountain of recycled glass can have disastrous consequences for the finished glass product. Raw materials technologists at the department of Applied Earth Sciences at Delft University of Technology are currently developing a system that uses mathematical (Fourier) transformations, customs detection systems, and hammers to separate the sheep from the goats. The use of X-rays opens the way to separation methods that were impossible until now, including the recognition of oven-proof glass in a mass of normal glass.

Four years ago, Holger Kattentidt prophesied that in another four years, an industrial system would be available that could distinguish cast aluminium from wrought aluminium. The process involves a camera, Fourier transformations, and a neural network and is based on the difference in shape of the two materials as they emerge from the car wreck shredder. Cast aluminium is angular in shape, whereas wrought aluminium looks crumpled. It is economically attractive to be able to tell the two apart, since the alloy making up wrought aluminium brings in substantially more money than the silicon alloy that goes into aluminium castings. A mixture of both would only be acceptable for the cheaper casting route. Four years have now passed, but the German Diplom-Ingenieur, who has in the meantime added Dr. to his name, has not seen his prediction come true. Not that it really matters, since the separation of the aluminium alloys was just one example of a much broader system that uses sensors, mathematics, information technology, and mechanical engineering to separate waste materials in an economically viable way. Kattentidt is currently putting the finishing touches to a detection system that will use a camera, lasers, and the ingredients mentioned above to distinguish pottery shards from a flow of glass particles, based on their shape. The process is to be incorporated into a quality control system. The sorting machine of the manufacturer, s+s, from Schönberg in Germany, is an existing system fitted with a laser array that measures the transparency of the particles passing through it. An air jet ejects any opaque pottery shards detected by the system from the particle flow as it drops off the conveyor belt. In the existing system, the final separation result is still checked by hand. Pottery shards can be highly destructive if they end up in a glass product. A bottle containing grains of pottery will go straight into the waste bin. Too much pottery debris makes glass unsuitable for recycling, and may cause 200 tons of reclaimed glass to be consigned to a landfill.

**Water pistol**

Wrought and cast aluminium, glass granules, and pottery shards are separated, or at least detected on the strength of their distinctive appearances. However, there are...
are other properties that allow materials to be separated from each other, colour for instance, or conductivity. Yet another option originates from everyday practice. For many years now, customs officers have been using an X-ray detection system to check the luggage of airline passengers. The system is capable of distinguishing a number of different materials, and presenting them to the customs officer in different colours. This enables customs to see the difference between a water pistol and a real gun, to give one example. ‘The X-ray technology used by customs proved to be eminently suitable for monitoring waste flows,’ says researcher, Dr. Ir. Tako de Jong. Of course it is, but if the system has been in use for so long, how come nobody thought of this application before? De Jong, who is a raw materials technologist, says he hasn’t been able to find any reference to this type of application. ‘Other companies we cooperate with, like S+S, didn’t know about it either. The first application the Delft researchers came up with was the separation of glass waste flows by removing plumbiferous and oven-proof glass from the reclaimed material. The X-ray sensor proved excellent for the purpose, as well as for separating heavy and light nonferrous metals, distinguishing between various types of plastics, detecting plastics such as pvc so they can be extracted from household waste destined for incineration, etc. Of course, the X-ray detection system was made to be used by customs, but we’re adapting the method for use in material flow separation or monitoring systems. One of our adaptations is to change the way in which images are processed. In combination with outline recognition this results in a wide range of possible applications. This confirms the value of the general concept of using sensors to separate waste or raw materials as we use it here at the department of Applied Earth Sciences.’ According to De Jong, their separation philosophy may not be simple to implement, but it offers the great advantage of modular expansion. ‘Each material has its own specific parameters that can be used to distinguish it from other materials. Based on these properties, you can compile an entire database telling you which sensor system to use for which types of material.’ The researchers have constructed a mathematical model that can be used to calculate the best methods to obtain maximum separation for different materials. De Jong: ‘The point of this system is that you don’t have to come up with a new sensor system for each new type of material. It offers a universal approach.’

