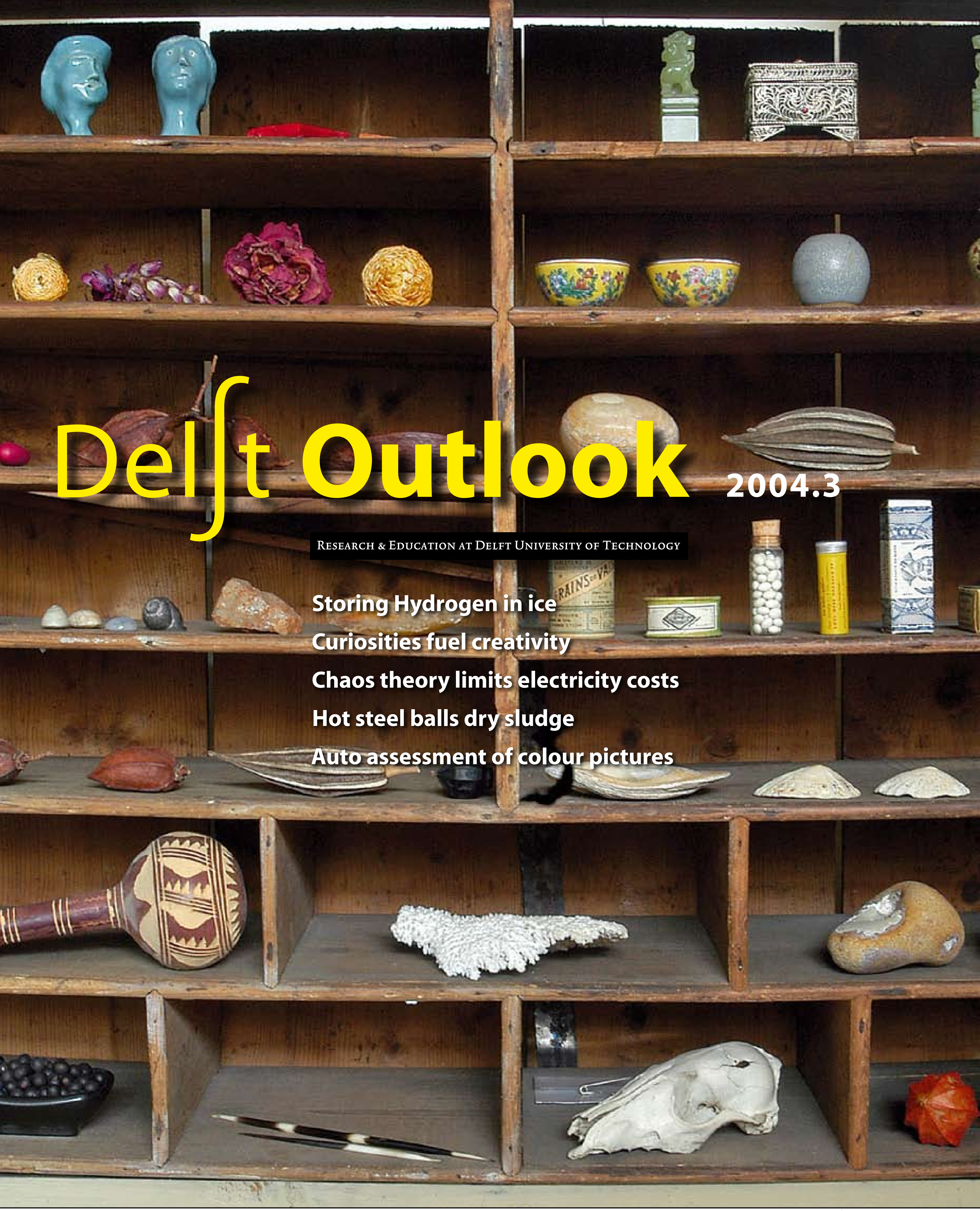

Delft Outlook

2004.3

Research & Education at Delft University of Technology

Storing Hydrogen in ice

Curiosities fuel creativity

Chaos theory limits electricity costs

Hot steel balls dry sludge

Auto assessment of colour pictures

TU Delft

Delft University of Technology

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Delft outlook

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PHOTO: GVB AMSTERDAM

Nine European public transport companies are currently testing buses driven by electric motors as part of the European Clean Urban Transport for Europe (CUTE) project. The silent motors are powered by fuel cells fed with hydrogen. The only thing to come out of the exhaust is water vapour. Amsterdam municipal transport company, GVB is participating in the project with three of these vehicles.

Storage of 'clean' energy carrier in gas hydrates at only 100 bar

A hydrogen ice cube

BY ARNO SCHRAUWERS

Hydrogen is considered to be a highly promising energy carrier. Nonetheless, before hydrogen can become the fuel of choice for the future a number of slight problems will have to be overcome. For example, how can hydrogen be safely stored? Motor vehicles running on hydrogen may be clean in concept but where can we put the hydrogen? For many years now metal hydrides, which are compounds of metals and hydrogen, have been considered the perfect solution for this storage and safety problem but a car fitted with a metal hydride storage system would break its suspension under the enormous weight of the device. Cor Peters at the Delft faculty of ChemTech, together with chemical engineer Louw Florusse and energy expert Joop Schoonman, came up with the solution over a cup of coffee: simply store the hydrogen in ice, and your storage problems are over. Brilliant, the only remaining problem was that hydrogen hydrate can only exist in extremely impractical conditions. The solution to this problem followed the week after. The industrial customers are waiting in line.

Who said romance in science is dead? Early this year at the coffee machine, Dr. Ir. Cor Peters bumped into Prof. Dr. Joop Schoonman, whose main interest is energy. The conversation turned to the possibilities of a hydrogen economy. The previous evening Schoonman had been asked by the editors of 'Noorderlicht', the science programme of VPRO television, whether it was possible to store hydrogen in the form of a gas hydrate.

"Impossible," Schoonman had replied, "since the pressure required would be extremely high."

His response was based on a recent article on the subject in PNAS, the journal of the National Academy of Sciences in the United States. Schoonman said that although technical solutions could be found for most of the problems surrounding hydrogen, storage remained an obstacle.

"Why," Peters asked Schoonman, "don't we solve the problem with hydrates and do it our own way?"

Fuel	Energy (kJ/g)	Energy (kJ/l)
Coal	29.3	–
Lignite	8.1	–
Wood	14.6	–
Petrol	43.5	30590
Diesel fuel	42.7	29890
Methanol	19.6	15630
Natural gas	50.02	31.7
Hydrogen	119.9	10

Compared with other types of fuel, the energy content of hydrogen per unit of mass is high, but it is low per unit of volume. This is why the storage of hydrogen presents scientists all over the world with such a problem.

Hydrogen is currently being produced on a large scale using natural gas and steam. A production capacity of 100,000 m³ per hour is not unusual.

• Partial oxidisation

• Reaction of natural gas with steam

$$CH_4(g) + H_2O(g) \xrightarrow[2.5bar]{850°C} CO(g) + 3H_2(g)$$

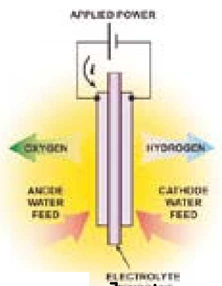
• Reaction of natural gas with steam

$$CO(g) + H_2O(g) \xrightarrow{250°C} CO_2(g) + H_2(g)$$

Anode : $4\,OH^- \longrightarrow O_2 + 2\,H_2O + 4\,e^-$

Cathode : $4\,H_2O + 4\,e^- \longrightarrow 2\,H_2 + 4\,OH^-$

Overall : $2\,H_2O \longrightarrow 2\,H_2 + O_2$



Composition of the electrolyte

Pure water rσ(< 5 μS/cm) + 30% KOH

Using electrolysis hydrogen can be produced from water anywhere in the world as long as an electric power source is available. This means that the energy produced by discontinuous renewable resources (e.g. wind and solar generators) can be saved by converting it into hydrogen. Again, the problem is storage which until now has consumed too much energy.

Schematic diagram of a fuel cell based on a polymer electrolyte (NAFION). On the hydrogen side (left) hydrogen molecules are split into protons and electrons. The protons diffuse through the electrolyte to the oxygen electrode (right) while the electrons create a current in an external electrical circuit (e.g. a lamp or an electric motor). The reaction of the protons and electrons with oxygen produces water molecules.

The drawback of storing hydrogen in liquid form is that one third of the available energy has to be used to keep the hydrogen liquid at –253 °C (20 K). Evaporation results in a loss of 5% per day, which explains why the safety aspects of hydrogen storage receive so much attention.

His suggestion wasn't all that far-fetched, since Peters, whose field is thermodynamics, has spent quite a bit of his professional life studying gas hydrates.

At this point it might be a good idea to explain what hydrates are. A hydrate is a compound of water molecules and other chemicals. This definition is close enough for crystalline water adhered to a salt, but for gas hydrates, matters are a bit different. Gas hydrates could be seen as ice in whose "pores" (cavities on a molecular scale) gas is trapped. This is not pure conjecture since it has become clear since the 1980s that the depths of the oceans and the permafrost contain enormous quantities of methane hydrate (methane being roughly the same as natural gas). In terms of the energy they represent, these reserves are estimated to be several times as big as the currently known energy reserves stored in the form of natural gas, coal, and oil.

Extreme The trick is to 'squeeze' the hydrogen into the myriads of microscopic cavities found in ice, which is far from easy.

"Theoretically," Peters says, "it should be possible to get as much as 6.71 percent hydrogen by weight into ice, so practically speaking, 5% should be feasible. This would mean that to drive the average hydrogen car 500 km, it would have to take in about 120 litres of hydrogen hydrate; that is the equivalent of 120 kilos. If on the other hand, the storage medium were a metal hydride, loading the same quantity of hydrogen (about 6 kg), would take about 300 kilos, making the car unacceptably heavy."

There was just a small problem: hydrogen hydrate will only form under extreme conditions, at a very low temperature and at a pressure of approximately 2300 bar.

"Because of this," Peters says, "practically nobody could see any practical application for hydrogen hydrates."

Fortunately there proved to be a way out. Early this year, Ir. Miranda Mooijer was awarded her doctorate at TU Delft for her research into chemicals, so-called promotors, that change the stability of the gas hydrates in such a way that they can also exist under more acceptable conditions.

Peters: "Using a chemical called tetrahydrofuran (THF), we can reduce the pressure to below 100 bar, which is low enough for practical application. Considering the fact that the hydrogen buses currently being tested in Amsterdam use a hydrogen pressure of 350 bar, our 100 bar becomes very attractive."

So was THF simply a wild guess?

"No. We knew from Mooijer's research which chemicals will stabilise gas hydrates. You only need relatively small quantities to achieve the desired effect. Within a week of talking to Schoonman at the coffee machine, my colleague Louw Florusse and I had proven by experiment that hydrate can be used as a storage medium for hydrogen. As luck would have it a visitor dropped by who was spending a sabbatical at the Colorado School of Mines, an institute with which we maintain close contacts. One thing led to another and it soon emerged that the people in Colorado were working on the same thing. E. Dendy Sloan, the big man on the subject of hydrate research in Colorado, had to admit that we were a week ahead of him. We often collaborate with them. For example, Miranda Mooijer spent a few months of her research working in Colorado. They can do things we can't, and vice versa. The institutes complement each other."

At Colorado they have certain spectroscopic methods for looking inside a hydrate, which brought to light a curious phenomenon. According to a theory by Van der Waals/Platteeuw, the hydrate should contain only one molecule in each cavity, but the hydrogen hydrate contains two, and sometimes even more, hydrogen molecules per cavity.

"Those research results put us on the track of two facts. One, it is possible to make hydrogen hydrate under acceptable conditions; and two, contrary to what the Van der Waals/Platteeuw theory dictates, the energy density of hydrogen hydrate is considerable due to the multiple occupation of the cavities."

