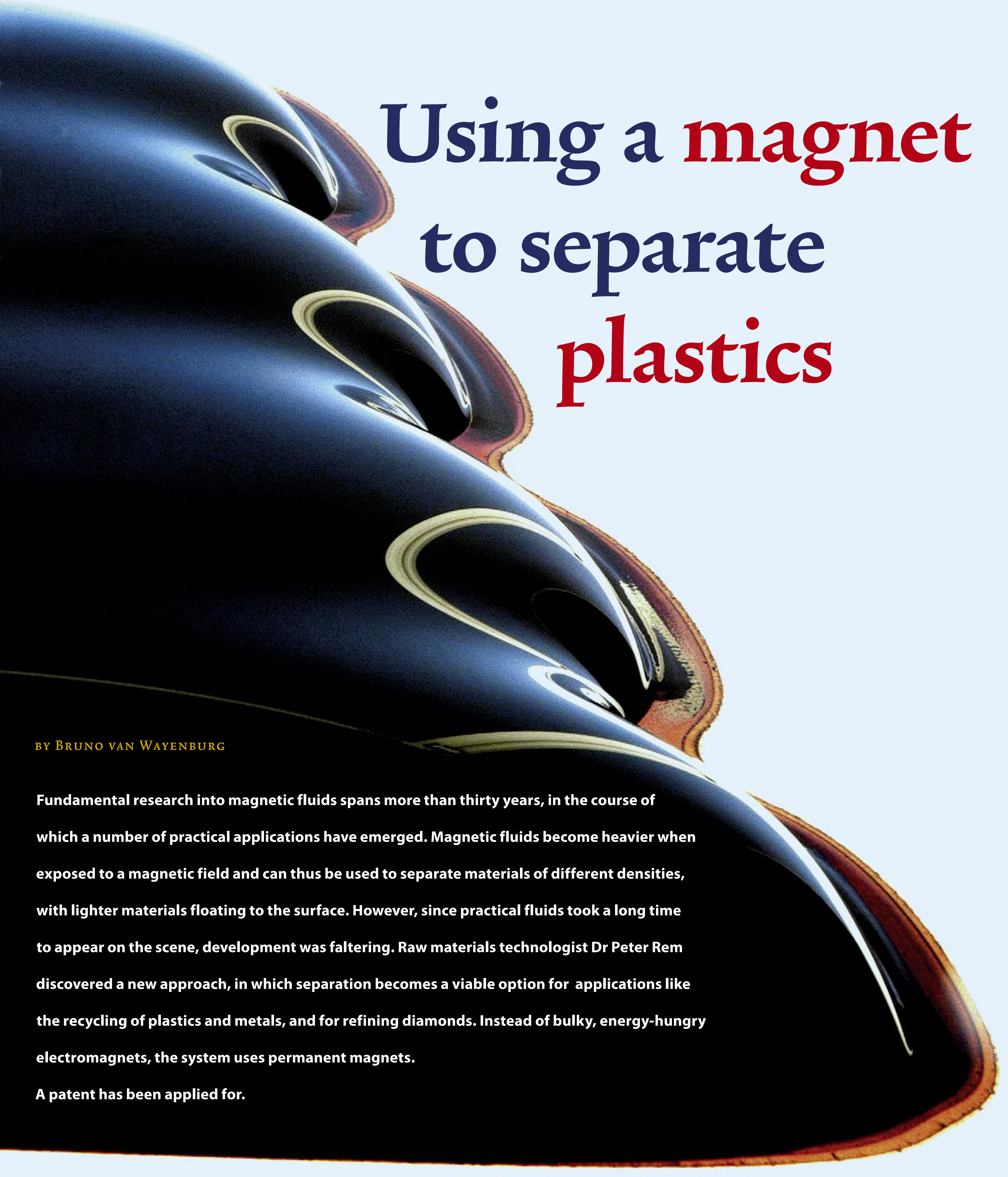
Variable-density fluid accurately separates plastics in a single process

Using a magnet to separate plastics



by Bruno van Wayenburg

Fundamental research into magnetic fluids spans more than thirty years, in the course of which a number of practical applications have emerged. Magnetic fluids become heavier when exposed to a magnetic field and can thus be used to separate materials of different densities, with lighter materials floating to the surface. However, since practical fluids took a long time to appear on the scene, development was faltering. Raw materials technologist Dr Peter Rem discovered a new approach, in which separation becomes a viable option for applications like the recycling of plastics and metals, and for refining diamonds. Instead of bulky, energy-hungry electromagnets, the system uses permanent magnets.