**Hammers**

It all sounds very promising, but there is more to it than that. A detection system like this may be able to spot bits of oven-proof glass among the glass flow destined to be recycled as bottles, but it doesn’t get rid of them. Current separating systems have a way of dealing with this, too. Once they have been detected, the unwanted bits are blown by a jet of air from the particle flow as it drops from a conveyer belt. Of course, this requires perfect coordination between detection, location, and drop speed, which is extremely difficult. Raw materials

The effect of a minute contamination. It not only renders the affected bottle useless, but can also severely disrupt the packaging process.

In Europe in particular, waste flows are practically the only available sources of raw materials. Their economic value depends entirely on the purity of the sorted fractions. In Asia, scrap metal is sorted by hand. Much of it is imported from the West by ship.

(Photos: W.L. Dalmijn / TU Delft)

Some years ago, Dr. Dipl.-Ing. Holger Kattentidt developed a method to separate cast aluminium from wrought aluminium based on the shape of scrap particles. By removing the cast aluminium fraction the value of the remaining wrought aluminium is dramatically increased.
technologist at Delft University of Technology have come up with an ingenious solution. The unwanted particles are hammered off the conveyor belt. The hammer system has the advantage that the conveyor belt no longer needs to be porous (which gave problems as a result of pollution), and that a single method suffices to separate a much larger number of different types of material particles from each other. After being knocked off the conveyor, the particles are caught in a trough. By combining the detection of the type of unwanted (or indeed, wanted) particle with the force and direction of the hammer blow, the different materials can be divided, each into its own trough. To make sure the right bits are knocked from the flow, the conveyor speed is linked to the sensor. Patents have been applied for, both for the hammer separation system and the use of X-rays to distinguish (and separate) different materials.

**Ash content**
Even without the separating system, the X-ray detection method has great potential, according to De Jong. ‘A system like this could be used to assess the quality of certain materials before reusing them or sending them to be incinerated. In the latter case, it might be used to control the furnace settings. For instance, you could determine the ash content of coal.’ The main advantage of the X-ray separation method is that it is a dry method. Light and heavy nonferrous metals may be separated from each other, as is the current practice, by throwing them into a clay bath, but that is a rather expensive separating system with a potentially high environmental impact. Another major advantage of the X-ray method, or rather of the separation concept as a whole as developed by Delft University, is that it automatically embodies a certain degree of intelligence. IC intelligence, true, but intelligence nevertheless. This enables a number of records to be kept without too much effort. De Jong estimates that the X-ray system is capable of distinguishing between some 100 to 200 particles per second, which is sufficient for commercial use. However, the particles must not be too small. De Jong: ‘Technically speaking, at less than 8 mm the particles can still be detected, but given the current state of technology, the system would lose its commercial viability. Even so, this may change over the next few years.’ So when can we order our X-ray separator? A little patience seems to be indicated. ‘It will certainly take another six to twelve months,’ De Jong says. ‘We are optimistic, since we have managed to solve a number of major problems, including system communications and software. Problems aren’t our first worry. It’s just going to take a lot of hard work to finish the system. We will need a mechanical design. Companies will have to come and talk to see what they want. How robust should the system be, and does it have to be foolproof? That kind of thing.’

**Conductivity**
Another researcher, Rumanian-born Bogdan Mesina, is currently working on a sensor system that measures the conductivity of materials using variable-frequency alternating currents. Copper and zinc are difficult to
distinguish using the X-ray system, but they vary considerably in conductivity. De Jong: ‘We have also been able to use a colour sensor, but the problem with colour detection is that most of the particles are rather dirty. Even so, copper and brass are easily spotted. It can be done. Each of these systems complements the others, and depending on the needs of a particular company you pick your sensor combinations.’ In the laboratory, the S+S sorting machine has been fitted with the shape detection system for field testing. As mentioned, S+S themselves use a laser to distinguish between the opaque bits of pottery and the transparent fragments of glass. Holger Kattentidt picks up a handful of pottery shards. ‘Our online detection system can measure the pottery bits in a reclaimed glass flow down to 20 ppm. That’s no more than a handful of pottery in a ton of glass. Quality control is now still being done by hand. The machine containing the laser technology belongs to S+S, Delft University supplies the software and the camera.’ It may not be quite the same as different types of aluminium, but it isn’t too far removed, either.