Patent All in all, it would appear to be the solution to the main storage problem troubling Schoonman (and many others). The economic implications of such a solution could be enormous. The United States in particular is banking on hydrogen but, as Schoonman has indicated, its future will be determined by the availability of a reliable and safe storage system.

As mentioned storage alternatives do exist but they all come with considerable strings attached. Hydrogen can be compressed (as in de buses being tested in Amsterdam), liquefied, or 'adhered' to metal (in the form of metal hydrides), but each solution comes at a price, and that can be very high.

"In addition to the weight problem," Peters says, "metal hydrides introduce considerable problems of reversibility, since getting the metal to release the hydrogen can be tricky. Hydrogen hydrate does not have this problem. You simply lower the pressure a bit, and hydrogen is immediately released from the hydrate."

Current research includes the development of systems in which hydrogen is stored in nanotubes (tubular molecules made of carbon). Despite a lot of progress, the solution is still a long way off. Hydrogen hydrates will do the job, as Peters and his researchers have demonstrated. In present-day scientific circles this means that a patent application will have to be made.

Peters: "Patents are not exactly our main interest but the university wanted us to go for it. I must admit that the TU Delft patent office gave us excellent support. The Dutch patent was filed in early April 2004. We are still undecided as to whether we should apply for a worldwide patent."

Public The coffee machine conversation had other consequences too. First of all, the invention had to made public which almost inevitably means going to Science or Nature, at least if you want a publication of sufficient standing outside scientific circles.

"The editor of Nature was very forthcoming as were the three reviewers who were to check the scientific content of our submission. That still left us with the task of writing an article presenting incontrovertible proof that hydrogen hydrate can be produced in large quantities. Nonetheless, these experiments take time and in view of the novelty value of our invention, we decided to offer the article to Science. Science, unlike Nature, looks more at the science behind the story as the name suggests. The paper is now in print."

In the meantime industrial circles have also demonstrated their interest in the Delft invention. Shell Global Solutions is among those watching closely what might just prove to be the solution to the hydrogen storage problem, as are car manufacturers GM and Toyota, and oil companies Chevron, Texaco, and BP.

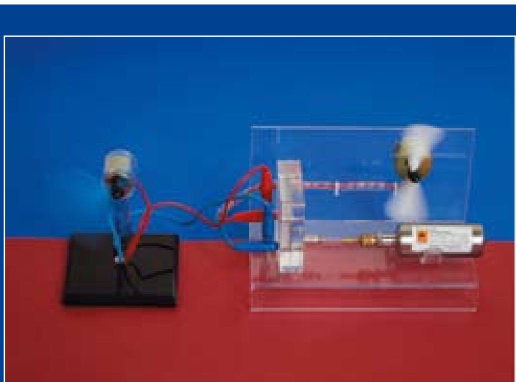
Postdoc Peters: "Of course Joop Schoonman knows the importance of this kind of research and so he has managed to find the means of funding a postdoc researcher to continue the work here at TU Delft. The postdoc researcher is Laura Rovetto, who arrived in Delft from Argentina in June and who has already started work on the project. If we had gone through the normal procedures to get funding for continued research it would have taken an extra eighteen months. Our American counterparts tend to be a bit quicker in this respect. In time we may still find ourselves caught up in a tug of war but I think the patent will give us the protection we need. Whatever the case, my preference is to set up a consortium with our American colleague at the Colorado School of Mines to continue work on this solution to the hydrogen storage problem. It will mean that Rovetto will have to spend some time in Colorado. The best

PHOTO: GVB AMSTERDAM

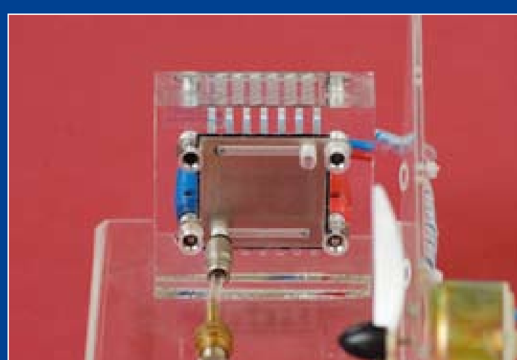
At six thirty in the morning, each of the three Amsterdam fuel cell buses takes on its load of hydrogen. The hydrogen is stored in liquid form in nine high-pressure cylinders fitted to the roof of the bus. The fuel cells in the Mercedes Citaro bus generate 200 kW of power. [For more information, see www.gvb.nl]

Compound	Hydrogen content [w t%]	H atoms per unit of volume [10^{22} cm^{-3}]	Density [kg/m³]
H_2O	11	30	1000
liq. CH_4	25	6	425
H_2 (g), 150 atm	100	0.7	12
H_2 (l), 20 K	100	4.3	71
Graphite	4	–	–
C nanotubes	2	–	–
TiH_2	4	9	3800
MgH_2	7.6	6.5	–
LaH_3	2.1	6.5	–
$LaNi_5H_6$	1.4	5.5	6225
$TiFeH_2$	1.9	6	5470

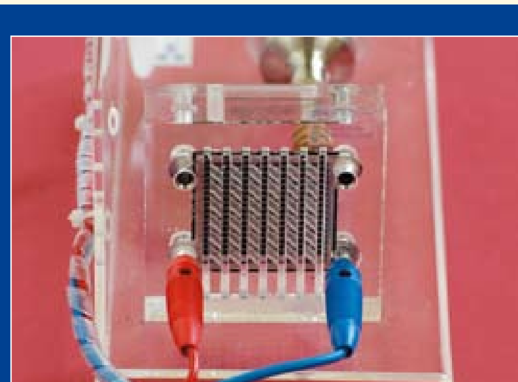
Comparison of the storage capacity of hydrogen for a number of compounds. Note that the density of hydrogen in the various metal hydrides exceeds that of liquid hydrogen. The drawback lies in the weight of the metal hydrides.



Demonstration model of a polymer electrolyte fuel cell. The cylinder contains an iron-titanium alloy into which hydrogen has been absorbed. Using metal hydride for storage is a very safe method but the weight of the iron-titanium hydride is a drawback. The contents of the cylinder are sufficient for the fuel cell to provide 48 hours of electric power.



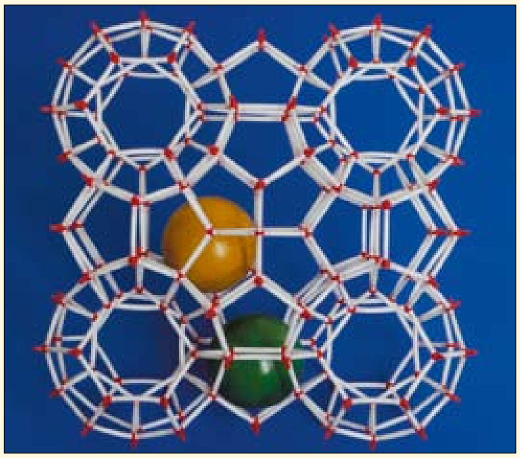
The hydrogen electrode side of the fuel cell.



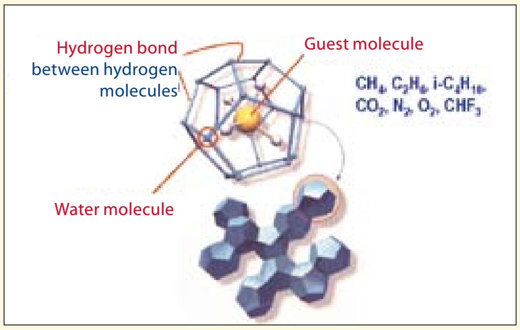
The oxygen electrode side of the fuel cell is slotted to allow oxygen to flow freely along the electrode.

thing is that this research not only created the foundation for the solution to a technical problem it also gave us a nice theoretical bone to chew on. My next job is to see how I can reformulate the Van der Waals/Platteeuw theory.”
There is no point in being gentle in science but it pays to be straightforward. “Being straightforward gets you there in the end,” Peters says, “as it did this time.”

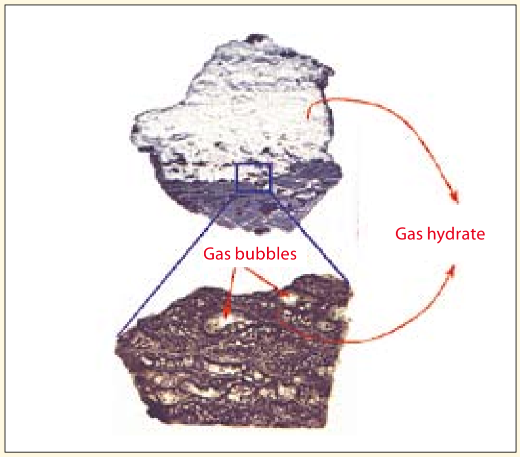
For more information, please contact Dr. Ir. Cor J. Peters, phone +31 15 278 2660, e-mail c.j.peters@tnw.tudelft.nl, or Prof. Dr. Joop Schoonman, phone +31 15 278 2647, e-mail j.schoonman@tnw.tudelft.nl.



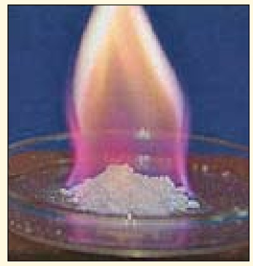
Model of a gas hydrate structure, with water molecules containing two captured guest molecules.



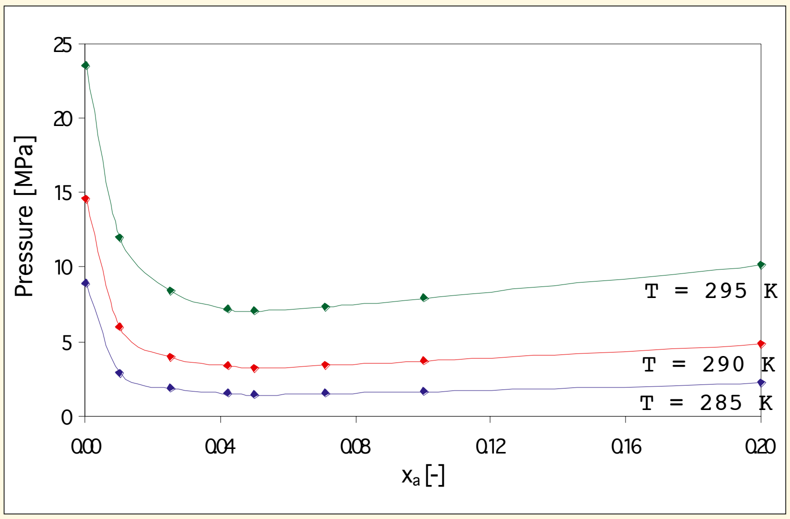
Cavities in water near freezing form an excellent storage facility for guest molecules, including methane, CO_2, and hydrogen. If, for example, a methane molecule is added to a cage of water molecules, it has a stabilising effect on the hydrogen bridges, reinforcing the cage so it can exist at temperatures above the freezing point of pure water. Many cages together form the macroscopic gas hydrate.



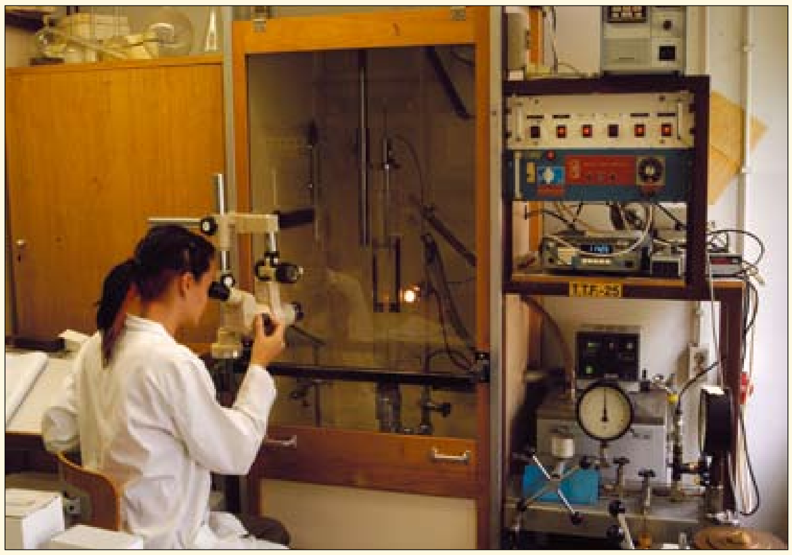
Example of a methane hydrate containing captured gas bubbles as discovered in sediment on the ocean floor. As the hydrate melts, the gas is released.