A patent has been applied for.

(Photo: Reko BV, Geleen)

In the Netherlands alone, 15,000 tonnes of PET waste gets recycled every year. The total quantity of waste plastics is far greater, which is where part of the problem lies, since separating different types of plastics remains a commercially unattractive proposition. Also, if the separated plastic cannot be made pure enough, the product's value plummets.

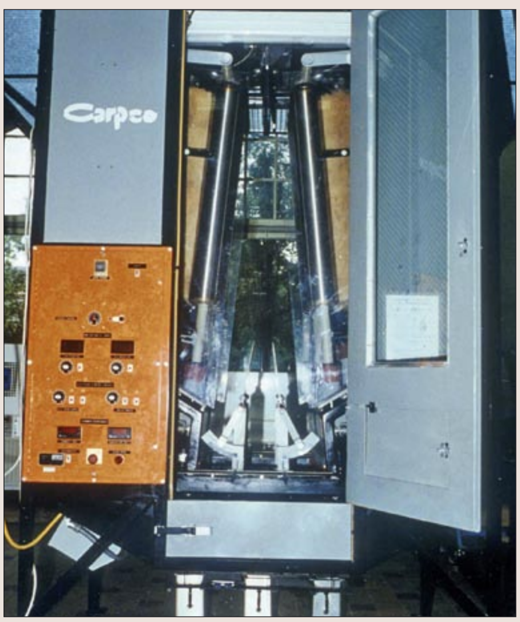
In order to process recycled PET bottles, they are shredded and any dirt and other unwanted materials such as bottle caps, labels, and whatever consumers have left behind, are removed.

Contaminants that currently get left behind in the cleaned PET:

Aluminium, stainless steel, and other non-magnetic metals

Iron

Stone and glass



Electrostatic separator for removing PVC particles from shredded PET waste. Intensive stirring of the mixture imparts different electrostatic charges to the PET and PVC particles. The mixture is then dropped between the two vertical electrodes, across which a 60,000 volts electrostatic field is maintained. As they drop past the electrodes, the PET and PVC flows become separated.

Recycling materials like plastics, glass and metal has really taken off over the past decades. Even so, many of the recycled materials, like plastics for instance, cannot be used for their original purpose, because they are not pure enough. They are contaminated with wood chips (car shredding), textile, domestic waste, metals (shredded electronics) and other types of plastics. The 15,000 tons of PET bottles collected every year in the Netherlands alone are mostly for the manufacture of plastic straps and synthetic fleece material. Reusing the plastic to make new PET bottles is difficult because the maximum level of impurity arising from non-PET material must not exceed 50 parts per million. Even minor impurities could result in weak spots, and a bottle manufacturer cannot afford to supply leaking or exploding bottles.

Bollards

The current separating techniques, based on the difference in flotation properties in water, can be used to separate lighter types of plastic such as polypropylene (PP) and polyethylene (PE) from the heavier types such as PET and PVC. Even so, PP and PE together are both difficult to separate and chemically incompatible, making low-quality objects such as traffic bollards the most common recycling application. The combination of PVC and PET, which used to be common when PET bottles were fitted with PVC screw caps, is even worse. The components cannot be separated, and PVC burns at PET processing temperatures.

"Fortunately the PET recycling market has managed to persuade the manufacturers to stop using that particular combination of materials," says Dr Peter Rem, associate professor of raw materials technology, at the sub faculty of Applied Earth Sciences, "but even so, we're still not very good at separating different types of plastics."

Rem and his doctoral student, Erwin Bakker are working on a separation technology that should be able to produce the required levels of purity. In addition their technology, density separation by means of magnetic fluids, is capable of separating several other types of materials in a single process. Such fluids change their density when subjected to a magnetic field.

Pink liquid

If Archimedes had ever got round to publishing his bathtub eureka moment in a scientific journal, Rem and Bakker would now be including a reference to his work. As part of an assignment by a king who suspected fraud, the famous Greek scientist measured the exact difference in density between silver and gold by means of weighing and immersion in water to determine volume. The Delft team uses a related method.

"Just look at this," says Rem in the laboratory of the research group in the former Mining Institute of TU Delft. He drops a lump of metal into a cup containing a transparent pink liquid, a solution of manganese chloride. The metal sinks straight to the bottom of the cup, but when Rem places the cup on a specially prepared surface over a powerful magnet ("mind you keep pens and watches out of harm's way"), the metal rises from the bottom to remain suspended halfway to the surface.