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A machine has been constructed at the Laboratory of Raw Materials Technology which monitors the quality of glass flows in order to increase the accuracy with which shards of ceramic material are detected. The process involved mounting a video camera on the equipment, and developing special software to process the video data.

Due to the high data acquisition rate of the video camera, a special light source was required. The light emitted by an incandescent or fluorescent lamp fluctuates with the mains voltage, which would cause image interference. Both for reasons of lighting stability and because of the limited space available, an array of light-emitting diodes (LEDs) was constructed.

Schematic diagram of the quality control system. The glass flow is observed simultaneously by a laser gate and the video camera. The laser gate detects contaminants that show up as opaque materials, after which the camera determines the nature of the detected object – ceramics, metal, corks, bottle caps, etc. – and stores the resulting data as quality information (CSP level) for a particular batch of glass.
X-ray equipment is used by customs officers at airports and border crossings to check luggage for contraband.

The researchers at Delft University realised that the equipment offered even more potential if it could be used to identify different materials. This new application is the subject of a patent application.

Schematic diagram of an X-ray sorting machine, in which the nature of a particle decides which of a number of air jets ejects it from the material flow.
De Jong and Kattentidt envisage a universal waste separator that integrates a number of different separation techniques. The advantage of such a system is that it will be suitable for any type of (dry) waste, instead of requiring a separate system for each different type of waste flow.

Normally, air vents are used to remove only a single fraction from a waste flow. The Raw Materials Technology group have developed a system that uses hammers below a conveyor belt to knock (computer-selected) directly into a collecting trough. The suction created by low pressure under the belt prevents other particles from being disturbed. (The hammer array chamber has been tilted for the photograph.)
Oven-proof glass causes problems when glass is remelted due to the fact that its viscosity differs from that of normal glass. Until now, there was no way to separate the two types of glass, but X-ray separation appears to be a very suitable method. The oven-proof glass shows up blue in the X-ray image.

The recycling of old cars releases large quantities of flammable waste in the form of plastics, rubber, carpeting, wiring, etc. At first sight, the simplest solution would appear to be to use the waste as fuel, but the cost would be prohibitive as a result of the PVC content. Incineration would release chlorine, which would necessitate the construction of an expensive flue gas scrubber, and so the material is now simply dumped. This is another case in which X-ray separation could provide a solution, as it can also detect chlorine compounds. The chlorine and metal particles show up blue in the X-ray images.

Heavy nonferrous metals (copper, brass, and stainless steel, on the left) and light nonferrous metals (aluminium and magnesium, on the right) from scrapped cars are very valuable. The X-ray image clearly shows the difference between the two groups. It also shows contaminations, such as the screws in the piece of aluminium on the right, which could pollute the aluminium fraction.
In addition to coal, coal mining produces an identical quantity of other materials, which have to be removed from the coal. Currently, this is done by means of liquid density separation processes. Not only do the Delft team expect the X-ray separation method to be more efficient, it will also enable the ash content (the calorific value) of the coal to be monitored on a continuous basis. This will enable a coal mine to provide better guarantees of the quality of its products.

The test set-up of doctoral researcher Bogdan Mesina comprises a frequency generator (on the right), a sensor (in the middle), and a computer. The sensor consists of a transmitter coil (top) and a measuring face with sixty receiver coils mounted below it.

Metals and alloys have different electrical conductivity values. This provides a basis for waste separation.
Operating principle of the electromagnetic identification of metals. A frequency generator and a transmitter coil produce an electromagnetic field. When an electrically conductive material enters the field, the field changes. The change, the extent of which is characteristic for each type of metal, can be detected using a receiver coil.