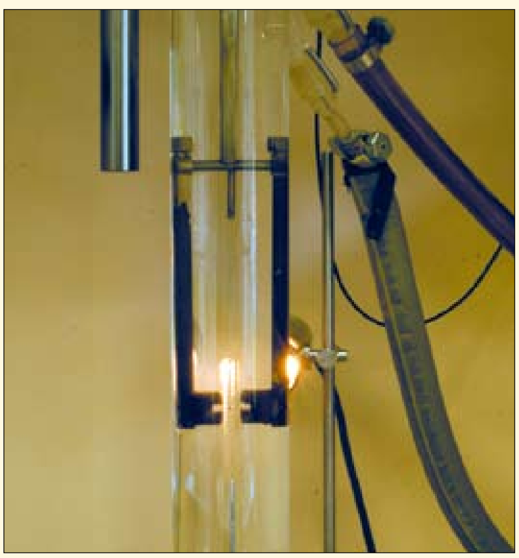
Methane released by the snow-like gas hydrate will easily burn.



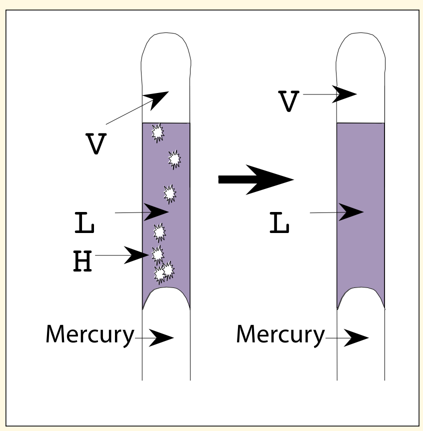
The effect of a promotor on the stability of a gas hydrate. This example involves methane hydrate. Even at low promotor concentrations the pressure is considerably reduced whereas at higher concentrations the pressure gradually increases again. The same mechanism applies to hydrogen hydrate.



Dr Laura Rovetto recently started the continued research into the effect of various promotor molecules on reducing the pressure at which gas hydrates are formed. The research is to culminate in a commercial process for low-pressure storage of hydrogen in gas hydrates.



Close-up view of the test set-up.



Principle of measuring the stability of a gas hydrate. The point at which the last hydrate crystal melts can be determined by gradually increasing the temperature at a constant pressure.

Cabinet of curiosities fuels creativity

By Joost van Kasteren

Useful tool to stimulate designers' inspiration

During the initial stages of the design process, industrial designers often use their private collection of images, magazines, and objects to gather ideas and to discuss matters with their colleagues. These collections are rather like the cabinet of curiosities or *wunderkammer* that the well-to-do of the sixteenth and seventeenth centuries liked to create. Ir. Ianus Keller, a doctorate student at the ID-Studiolab of the Industrial Design Engineering faculty of TU Delft, has developed an electronic cabinet of curiosities that enables the designer to concentrate on playing and associating with images to produce new ideas.

One of the major research themes at the Studiolab is the development of so-called tools for inspiration, tools and techniques that support industrial designers during the initial, concept phase of the design process. The focus is on enhancing the interaction between designer and environment. Ianus Keller distinguishes three levels of interaction (see TRI text box). To begin with designers at their workplace like to surround themselves with images and compilations of, for example, the target group and comparable products, simply to get the feel of what they are working on. The images outline the limits, the prerequisites, within which the design is to be given shape, as it were.
The second level of interaction involves moving objects and images around, arranging them on a table top or on a wall in sweeping movements to be compared, grouped, and discussed.
Finally, the third level is to prepare sketches, drawings, and (foam) models. These are precision actions that require quite a bit of eye to hand coordination. The ideas often come during the first two levels of interaction. Once the third level is reached designers usually know what they want to make. Whatever the level conceptual design is a manual process as well as a cerebral one.

Spatial memory The 'Cabinet' developed by Keller picks up on the habit of many designers to collect images and objects to be used during the initial stages of the design process. During workplace interviews and observations Keller noticed that some designers took great care in cutting out the images and pasteing them on cards.
Keller: "They spend quite a bit of energy on individual photographs, sketches, and objects, only to put them back on a pile. They do not catalogue them in any particular way, but there appears to be little need for that, since most of these people seem to know exactly where to find the image they want among thousands of others. Designers, by their very nature, have a well-developed spatial memory. A lack of structure when storing the images also has the advantage that you may find yourself getting new ideas just from rifling through them."
A computer could be used to provide easier access to a collection of images. Various software titles are available for this purpose. However, according to Keller such library systems are unsuitable for the informal collection of a designer.

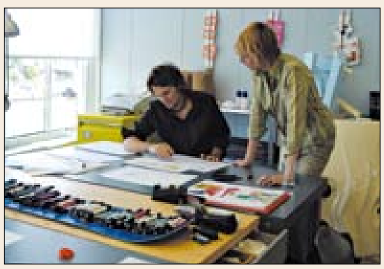
The collections created by designers comprise stock photo books, images, catalogues, etc. The computer has been unable to replace physical collections because it does not offer the same level of overview and control.

In addition to images designers also collect physical objects.

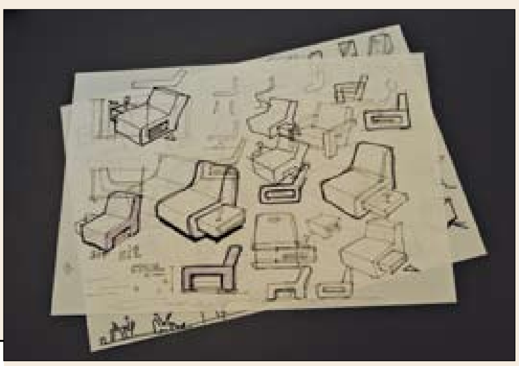
In order to be able to retrieve images most designers mark the pages of magazines and books with yellow Post-it tags, sometimes adding keywords and project names.

Once an image is selected for adding to the collection designers spend a lot of effort on getting the cropping and storing the result. According to Keller, they spend less effort on arranging the collection beforehand, but even so they can always find the images they want.

Designers like the ones here at the SMOOL design studio in Haarlem like to be inspired by the collections with which they surround themselves on the walls and on their desk. The images influence the designer from the periphery of his vision, something that would be impossible with current computer set-ups which claim too much of the stage.



During the design process images from the collection are placed on the table to discuss and arrange them. According to Keller, the added value of arranging the pictures lies not just in the separate images, but also in their relationship and composition.



Ideas are converted into sketches, which are not simply separate images, as each sketch affects the next. It is a process of growth with a feedback element, resulting in complex compositions.

"To make the system work you have to store a whole range of information about the image, including name, date, subject, etc. To retrieve the image, the user again has to type in a set of keywords. It is all very verbal, which is of little use to designers, who like to do things visually. What's more, the purpose of their collections is not so much to retrieve the images or to show them to others, but to use them to gain inspiration. The importance is not just what the picture represents, but also its physical appearance, i.e. its size, wear and tear, colours, and other physical aspects."

Keller's Cabinet, by forming a source of inspiration, offers the designer a starting point when making the first tentative steps on the way to a new design.

At the same time, however, cabinet of curiosities these days tend to come in digital form. Surfing the Internet is one way of bumping into images and objects that stick in your mind. Of course you could print them, but the results are often less than ideal. One of the purposes of the Cabinet developed by Keller is to combine computer images with a collection of physical artefacts a designer collects over the years.

Fingers To emphasise the link with the physical collection the system does not resemble a computer. Instead it appears to the user as a worktop that doubles as a projection screen. The images are produced by a beamer fitted below the worktop that projects the images onto the worktop via an overhead mirror. The images can be moved around using an electronic pointing device.

The screen displays a number of virtual stacks of photographs and sketches, just like they might appear on a designer's normal worktop. The pen-like pointer lets you go through the stacks and spread the images all over the worktop, just like you would do with your fingers to move paper pictures around a table.

You can also add new images to the collection. These can be computer images transferred from a USB memory device or pictures straight from a magazine.

Keller looks up a cigarette ad in a magazine showing a designer putting up his feet in a studio filled with drawing boards, puts the ad on the worktop, and presses a button. When the magazine is removed, a virtual copy of the original stays behind on the worktop in exactly the same place and of exactly the same size. There is a touch of magic about the process of something remaining where it is even when you remove it.

Once Keller finishes cropping the picture it is added to the collection, revolving to indicate to the user that it still has to be assigned its proper place in the collection or in one of the many stacks. No words are used in the process, so the designer can remain in visual mode all the time.

In addition to storing existing electronic images, the Cabinet can also be used to scan photographs, magazines, or even tangible objects to add them to the collection. In fact, it can do even more as it enables the user to add different textures and materials to wooden or foam plastic models using light projection.

Keller: "This works particularly well for adding buttons and even an interactive display to a model of a mobile phone. Many students have already used these projection techniques to tweak and present their design."

Physical images & Searching by image Keller designed the Cabinet to closely follow the way designers use their collection. For example, instead of displaying the images on an electronic screen, it shows them on the worktop of a separate table.

Keller: "When I talk with designers about their methods they are always getting up to get something from a shelf that they want to show me. This is something quite different from displaying an image on a computer screen, in which case the person's, i.e. the designer's, attention shifts from the person to whom he's talking to the computer screen. As the focus turns to the computer, the interaction is lost. This effect occurs much less with physical images.

In addition, the interactive Cabinet stimulates interaction by enabling more than two persons to gather round it, and anyone can point to the images or move them around."

Another feature is the search function which unlike most other search engines uses images and distances instead of words and is based on the patented MDS-I (Multi Dimensional Scaling Interactive) system developed at TU Delft (*see also Delft Outlook 2000.4*). In practical terms, it goes like this. A user places the tip of the pointer between two images, and the computer then searches its library for other images that resemble those two. What is new about the Delft method is that it is interactive and enables you to search by clicking between two images.

Keller: "If you want to generate ideas for the design of a new product, it helps to use existing designs as a starting point. So you use a bit from one image and combine it with a bit from another, and a bit from yet another. The creative process often consists of developing new combinations."

Electronic shuffleboard The Cabinet spent four weeks on trial at WAAC's designers in Rotterdam (known from the Senseo Crema coffee-maker system marketed by Philips and Douwe Egberts). It was then moved to spend another month with Fabrique designers in Delft, whose designs include the Albert Heijn on-line supermarket. Finally, the Cabinet was used by SMOOL designers in Haarlem.

"The object of the exercise was not so much to test the system," says Keller, "as to observe the behaviour of designers as they used the product. Research with prototypes is an important part of Research through Design." (*See text box below*)

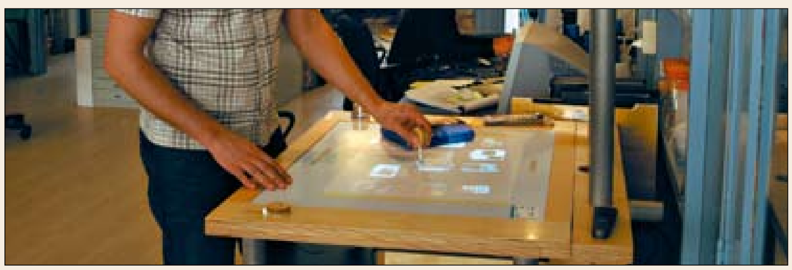
Renate Frotscher of the Fabrique design studio used the Cabinet to analyse the look and feel of a magazine that was to be "translated" from paper to a web-based magazine. Elements that determine the character of a magazine include pictures it contains, titles and headers, but also the layout and typesetting. The system proved to be very useful for this kind of analysis.