"That's all there is about it," Rem says concluding the demonstration.

The manganese chloride solution is paramagnetic, which means that the magnet attracts the liquid. As a result, the liquid immediately above the magnet increases in density and so effectively becomes heavier. The lump of metal, which is not paramagnetic and so remains unaffected, suddenly becomes lighter in weight than the liquid, and so rises. As the effect of the magnetic field diminishes away from the magnet, the effective density of the liquid decreases with it. At the point where the density corresponds with that of the metal, the lump remains suspended. The net effect of this phenomenon is to produce a strict horizontal separation of particles of different densities, which is ideal for separating a mixed flow into its weight components in a single process.

Ditch water

Even so, manganese chloride will not be the solution used in separation plants. Its only purpose here is to serve as a demonstration liquid, because it is so nice and clear. To make a solution like this, about 400 kilograms of salt have to be added to a cubic metre of water, Rem explains. Therefore, the density of the solution is 1400 kilograms per cubic metre.

"The effect of the magnetic field we're using is to add another 300 kilograms per cubic metre to the density," Rem says. Nice, but not nearly enough for full-range separation, and in addition the solution contains a lot of salt, all of which would have to be processed in a regeneration plant after use.

The real separator fluid Rem plans to use is a suspension of iron oxide particles in water, a brownish black liquid reminiscent of very dirty ditch water. Due to the small size of 20 nanometres of the particles, their thermal motion at room temperature is sufficient to keep them suspended. A special coating prevents them from locking together magnetically.

The particles, and with them the fluid, are ferromagnetic, i.e. each of the particles is a minute magnet, which greatly enhances the attraction effect. As a result, the quantity of iron oxide particles mixed with the water can be far less while achieving the same effect: only about 10 kilograms per cubic metre, i.e. 1 per cent. "On top of that, iron oxide is cheap and harmless," Rem says, "look in any sewer and you're bound to find it."

A number of plastic balls in four different colours can just be made out in the glass beaker of murky liquid which he places on the magnetic plate. Each ball remains suspended at its own level determined by the type of plastic it is made of, and consequently its density.

"This is the separating principle in a nutshell," Rem says.

Copper, gold, and other metals

Over thirty years of research into density separation by means of magnetic fluids, with particular emphasis on separating metals and metal ores, seems like a long time to have come up with such a simple solution.

Rem: "The thing is that research has always focused on finding a magnetic field in which the liquid would have a constant effective density, just like any normal fluid."

This would make the extractable material float on the surface, like wood on water. Since no normal fluids exist that have the high densities of copper, gold, and many other metals, magnetic fluids would be just the thing for the job, or so it was thought.

If only more physicists had been involved in the research, it might have emerged earlier on that the idea in itself is literally a physical impossibility, Rem thinks. To obtain a uniform effective density, you need a magnetic field with a linear strength gradient (i.e. the plot of the magnetic field strength is a straight line). However, according to Maxwell's equations, which describe the behaviour of electrical and magnetic fields, a linear magnetic field cannot be created inside a volume.

The closest approach, a linear gradient field in a single plane, is the field that exists between the poles of an annular magnet with a specially formed cavity. Rem: "To create a magnetic field of any reasonable dimensions with such an instrument would require a set of electromagnets several metres in size."

Rem himself was actually working with just such a device some eight years ago, when he realised that there was no need for a continuous density, in fact it created an obstacle for an effective separation technique. The only reason for the preference had been that a homogeneous density came closest to classical fluids such as the water Archimedes had in his bath."

Frustrated

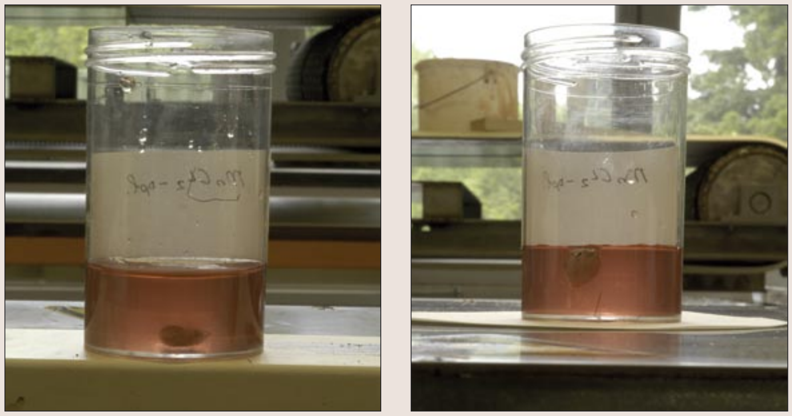
Unlike his Greek colleague, Rem never had his eureka moment, but in 2004 he realised there was another way. Rem calculated a magnetic field with a strength that decreases exponentially as the distance from the magnet increases. This results in an exponential decrease in the attractive force and consequently, a change in effective density, so that each type of material can find its own level of equilibrium in the magnetic liquid. This has the advantage that a large number of components of different densities can be accurately separated from each other in a single process.