Frotscher: "Normally you would start taking cuttings which you then move around to classify the various elements that make up the magazine's qualities. With this interactive system you can simply take a picture, crop it, and then move it around electronically to see if you can evoke the same atmosphere. Of course, you could do the same thing on a computer display, but it would require much more effort. You would have to scan the images, process them, and then store them in a folder where they would be out of view. One major difference is that thumbnail images on the computer screen tend to be arranged in neat rows and columns, whereas the new system lets you move them around and put them where you want. And, they are much easier to find when you have temporarily moved them aside."

Roy Gilsing of WAAC's considers himself a critical user in the sense that some

With his Cabinet, shown here at WAAC's in Rotterdam, Keller wishes to close the gap between physical collections and the digital world. Collecting is much nicer to do in the real world but a computer offers much better opportunities for processing the information and making collages.

The Cabinet comprises a touch-sensitive A2-size tablet manufactured by WACOM, an Apple PowerBook computer sans display, a projector, and a digital camera. The image is projected onto the touch-sensitive surface via a mirror. The user can move images around and collect them in groups using a special pointing device,. New material can be added in the form of pre-processed digital images from a memory device through the USB connection (front right) or images from physical objects through the digital camera using the button on the front left.



Research through design

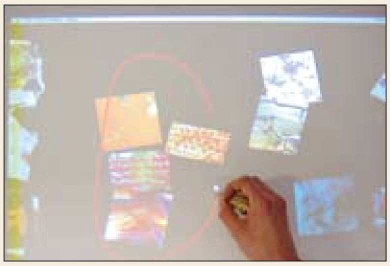
The Cabinet was developed at the ID-Studiolab, a group of researchers and designers advocating what they call 'Research through Design'. The principle is that a design researcher should not act purely in his capacity as a psychologist or ergonomics engineer, but also as a designer himself in researching design processes.

The emphasis is on making empirical, well-designed and finished prototypes that work well enough to be used as tools by researchers and users. The experiential working prototypes serve as research media, and their role in the research is as important as that of the results of user interviews. The purpose of the Cabinet is to test hypotheses regarding the use of images in the design process by looking at the log files to see how designers used the interactive system.

The purpose of the working prototypes is not so much to develop or demonstrate new technology as to help apply existing technology with fresh insights about the way people can use technology.

The electronics for the Cabinet were constructed by Ing. Rob Luxen. Ing. Aadjan van der Helm, who has experience in the field of designing for artists, developed the software using the fluid interaction styles created by Ir. Aldo Hoeben. Impromptu remarks and interesting applications by other researchers and designers at the ID-Studiolab also proved crucial to the development of the prototype of the Cabinet.

Adding a picture from a book. The camera records the image and projects it onto the original object. When the book is removed, an identical image remains behind, a truly fascinating experience.



The Cabinet works without words. Users can work with images intuitively the way they like to do on a table, i.e. by arranging, moving, grouping, and stacking them. A computer requires some measure of order beforehand, but the Cabinet enables the user to handle freely and creatively producing images, arrangements, stacks and compositions.

A working prototype of the Cabinet spent several months at a number of design studios for field tests as part of the normal design process. At the Fabrique studio in Delft, the Cabinet was used to improve the website of the supermarket chain Albert Heijn.

During the field tests Keller ran into some unexpected phenomena, such as the way in which one of the participating designers frantically tries to stop her colleagues messing up her collection. Again, the boundaries between real Post-It notes and their digital counterparts have become blurred.

aspects of the way the Cabinet is used are not as logical as he would like. “The emphasis is on storing images. I would much prefer a system that would help me retrieve images, such as a search engine that would search the Internet for images to match a theme, and help me to process and scale them. Nonetheless, the interactive system is very useful for discussions with other people such as other designers and clients. You can gather round it with a couple of people and move images and sketches around, which is very useful,” Gilsing says.

All in all, the interactive Cabinet appears to be a useful tool for inspiration. Keller: “Using a theoretical design approach allows us to think in a radically different way about interfaces. This system succeeds in blurring the difference between physical and digital pictures, bridging the physical digital divide.”

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The TRI set-up.

TRI

You will find them on the wall in any designer’s studio: collections of (sections of) pictures, sketches and in some case, bits of material and cardboard. Ianus Keller, himself an industrial designer with five years experience in industry, knows what he is talking about when he says that designers don’t just go off on a limb when they start a design. On the contrary, they try to figure out in the best possible way how their product will be used and in which conditions. The designer’s collection on the wall serves as a showroom of ideas and indicate the framework within which individual and collective creativity can be expressed.

In recent years, electronic aids have become available to help shape the designer’s showroom. People go out with video cameras, or even better, a computer is used to create a synthetic environment, a virtual reality.

“It’s fantastic to see,” Keller says, “but before you get to that point, you need to program every detail, which is very time-consuming. Anyway, there is no need for so much realism to experience the environment in which the product is to be used. On the contrary, with everything looking that slick it tends to become a movie where you sit back and relax to watch. It no longer stimulates creativity.”

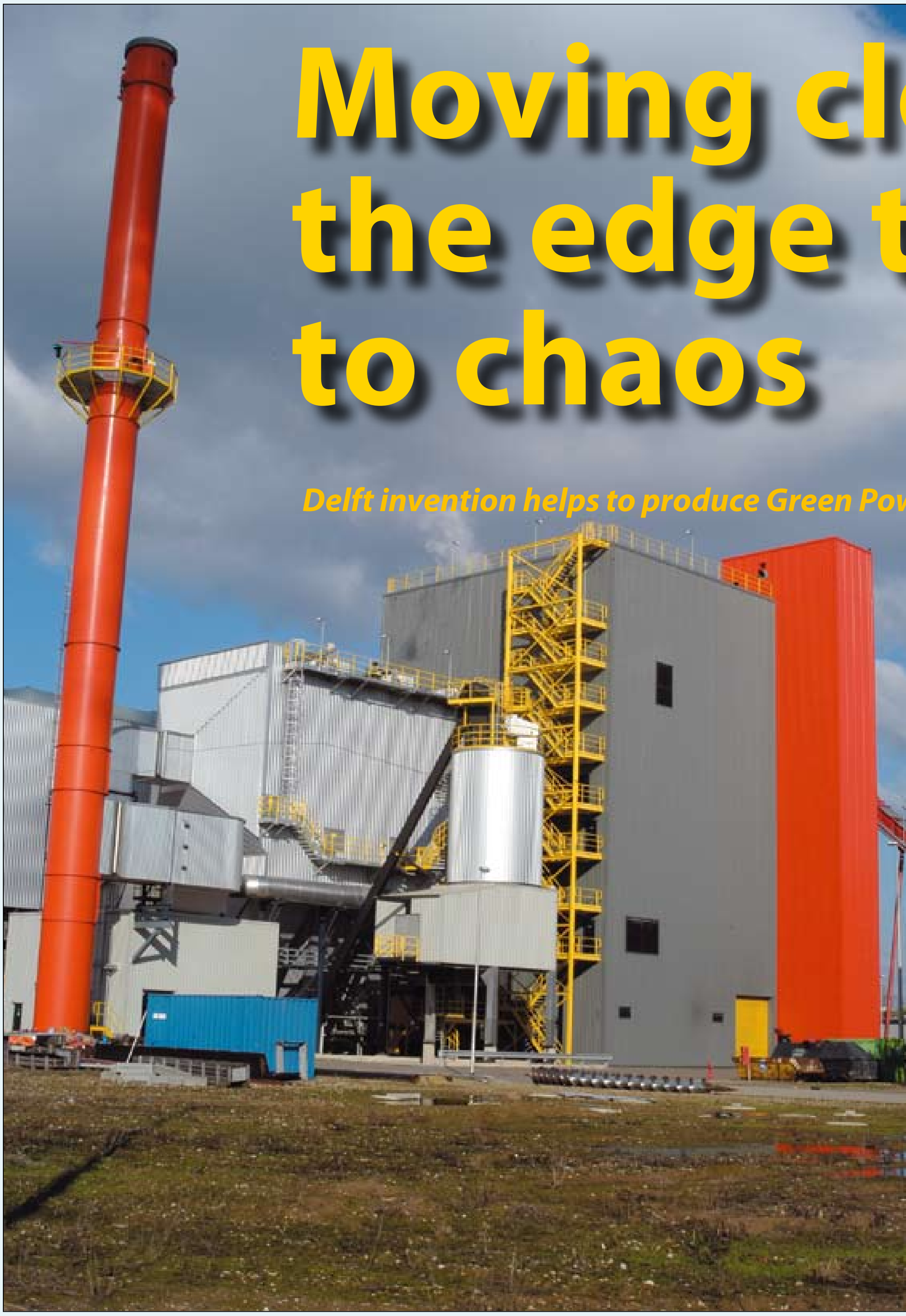
As an alternative the ID-Studiolab has developed the TRI system. TRI is a pun on ‘try’ to express the explorative, tentative and playful use for which it is intended. It also stands for Three Ranges of Interaction, which refers to the three levels of interaction discussed in the main text of this article. Its purpose is to serve as an aid. when making video collages for instance. A picture of a kitchen is projected onto a cardboard screen. A woman is cutting up vegetables, which she then puts into a pan. The image animation is jerky.

Keller: “We intentionally opted for an image-by-image presentation, again to prevent it becoming too much like the movies. The images were not recorded with a video camera but with a still camera. The interruptions between the images make you look more closely. You might compare it to making music. Miles Davis once said that music is not just about the notes you play, but more about the ones you don’t play. The designer must decide for himself which images to include in the video collage, and the spectator must enter into the projected image.”

TRI also uses a horizontal worktop on which both physical objects and images can be moved around. According to Keller this helps the users to group, present, and discuss ideas. Another possibility is to project different colours, patterns, and textures onto a foam or wood model of the product. It also enables the user to get some idea about the way the product should be shaped in order to make it easy to handle. The worktop also contains an LCD touch screen that can be used in combination with a digital pen to make sketches which are then stored in the computer and which can be used as a basis for more detailed sketches and images of the product.

TRI also served as the basis for further prototype development. The technology and scale of interaction of the Cabinet can be regarded as a spin-off driven by the experience gained from TRI.

Projected images can be used to flexibly try out textures, buttons, displays, etc. on foam models.



Moving closer to the edge thanks to chaos

BY ARNO SCHRAUWERS

Delft invention helps to produce Green Power and to predict epileptic fitst

Power company Essent's biopower station at Cuijk, a small town near Nijmegen. The heart of the plant consists of a fluidised bed in which wood chips are combusted to generate green electricity.

The Netherlands annually produces 2.7 million tonnes of biomass, 230,000 tonnes of which consists of clippings from public parks.

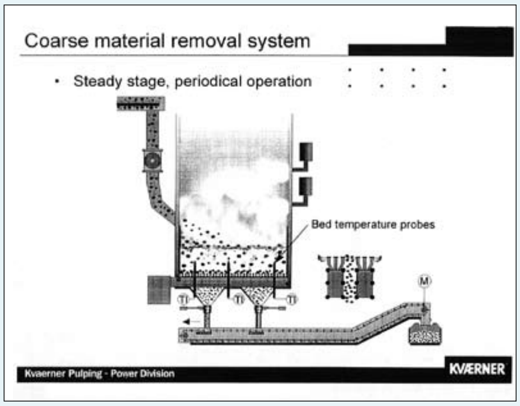
Fluidised bed reactors are in common use in the chemical industry and for generating electricity. A relatively recent application is the combustion of biomass to produce what is called Green Power. The thing about fluidised bed reactors is that they can be used in a wide range of production processes and they have excellent heat transmission.

In the late 1980s chemical engineer Prof. Ir. Cor van den Bleek came to be regarded by his colleagues as a bit unconventional, to put it mildly, for proposing to use the chaos theory to solve problems in fluidised bed reactors. Today Dr. Ir. Ruud van Ommen and Ir. John Nijenhuis have managed to build on the disparaged theory to develop a detection system giving operators of chemical plants and power stations early warning of impending reactor errors, thus avoiding much inconvenience and cost.