Rem calculated a configuration of magnets that would produce such a field. Magnet manufacturers Bakker Magnetics, who specialise in the manufacture of complex magnet systems, then produced the configuration for the research group. Creating the experimental magnet plate was not a simple task. Its main ingredient is a set of extremely powerful permanent iron-neodymium-borium magnets.

"The field strength just above the magnets is 1 tesla, which is pretty strong for a permanent magnet," Rem says. The magnets are mounted in a 'frustrated' configuration, which means that they are out of balance and subject to large forces acting between them. It is a good thing that the whole assembly is covered by a steel plate to protect researchers from being hit by any magnet fragments that may become detached from the main mass.

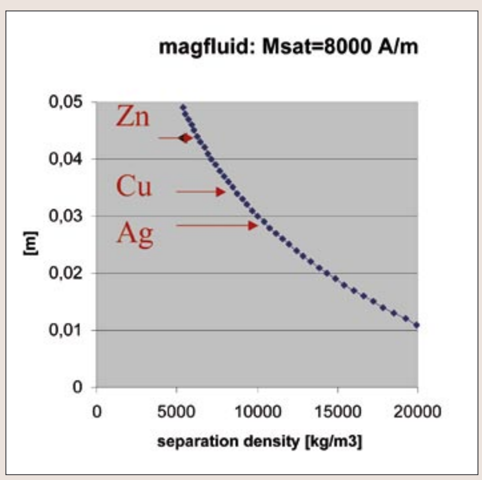
In addition the plate screens the assembly from curious gazes, as the magnet

Eddy current separator used for separating aluminium from PET waste. It uses a rapidly changing magnetic field to eject the aluminium particles from the mixture.



If a lump of magnesium (density approx. 1700 kg/m^3) is dropped into a manganese chloride solution (density approx. 1400 kg/m^3), it sinks to the bottom. If the container holding the solution and the metal is then placed on a magnet, the metal will rise in the solution (picture on the right) because of the increased density of the fluid.

By making use of the decreasing effect of the magnetic field at higher level in the liquid, balls made of different types of plastics will float at different levels according to their specific gravity, with the heavy balls sitting lowest in the liquid, and the lightest ones at the top.



Relation between the specific gravity of a material and the level at which a particle of the material will float in the magnetic liquid.

Test set-up of an inclined conveyor belt carrying a large blob of magnetic fluid, used for separating different types of metal.

The 2 litre blob is held in place by a heavy permanent magnet located directly below the belt. The magnet consists of nine poles and weighs about 120 kilograms.

As the conveyor belt carries the metal particles into the blob of magnetic fluid, the lighter particles will start to float, while heavier particles will remain lying on the belt.

configuration calculated by Rem is a secret.

"Our patent application mentions something like 'any person trained in the art is capable of creating such a field', but in practice it is not quite that simple," Rem admits with a smile.

The researchers are still in discussion with Bakker Magnetics and SenterNovem, who are funding the innovation research, to trade the patent rights for a single doctoral research grant to support Erwin Bakker. Erwin is a mining engineer who has been working for the department as an assistant researcher ever since he graduated.

Rem: "The purpose of our research is not to get rich, but rather to continue the research, and this would be one way of doing that."

Test rigs The only thing left to do at this stage is to construct a working separation plant.

Rem: "The separation principle itself works all right, but the trick is to get the materials into the separator in an orderly and effective fashion, allow them just enough time to get separated, and then extract them without disturbing the separation process."

The speed and size of the machine, and consequently, the cost of the separating process, are crucial elements in an industry processing tonnes of material for just a handful of euros, and having to do it quickly and with the smallest possible plant.

Two test rigs have now been set up. One of these is used to separate metal particles and consists of a conveyor belt running across the magnetic plate. The magnetic liquid (which in this case is pitch black due to the much higher concentration of iron oxide particles) sits stationary over the magnetic plate, like some weird outsize blob of ink, while below it the conveyor belt moves along, bringing in the metal particles.

Once inside the liquid, the various metal particles float at different levels, so horizontal separator louvres can lift them out.