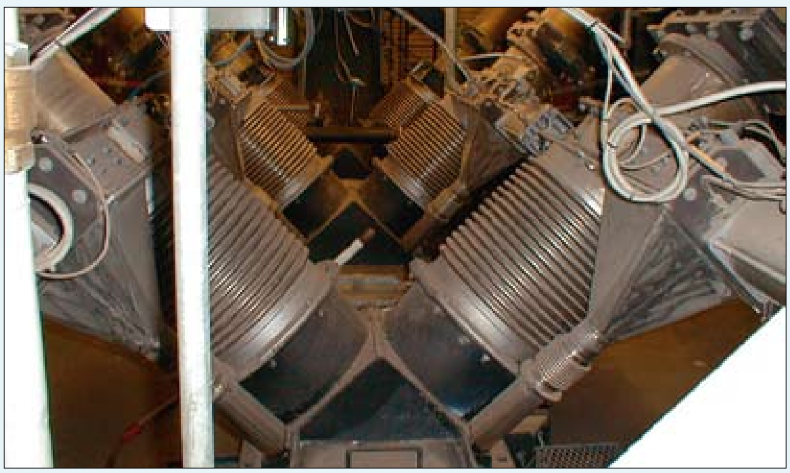
In medicine too, applications have been found for the 'chaotic' technique. The first product has already hit the market.

The clippings for the Cuijk power station come from public parks services in the surrounding areas.

In the daytime on workdays the power station runs on the constant supply of clippings. At night and during the weekends when no clippings are brought in the plant is fed from a pair of silos that together contain 10,000 m³ of wood chips.



Sectional view of a fluidised bed as used in the Cuijk power plant. The fluidised bed consists of a layer of sand that is kept in suspension by an airflow from below. Together with the wood chips, the sand becomes a constantly moving mass that behaves like a fluid.



To prevent a build up of ashes in the fluidised bed, so-called troughs continuously draw off a part, together with a quantity of sand. A conveyor belt transports the mixture to containers.

During the combustion process at 850 °C the sand and the sticky ashes can start to form lumps. This can become so serious that the whole plant has to be shut down to be cleaned by hand. The air injectors can be seen near the feet of the engineer in the picture.

Fluidised bed installations are used for one thing for the combustion of coal or wood chips (biomass), for producing and drying polymer granules, for making granules from powders in the pharmaceutical industry, and also for producing fertilizer pellets. Fluidised bed reactors are also used for catalytic reactions, for example to produce synthetic crude oil from coal or biomass. In a fluidised bed installation, grains of sand (or some other material) are suspended, or fluidised, by injecting an airflow from below (in some cases, another type of gas); hence the name of the process. The fluidised grains of sand ensure that the heat and material inside the reactor are closely mixed to facilitate the processes in the fluidised bed, e.g. the combustion of biomass. The suspended mixture behaves like a fluid.

In addition to the desired effects, all kinds of undesired reactions and processes can take place that adversely affect the process. If the worst comes to the worst, the reactor even has to be shut down, emptied, and restarted.

Now that governments and other authorities have clearly indicated the need for a sustainable society (witness the introduction of Green Power), the use of biomass as fuel has entered the picture.

However, biomass as a fuel for generating electricity is not without its problems, says Ruud van Ommen, assistant professor at the Delft section of Reaction & Catalysis Engineering. One of the things he looked into as part of his doctorate research (1997–2001) was the combustion of wood chips.

“When you burn coal, you end up with nice, clean ashes, but when the fuel is biomass, for example straw or wood chips, some of the salts from the biomass will react with the sand of the fluidised bed. As a result of this, the melting point of the sand will drop below the temperature of the fluidised bed. This leads to agglomeration. In other words, lumps are formed,” van Ommen explains.

As more lumps are formed, the performance of the fluidised bed installation decreases until eventually the process has to be shut down and the reactor cleaned, which has to be done by hand. On his desk, van Ommen has a couple of fist-sized examples of fluidised bed lumps on show. Some of them look like bits of coral. The may be nice to look at, but they are far from welcome. In addition to the cost of cleaning out the reactor, there is the loss of production.

Operators try to avoid the damaging lumps by extracting the agglomerated grains just in time and replacing them with fresh sand. According to Ir. John Nijenhuis, a research engineer in van Ommen’s group, operators do this on the basis of a gut feeling.

“It is the kind of instinctive knowledge that is very difficult to transfer from one person to another.”

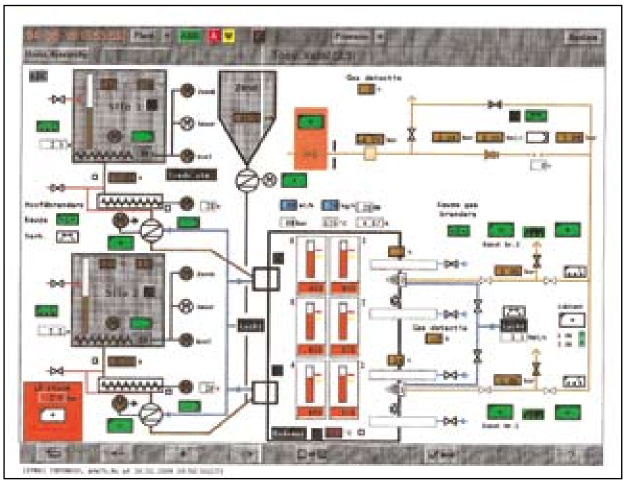
Of course a fluidised bed system includes a number of variables that can be used to warn the operator of an impending obstruction. Pressure and temperature are good indicators, since the formation of lumps will affect the pressure drop or the temperature distribution inside the reactor. Measuring temperature is not very practical, as it would require the installation of temperature probes in many locations throughout the fluidised bed, since each probe can provide only limited, local information.

On top of that the probes in a fluidised bed would be constantly sand-blasted by the abrasive material flying about the place. What remains to be measured therefore, is pressure. Pressure probes provide information from a wider area, which means that they can be fitted to a ‘branch’ of the reactor, where they will be safe from the sand bombardment. This is why measuring the pressure changes inside the reactor, or part of it, is a popular method for keeping track of what goes on inside a fluidised bed.

Waste & chaos

“However,” says van Ommen, “one drawback of these systems is that by the time you get the warning, the damage has already been done. What you really need is a system that will give an early warning so you can take the necessary precautions in time. The problem with the current ‘gut feeling’ methods is that they involve the extraction of considerable quantities of agglomerated sand, which is designated chemical waste. Even though it is not considered hazardous chemical waste, the only remaining practical application for it is as filling material in road construction works. An early warning system would dramatically reduce this flow of waste material, which in turn would spare the environment and save a lot of money.”

“Pressure drop probes of the kind in use today,” van Ommen continues, “provide very little information, because their sampling rate is only once every second.



Schematic diagram of the fluidised bed control system.

If we were to measure the pressure more often, say one hundred times a second, we could get an impression of the pressure fluctuations on a time scale of ten milliseconds. That would give us much more information about the behaviour of the fluidised bed, which is strongly affected by the gas that bubbles up through it. The different properties of the gas bubbles, such as size, velocity, and shape, can tell us a lot about the behaviour of the sand grains. The pressure fluctuations give us information about the gas bubbles, and consequently, about the sand."

Attractor A high-frequency sensor system may provide information about the pressure fluctuations in the fluidised bed reactor, but what use are they to the operator? In other words, how can the fluctuations be used to drive a practical warning system for the operator? This is where the chaos theory comes in.
Van Ommen: "In the 1990's Prof. Cor van den Bleek proposed using chaos theory to solve control problems like this one. I came to work for him as a doctorate student in 1997. I worked on his proposal, but unfortunately it didn't work the way it should have. What we were doing was to look at the largest fluctuations, which were of little use to us."
A mathematical trick was needed, and it came in the form of the attractor. Right. So what is an attractor?
Van Ommen sketches a ragged plot to indicate the pressure changes inside a fluidised bed. "An attractor is a term from chaos theory. If you take three consecutive points from this plot at delta-t intervals, and transpose them to a single point in a three-axis system, and delta-t later you take another three points with the same interval, etcetera, you end up with a new plot. This is called the attractor. In fact it is the same as plotting all of a system's variables against each other."
"A properly running process produces an attractor of a certain shape. What you can do to keep a check on the process is to determine the attractor in, say, ten-minute blocks, and then compare it with the attractor of a properly running process. If the deviation, which is referred to as S, becomes to much, things are starting to go wrong, and it is time to act. At Lyngby in Denmark we conducted biomass combustion tests together with the Danmarks Tekniske Universitet. The results were compared with those of conventional pressure-drop measurements. The tests were extensively repeated at ECN at Petten here in the Netherlands, and showed that the chaos technique indicates that things are going wrong inside the reactor long before the pressure-drop readings give cause for alarm. The conventional pressure-drop method cannot raise the alarm before things have already gone wrong. The chaos system is an early warning system that improves the running of the process."
Nijenhuis: "Preventing or postponing downtime of a large plant will easily save hundreds of thousands of euros each time, and this method will let you use the system to full capacity."

Market "The chemical industry is conservative," van Ommen observes, and he is not the first to do so. "They simply want no part of it, so we roped in the power industry for our field tests, which were conducted at the Essent power company's fluidised bed plant at Cuijk, in cooperation with ECN."
Current process control systems in the chemical industry cannot cope with relatively high-frequency measurements. However, the Delft researcher says that this is not a problem: "In fact, the system operates independently, and can

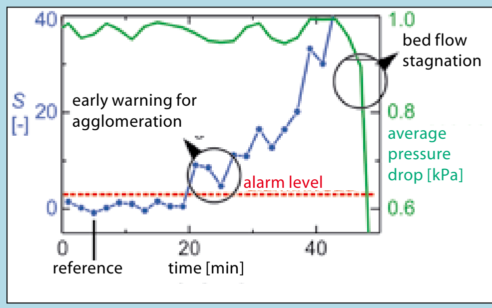
The control room of the Cuijk power plant. Usually, the process is controlled from a central control room in Eindhoven.

Researchers at TU Delft decided that a better way to measure the variations in the combustion process would be to use fast pressure probes rather than temperature probes. The pressure probe readings give an indication of the conditions in a larger part of the fluidised bed. Moreover temperature probes are quickly damaged by the abrasive action of the sand.

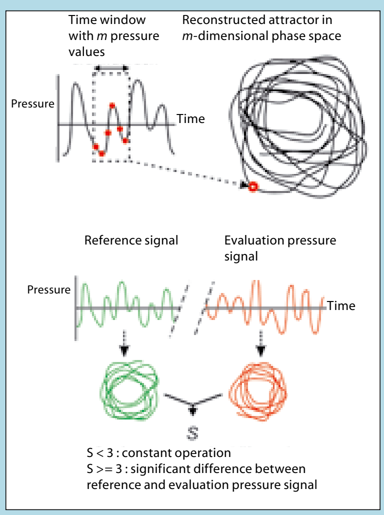
The Kistler probes can provide a fresh pressure reading every 10 milliseconds.

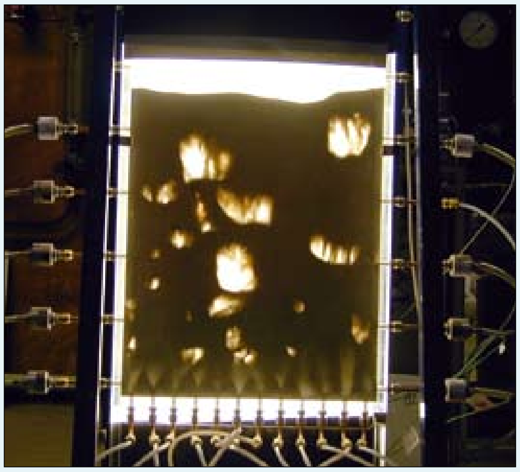
The pressure probe originally installed in the fluidised bed was of no use to the Delft research team, because its location was wrong. For the experiments, six fast pressure probes were installed through the bottom of the fluidised bed.

ATTRACTOR



Instead of being constant the pressure in the fluidised bed continually fluctuates slightly. The fluctuations give an idea about the state of the gas bubbles that pass through the bed and about the size and adhesion of the sand grains that make up the bed. Unfortunately detecting differences directly from the pressure signal is very difficult. To observe the fluctuations nonetheless a technique known as an attractor reconstruction is used in which the pressure signal is converted into an attractor, i.e. a number of successive pressure readings (m values in the plot) are converted into another space, known as the state space. In other words the pressure values are used as coordinates for a point in the state space. The pressure readings are taken at ten millisecond intervals. Conversion of a ten-minute pressure signal into such points results in an attractor in the state space. The attractor characterises the behaviour of the fluidised bed during that period. To begin with a reference attractor is generated for a period during which the process in the fluidised bed ran perfectly. Once the fluidised bed comes into service new attractors are constantly being generated from the pressure readings that come in every ten milliseconds. Each new attractor is then compared with the reference attractor. A statistical test is used to assess the result producing the similarity index, S. If both attractors are similar S will be close to 0. If the value of S exceeds 3 this is a warning that something is changing in the fluidised bed, for example that the grains are agglomerating. This provides an early warning so measures can be taken to prevent further problems.





2D test bed for studying the bubble pattern in a fluidised bed for correlation with pressure fluctuations.

Among other applications, the insight gained from the 2D test bed was used in this 40 cm Perspex reactor at the Reactor & Catalyses Engineering group laboratory. The question is whether bubble size and distribution can be derived from the pressure fluctuations.

The South African SASOL slurry reactor that produces petrol and diesel fuel from coal. The Delft monitoring method can also be used in this type of reactor to detect the early stages of undesirable behaviour.

be linked as an external loop to the main control system. The only parameter to be passed to the control system is what the operator needs, which is the value of S."
The Delft group has come to an agreement with the Belgian-Dutch company, IPCOS, who recently brought the early warning system to market. This is not the end of the story for Nijenhuis and van Ommen, however.
Van Ommen: "The range of applications is much wider than the fluidised bed alone. The system can also be used for detecting undesirable foaming in gas scrubbers, as we have tested here, and that makes the system suitable for use in various fields in biotechnology, where foaming tends to be a problem.
The system could also be put to good use in suspension reactors, which among other processes are used for the production of polypropylene and synthetic crude oil. In fact, it can be used in any dynamic system in which you can measure a rapidly fluctuating signal that gives an indication about an effect that may occur in the long run."

Patents & patience This means that the chaos instrument could be used not only for chemical or power-generating applications, but also in, for example, medical applications.
Van Ommen: "I'm thinking about heart rhythm disorders and epileptic fits. I have established contact with the University of Chicago Children Hospital, and we have proposed using this detection system to warn epilepsy patients of an impending fit. Epileptic fits can be made visible through electroencephalograms, and this technique would make it possible to analyse the fluctuations and indicate the probability of a fit."
Would such a system not be highly impractical? People with epilepsy would have to walk around wearing a set of head electrodes and an EEG recorder.
Van Ommen thinks this problem can be solved.
"These are all matters that are still open to further development. It is not as if we have sold our idea to IPCOS and can now sit back and reap the rewards. We will continue to developed the technique, partly within the Delft Centre for Sustainable Energy programme of TU Delft and in cooperation with ECN."
Then there's another thing. You have not applied for a patent. Are we missing something?
Van Ommen: "The point is that this system has developed gradually and that over the years we have published quite a lot on the subject. Once you do that the patent office no longer considers the subject new. As it is our publications bring in a lot of response that we would not have had if we had gone for a patent which would have meant working patiently in silence."

Abyss So how unusual is it to use chaos theory to solve control problems? "Rather special," van Ommen says. "When van den Bleek started the research, there was one other group in the USA but most academics tended to sneer at the idea. Today the same American group and our own Delft group are still leading the field."
Nijenhuis returns to the subject of gain: "To the uninitiated, the financial consequences of our system may be rather obscure. Reducing downtime, which is the time a plant needs to be shut down for repairs and maintenance, will save a lot of money. And as noted the system also saves a few percent in yield or energy costs, which for larger installations easily translates into at least hundreds of thousands of euros."
How much does the monitoring system cost?
Van Ommen: "We're talking in the order of magnitude of 120,000 euros. You need a fast computer, data acquisition equipment and software. On the other hand the cost is relatively small compared with the savings of a few hundreds of thousands of euros each time downtime is prevented. Johan Grievink, Professor of process integration of our department, recently said: "The best flowers are found along the edge of the abyss. This system helps you move closer to the edge."

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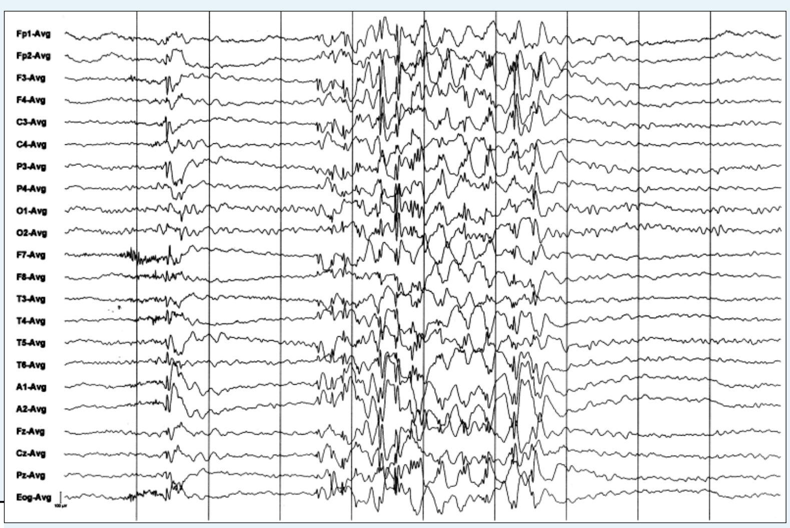
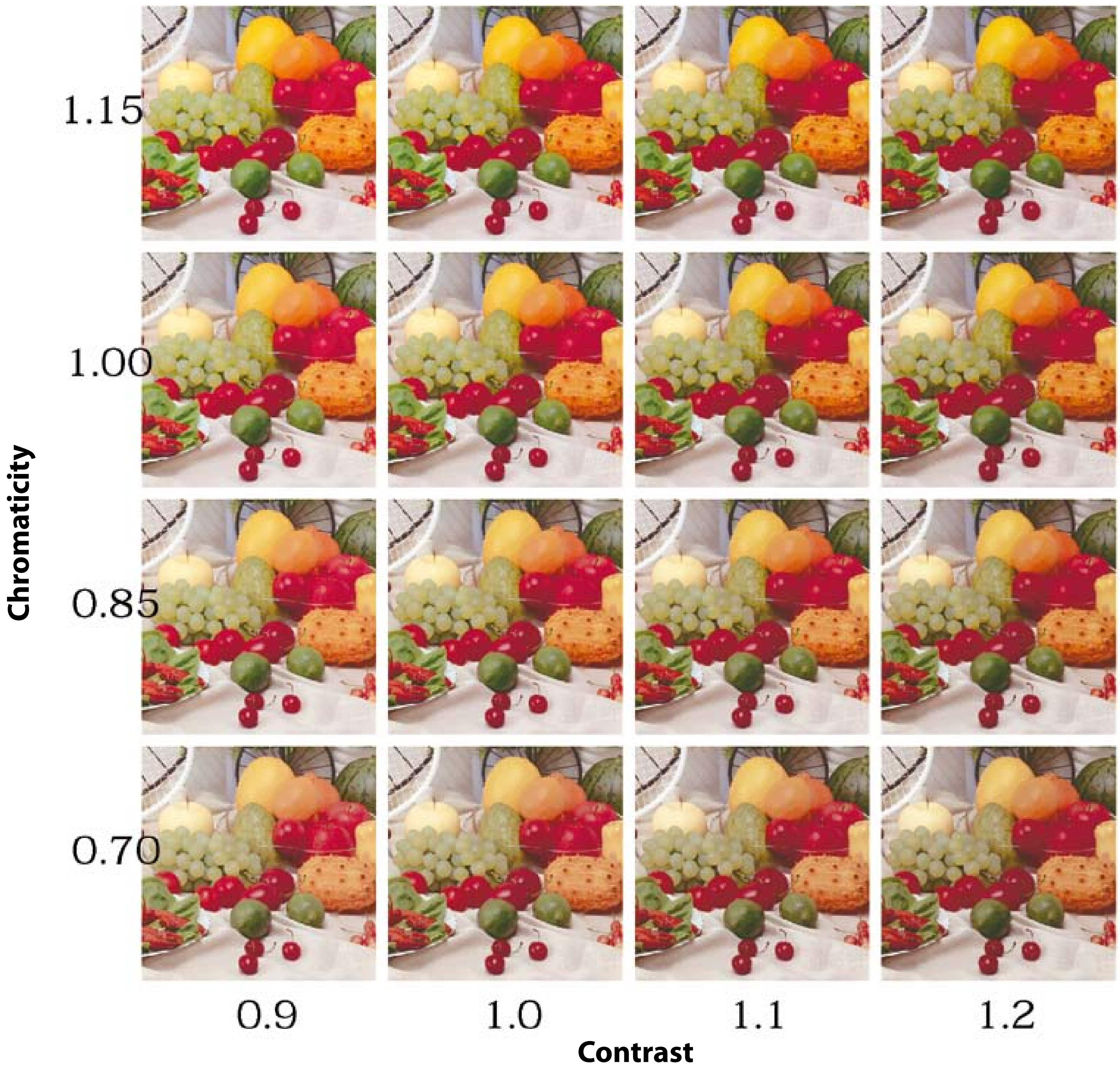


EEG signal of an epilepsy patient during a fit. The first tests appear to indicate that the Delft monitoring method may also be used to give an early warning in such cases. (http://psywifo.klinikum.uni-muenchen.de/forschung/hirnfunktionsdiagnostik/)



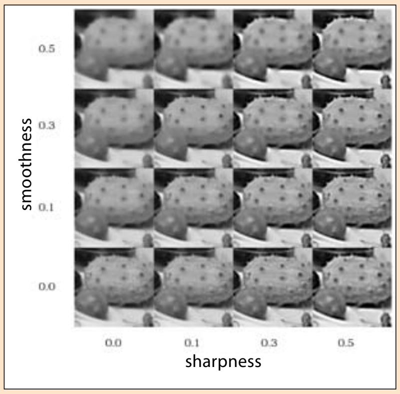
Towards automatic quality assessment for colour prints

Better-looking pictures

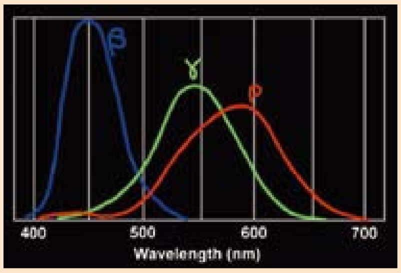
BY BENNIE MOLS

Although colour printers are constantly being improved to produce better results, manufacturers appear to favour trial and error methods in their research. Researchers of the Pattern Recognition & Image Processing group at Delft University of Technology are looking for a scientific and more general measure of quality to judge colour prints by. They are the first to have successfully devised a method that allows the preprocessing of digital images to take into account the fundamental limitations of any printing device. The results, for which a patent is pending, may help computer printers to produce images with better chromaticity.

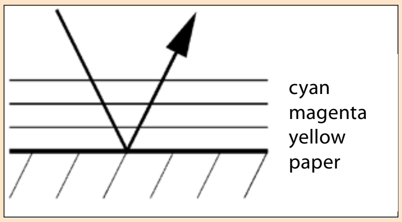
To compensate for the lack of quality in an original, most people are used to adjusting the contrast of their black & white prints to improve the result. Matters are slightly more complex for colour printers which add chromaticity to the equation. To be able to automate the process the first thing to assess is what the average user would consider to be good image quality. Doctorate student Judith Dijk has been looking for a measure of image quality. As part of one of her experiments, test subjects were asked to choose from pictures which differed in contrast and chromaticity. The winning picture, the third from the left on the second row, has normal chromaticity and slightly increased contrast.