"This demonstrates the viability of the principle," Rem says, "but we don't believe it is suitable for large-scale or high-speed applications."

Contaminants Erwin Bakker recently tested a different configuration that might serve as the basis of a continuous process for separating plastics. This time the liquid runs across the magnet in a continuous flow containing shreds of plastic to which contaminants in the form of glass, grit, and metal have been added. The contaminants sink to the bottom, whereas the particles of plastic are carried away by the magnetic liquid to be strained off later.

The liquid is reused, and in a future version the extracted plastic particles as well as the contaminant sediment could be collected by a conveyor belt in a fully continuous process.

"I have run this set-up for up to ten minutes, and it worked perfectly," Bakker says. He has undertaken a little market research to assess the economic possibilities of his technique. Including the 15,000 tonnes collected in the

A separator vane inserted into the fluid down to 2 cm above the belt is used to separate the floating particles from those lying on the belt. The heavier particles move under the vane and drop off the end of the belt. The lighter particles float over the vane to hit a V-shaped ridge that carries them away to the side of the belt.

Netherlands, the worldwide annual PET recycling figure comes to 750,000 tonnes, which in view of the current typical processing cost of a few dozen euros per tonne would be a useful market.

Another sector appealing to the researchers is recycling the many different kinds of plastics used in motorcars (8,000 tonnes each year in the Netherlands alone; 400,000 tonnes worldwide).

"A typical car contains six different types of plastic, apart from rubber and fabrics. For all the different makes together, the number of plastics is about twenty," Rem says.

Density separation by means of magnetic fluids can provide the required resolution to separate all these different types of plastic in a single process step. Most current techniques use a separate step for each different component.

As for separating (non-ferromagnetic) metal ores or recycled metals, the outlook is less favourable. These materials are heavier and would require a magnetic liquid of much higher concentration, which in a pure form would be rather expensive. Since a small portion of the liquid will inevitably be lost, the cost will also be higher.

Diamond A possible niche application might be the refining of diamonds. A South African colleague of Rem, who also worked for the De Beers diamond company, asked the Delft team whether they knew of a separating method for the final stages of the company's production process, in which the diamonds are separated from the extracted ore.

Rem: "In this case, the economic as well as the physical prerequisites are very different from those of plastics. This is a process in which you want to end up with the full 100 percent of the diamonds, and the collected material has to be 100 per cent pure."

In addition, De Beers intends to fully automate the process, since the number of people working in the diamond production facilities is kept to a bare minimum to reduce the risk of theft.

Rem: "On the other hand, cost is not a primary issue."

The separation technique developed by the Delft team appeared to be the most promising, both regarding separating effectiveness and suitability for automation, but even so there was no response when Rem asked his colleague for a test sample of diamonds.

"We never heard again from them," Rem says, laughing, "but we still needed something to experiment with."

Air bubbles The plastics and recycling industries on the other hand showed much more interest.

"One manufacturer even asked us how many square metres of his factory floor he would have to keep free for installing a separator unit this summer. Mind you, not as a test unit, but for full production use," Rem recalls.

Unfortunately, things are not that simple. Before a separating process can be standardised and left to run routinely, a lot of things have to be done. The flow properties of the fluid need to be better understood, and Rem plans to bring in his colleagues at the TU Delft Fluid Dynamics department at the faculty of Applied Physics.

Rem: "The fluid cannot remain stationary, since you want to separate any particles that are stuck together. On the other hand, you want to prevent turbulence, as that might jeopardize the separating process."

Even air bubbles, which can easily remain attached to the flat shreds of plastic, would upset the apple cart, but stirring or heating the mixture might offer a solution there.

The group intends to set up standard procedures for as many applications as possible, and document what the losses are in terms of raw materials and magnetic fluid, as well as how pure the end product is.

"We intend to keep the physics as simple as possible in order to better understand why our optimisation cannot be improved upon," Rem outlines the programme, "and we would be very happy indeed if we were to have a prototype in a year's time."

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See also www.bakkermagnetics.com.

The metal particles are extracted in two flows, one in the centre, and one along the edge.

Separated particles of aluminium and copper.

This test set-up devised by doctoral student Erwin Bakker was used for separating shredded PET from contaminants such as grit, glass, and metals. This test set-up also uses a magnetic fluid, but this time the fluid moves along with the PET particles. The contaminants remain behind at the bottom of the container. The PET particles are extracted by a screen.

Courtesy Royal Asscher Diamond Company, Amsterdam

Kimberlite diamond ore