Another experiment. Again the test subjects were asked to indicate which image from the series they preferred. The images are arranged according to sharpness and smoothness. The winning image, third from the left on the bottom row, has a slightly exaggerated sharpness and normal smoothness.



The basics of colour perception: the human eye contains three types of receptor in the retina. Each of these is sensitive to part of the visible spectrum. The three overlapping peak sensitivities are: on the left, green via blue to bluish purple, in the centre, red/orange via green to blue, and on the right, red via yellow to green. Even light consisting of a single wavelength will always stimulate at least two types of receptor cell. A knock on the head (when one is said to see stars) may stimulate a single nerve, which results in a pure nerve colour signal, like the indigo poets dream about.



Whereas a computer display mixes different quantities of red, green, and blue light (additive colour production), a printing press uses a quite different colour process, in which layers of ink are superimposed that are transparent to cyan, magenta, and yellow. The level of transparency of each type of ink determines the resulting colour. Magenta for example allows 50% of the red, 0% of the green, and 50% of the blue light to pass through. Yellow lets 50% of the red, 50% of the green, and 0% of the blue light through. For two or more superimposed layers of ink, the transparencies are multiplied (multiplicative mixing). Magenta on yellow for example, lets 0.5 × 0.5 = 25% of the red light through, 0 × 0.5 = 0% of the green light, and 0.5 × 0 = 0% of the blue light, resulting in red.

Light and colours

When we talk about light we usually mean the light that we can see with our eyes: visible light, which is only a small part of the full electromagnetic spectrum. Light is characterised by its frequency. As the frequency increases, so does the energy. Gamma rays have a high energy, radio waves are low in energy. Visible light is somewhere in between the two. Physically speaking they are all manifestations of the same type of radiation. In visible light each frequency corresponds with a certain colour as perceived by the human brain. Wavelengths of visible light vary between four hundred and seven hundred nanometres.

For us to be able to see an object it must either emit light or reflect (part of) the light striking it. If light strikes an object a number of different things may occur. These are reflection (as in a mirror), dispersion (reflection in many different directions from a rough surface, a sheet of paper for example), absorption (in which the object absorbs energy; a black object for example absorbs practically every wavelength of visible light, whereas a green leaf on a tree absorbs blue and red, but reflects green light), refraction (for example, a vertical pole that appears to be at an angle under water), and finally, passing through the object without effect (transparency).

The eye contains three different types of retinal cones, with peak sensitivities at red, green, and blue (the primary colours) respectively. Our brain interprets the overall response of these cones as a certain colour. If all three types of cones respond in more or less equal measure, we see white light. In addition to cones, the eye contains another type of receptor cell, rods, which are sensitive to light, but cannot convey colour information. Thanks to these rods, we can still make out shapes in the twilight, but little or no colour.

Whereas colour television sets and computer displays mix the three primary colours, red, green, and blue into other colours, printing and photography use a different set of primary colours. The reason for this is that pigments mix in a different manner than coloured light, because they obtain their colour through reflection and absorption rather than the emission of light. Offset printing uses ink dots in the colours CMYK, which can often be found in the margin of newspapers.

Although extensive research is being done on the image quality of computer monitors, the results of colour printers tend to receive less attention. People are perfectly capable of judging the quality of a colour print. If they like they can modify the original digital image file with an image-processing program to improve colour quality. However, this can be a time-consuming process, and it would be much quicker and cheaper if the computer could assess the quality of the image and make the necessary changes at the time the digital image is being taken, or if it could propose changes to the user. This requires an objective measure of quality for colour prints based on a mathematical model. The measure must coincide with the way an average person would judge the quality of the print, which is easier said than done. Many different factors affect the way a colour print is judged, including contrast, chromaticity, and sharpness, as well as the image content. Some images are loud, full of detail, and full of contrasting colours, while others are subdued with little variation in contrast and just a few related colours. A person's opinion of a print's quality does not always depend on the image as a whole. In some cases a small but important part of the image determines the outcome. It all goes to show that there is no such thing as an objective measure of quality yet. Which is another reason to find out scientifically what is and what is not possible for the development of an automatic measure of quality.

Industrial secrets Under the supervision of Dr. Piet Verbeek, doctorate student Judith Dijk has spent the last four years researching automatic print quality control in colour printers. Dijk conducted the image-processing part of the research at the Pattern Recognition & Image Processing department of the faculty of Applied Physics.

The perceptive part of the research took place at the Perception department of the research institute TNO Human Factors, in cooperation with Dr. Jan Walraven. This is also where the colour prints used in the research were made. The entire research project was conducted in cooperation with Océ, the Dutch manufacturer of copiers in the southern town of Venlo.

Ideally an objective measure for the image quality of printer output would form part of the program driving the colour printer.

"We do not know how current printer driver software goes about it, Verbeek says, "since that's an industrial secret. Some drivers use different settings for colour images and for text. They probably use different sharpness settings, because changing the sharpness of a colour image is much more complex than it is for black & white images."

Dijk gives an example of how, early on in her research, she sent a black & white photograph to a colour printer to be printed as a black & white image.

Greyscale "Contrary to what I expected the print did not consist entirely of greyscale tones. There was also a bit of colour thrown in. It could be that the printer manufacturer thinks this improves the result, but if I ask a printer to print an image in black & white, I certainly do not want the added colour. Most printers produce good results for the average user, but we do not know how they are produced. The process is useless for my research."

At the start of her research, Dijk also used the graphics software Adobe Photoshop to preprocess the images. The end results were very good but since she could not find out how they were produced from then on she has always written her own software to process the image at pixel level.

"It enables me to know exactly what I am doing."

Test panels Dijk looked at three different variables in the colour printer output, i.e. sharpness, luminance , and chromaticity. The latter indicates the extent to which for example the colour red is a pure red or a paler shade of red, i.e. some kind of colour mix of pure red and grey. In the second case, the chromaticity is less than it is in the pure red. Each of these variables can be expressed as a number, sometimes relative to the original digital image, sometimes as a measure of the colour print itself. Whereas a black & white image uses a single greyscale to express the value of a pixel, in a colour image, each pixel is stored in the form of three or more values.

For each experiment panels of four or eight test subjects were asked to grade a set of prints. The test subjects would arrange them, for example, in increasing order of sharpness, luminance , or chromaticity. They were also asked to indicate their preferred print without knowing what the original digital image looked like. The idea was to find out to what extent the print meets the expectations of the person viewing the image.

As the basis of her research, Dijk used a set of five standard digital ISO photographs as used by the printer industry. The images include a portrait, a picture of an outdoor café, a typical, complex still life featuring a penny-farthing bicycle, a picture of a fruit basket, and a photograph of a trio of musicians, each with a different skin colour. All five pictures are examples of natural images. The photographs are 300 dpi images stored in CMYK format (CMYK stands for Cyan/Magenta/Yellow/blacK, the four printing colours used in both the offset printing process and computer colour printers). The images, sized 12.8 x 16 cm, were printed on paper using an HP LaserJet printer for the sharpness experiment and an Epson inkjet printer for the colour experiment.

"It may well be that diagrams or text set slightly different quality requirements than the common or garden variety of images we looked at," Verbeek says. "After all, the context of the image also plays a role. This is what makes it so difficult to develop a single quality measure."

Dijk conducted experiments for sharpness, chromaticity, and luminance . First of all, she looked at the effect of changes in sharpness on the printer output. In this context, the keywords are sharpening and smoothing. Smoothing acts on areas, whereas sharpening affects edges.

For instance, take an image showing a green fern leaf. Smoothing will affect the bulk area of the leaf, and sharpening will affect the way we perceive the edge of the leaf.

"For each pixel, my program calculates whether the difference with its surroundings becomes more or less," Dijk explains. "If the difference increases, we assume that we are looking at an edge, and the pixel is included in the sharpening measure. If the difference decreases, it is included for smoothing. For this type of operations I used existing filters which I included in my own program."

Low smoothing, high sharpening

Dijk produced variations of both sharpening and smoothing and asked a test panel to judge the printed results.

"The test subjects were asked to grade the results according to sharpness and smoothing. The conclusion is that people are perfectly capable of assessing the differences. Their observations matched the criteria I used to modify sharpness and smoothing. It did not come as a surprise that people prefer low smoothing and high sharpening, which enables them to see sharp edges and details in larger areas. Generally speaking, people prefer sharp pictures until the result starts to look unnatural."

As it turns out people are better as distinguishing smoothing steps than they are at telling apart sharpening stages, and so the just noticable difference of the smoothing must be smaller than that of the sharpening.

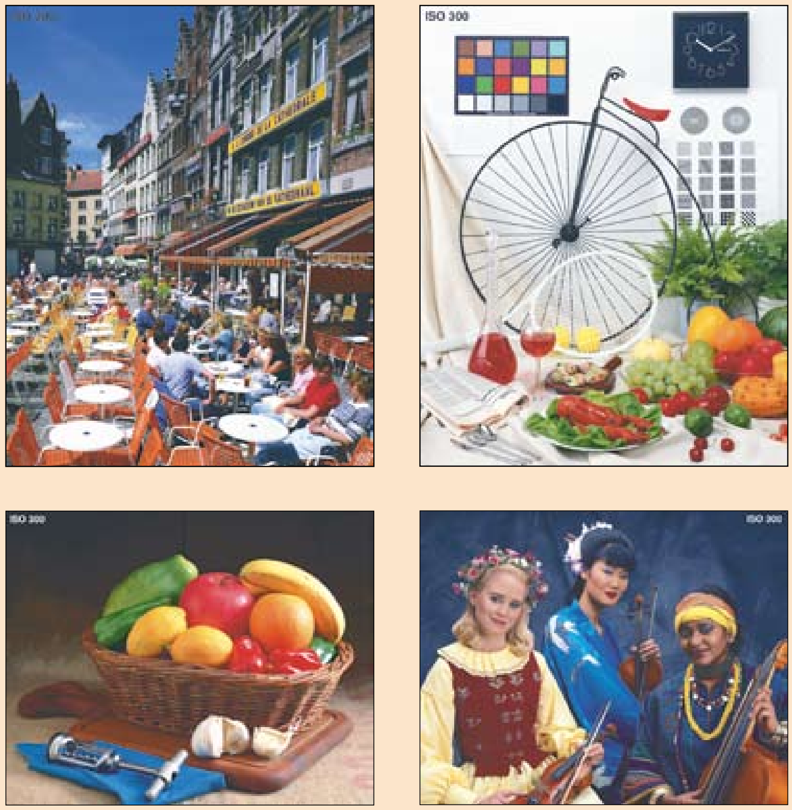
Even so the results do not mean that a formula can simply be defined to link the sharpness quality to the people's judgment.

Dijk: "I know that a similar quality scale exists for JPEG images, but JPEG images are compressed and therefore always of lower quality than the original. The question is if and how much difference is perceived? What we are looking for is an absolute quality rating of an image. Although an automatic quality scale for JPEG images is simpler, an entire research lab spent a couple of years defining the scale , which just goes to show how difficult it is."

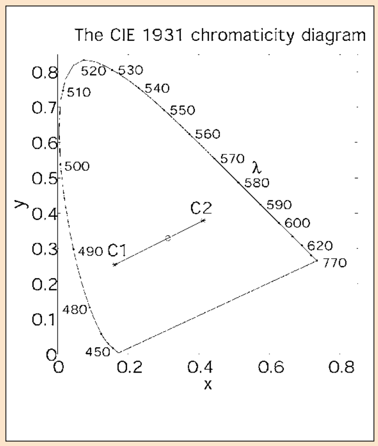
In addition, the picture content also makes it difficult to define such a scale. Even within a single picture one area can be more important than another. Dijk: "Take a portrait. If the background becomes blurred most people will not mind. However, if you blur the eyes, the effect is very annoying. It remains to be seen if and how a computer program can recognise the relevance of the various subareas."

A little more toddler's colours

The second variable the researcher focused on was colour, and in particular colour relative to changes in luminance and chromaticity. In the sharpness experiment the test subjects knew exactly what to look for (sharpness and smoothness), and the scales were set by the researchers. In the colour experiment, the images were altered according to a preset regime, but it became less easy for the subjects to define what exactly they were looking for.

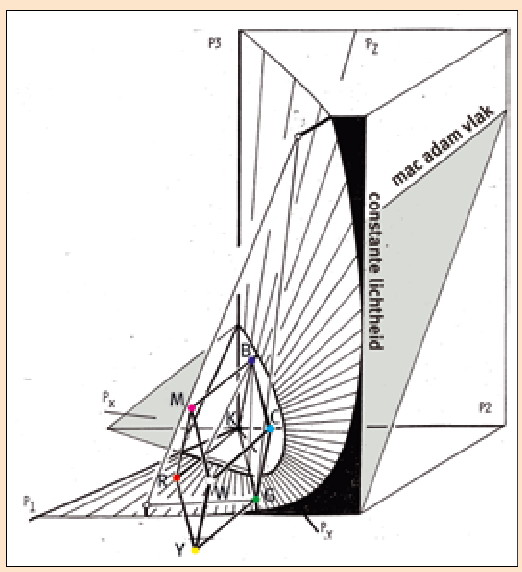


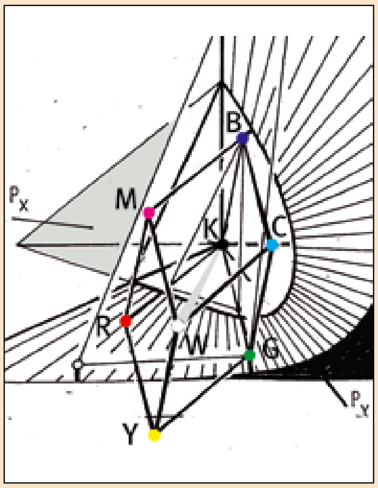
For her research, Dijk used these ISO images. Images like these are used as a standard reference in the printing industry.

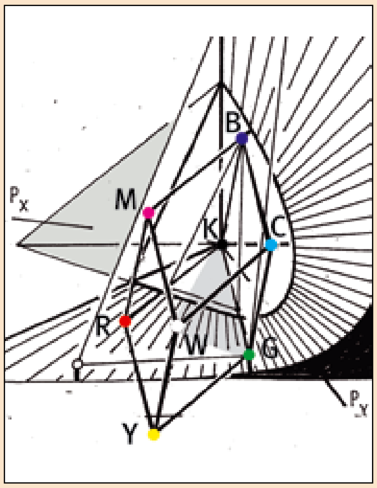


De xy colour 'triangle' as used since 1931. It does not take luminance into account. The single-wavelength xy colours are arranged along the 'horseshoe', with red at the bottom right, green at the top centre, and blue at the bottom left. An additive mixture of two xy colours, C1 and C2, corresponds with a point on the connecting line C1C2. Blue (roughly at C1) and yellow (roughly at C2, between red and green) mix to produce white (the small circle).

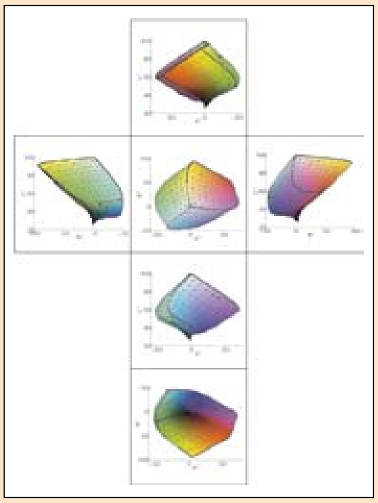
The nerve signals, which are always positive values, can be plotted along the axes P1, P2, and P3. This results in what is known as the XYZ space. The origin (K) contains black. As the luminance P1 increases, so does its cubic root, the lightness. The visible colours (not the ones we dream about) fill an oblique cone. If we intersect this cone with the angled MacAdam plane, the result is the xy colour triangle from the previous figure. Through any xy colour within the triangle, a line from K may be drawn which contains every version of the colour in increasing luminance. The coloured dots at KRGBCMYW, the corners of an oblique block, define the colour reproduction boundary of a colour computer display. The additive colour mixes filling the block comprise the full range of available colours, or gamut, of the display device. The block intersects the xy colour triangle to form a smaller triangle.



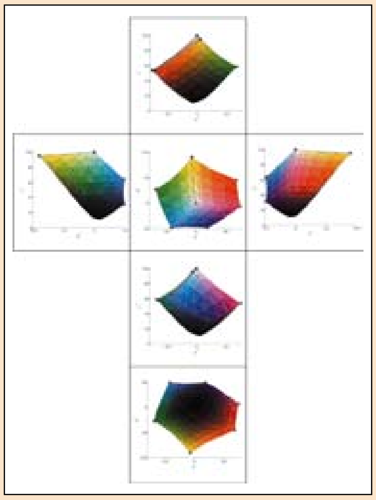




G is the point with the maximum chromaticity for green. Luminance variations are found parallel to the line KW. The plane GKW contains every chromaticity and luminance variation of colour G. Dijk calls this plane a 'flag' (with KW forming the 'flagpole'). Starting from yellow (Y), we get the flag YKW. Halfway between R and Y is orange (O). The OKW flag contains every luminance/chromaticity combination for orange (including brown).
The angle between any flag and RKW (counter-clockwise) is a measure of its colour tone.



Six views of the gamut of an inkjet printer. Due to the multiplicative colour mixing, the gamut of this type of printer is a distorted block which Dijk has succeeded in mapping after extensive measuring and calculations.



The boundary planes of the offset printing process gamut are concave.

Contrast (gamma) manipulation of the luminance at constant chromaticity in black & white and colour images. Normal practice has always been to project colours outside the gamut in colour images back onto the gamut, which dulls the colours. To prevent this happening to often, the chromaticity was first reduced by a fixed factor of 0.85.

"An image containing only greyscale values has zero chromaticity," Verbeek explains, "whereas an image containing only bright colours – I tend to call them toddler's colours – has high chromaticity. Chromaticity is a well-defined number ranging from 0 to 1. People prefer colours slightly more colourful than they really were. We like our holiday snaps to show slightly more blue in the sky, and slightly more green in the grass, than in real life. Colour film manufacturers have been using this knowledge for many years."
If we increase the lightness, the darker tones of the image are pushed together, whereas the lighter tones are pulled apart. Dijk discovered that with the setting used a change in lightness affects the perceived quality much more than a change in chromaticity does. She suspected that this is caused by the fact that manipulation of lightness does not occur in a natural environment whereas chromaticity changes do. Furthermore, changes in lightness clearly indicated an optimum value preferred by all test subjects.

Printer limitations A major difference between the image we see on a colour display and the picture produced by a colour printer is the colour range. A printer simply cannot print every colour the display can show, while on the other hand a display device may not be showing every colour a printer can produce. Generally speaking however the colour range of a display device exceeds that of a printer. Since current standard image-processing techniques do not take these limitations into account, Dijk investigated how such printer 'handicaps' might be automatically compensated.
To understand these limitations, it is important to know how colours are mixed.
"Colour mixing can be additive or multiplicative", Verbeek explains. "In a colour computer display the basic colours are red, green, and blue, and they mix additively, i.e. the individual spectra (intensity as a function of frequency) are added into a sum spectrum. In paint on the other hand, light, instead of being produced, is partly absorbed and partly reflected. The spectrum reaching the eye is the multiplication of the separate transmission spectra. In other words colour mixing is multiplicative as it is in printed matter and colour prints produced by inkjet printers."
A colour monitor uses red, green, and blue as primary colours. The human eye has three types of retinal cones (see text box), each of which can produce a nerve signal for red, green, or blue. Unfortunately, the red-sensitive are also slightly sensitive to green and blue. Researchers visualise the separate nerve colours in three dimensions (this is called the XYZ space). The result is a cube in which the point (1,1,1) represents white, and (0,0,0) represents black. The body diagonal from white to black represents the greyscale range. Other points within the cube represent all the possible nerve colour combinations of red, green, and blue. Some of these cannot be made using light. The 'pure green' nerve colour, for example, will never be seen because green light always stimulates the red cones to some extent. The colours visible to the human eye occupy a cone-shaped space, with the point of the cone in pure black.
Computer displays and printers are incapable of reproducing all these colours. "The colours produced by a computer display do not fill all of the cone, but occupy a cuboid within it," Verbeek says, "or rather, an oblique block." White and black and the primary and secondary colours occupy its corners. The primary display colours depend on the make of the display. The three-dimensional figure containing the accessible colour range is known to experts as the gamut. For multiplicative display devices such as a colour printer, the gamut is an oblique block with possibly concave boundary planes."

Less dull colours In today's colour devices certain increases in contrast would put the desired colours outside the gamut. In most cases the software will use the nearest point on the surface of the gamut. This means that increasing the contrast may cause a whole range of colour points to end up in the same gamut point. The result is that the print colours become dull. Dijk and Verbeek looked for a method that would enable them to automatically take the display device's gamut into account when increasing contrast. Each printer and each computer display has its own gamut. Printer gamuts are complicated matter. The quintessence is to calculate the amount of each colour to be used by the colour printer, based on the desired end colours in the colour print.
"Today's printer driver programs are probably the result of a long process of trial and error," Verbeek says. "The cook's secret recipe which we have no access to."

First of all Verbeek came up with a method for the relatively simpel computer display gamut, an oblique block.
"We started by restricting ourselves to greyscale operations which always act on a line parallel to the block's body diagonal running from white to black. This means that they do not affect chromaticity. In other words, these are achromatic image-processing operations. Depending on the leeway I had before running into the block's boundaries, I kept the changes smaller than I would have wanted. The smaller the distance to the gamut boundary, the smaller the changes you can make. This way all points that were neighbours before the transformation remain so afterwards."
In order to increase the leeway for the sharpening process, Verbeek introduced chromaticity changes. He replaced lines running parallel to the black-white line with lines to white and to black. The effect of this is to sharpen edges in the image by outlining them with a light/dark line of inconspicuously reduced chromaticity, an age-old painter's trick.
Next, Dijk generalised Verbeek's method for the achromatic improvement of colour images for the much more problematic printer gamut. Transformations within a concave block are much more complex than those within a cube. Dijk developed a general grey tone algorithm that modifies the lightness of the print while retaining the correct colours. In this mathematical method, the maximum and minimum lightness corrections for each pixel depend on the available space from the original point to the boundary of the gamut in a certain direction. By automatically taking into account the limitations imposed by the gamut, the colours of the printed result become less dull. The researchers have applied for a patent on this advanced luminance manipulation system that compensates for the limitations of the reproduction device. The method can be used for any reproduction device, not just colour printers.

Image quality measure

Finally, Dijk also developed an image quality measure to help select the image with the best luminance distribution from a series of images. Dijk based her measure on the homogeneity of the points within the boundaries of the available gamut. The better the distribution of the points within the boundaries of the gamut, the better the quality, or so the theory goes. She expressed the homogeneity as a number between 0 and 1. The value is 1 if the centre of gravity of all points is exactly in the centre of the gamut space. She tested the quality measure on three images, and the results were promising.
Nonetheless, the experiments all showed that the test subjects often based their quality judgment on isolated parts of an image. The standard ISO photograph of the three musicians is a good example. It shows a Caucasian, a black, and a lightly coloured, Asian musician.
Dijk: "If the entire image is made slightly darker, it improves the face of the white girl, whereas the face of the dark girl becomes obscured. Making the picture lighter produces the exact reverse effect. Neither of the changes has much effect on the colour of the Asian girl. Therefore people base their judgement either on the light girl, or on the dark girl. In order to be able to actually implement the quality chart, we must identify the relevant parts of the photograph. This shows how difficult it can be to integrate an objective quality measure in the form of a mathematical model in the driver program for a colour printer."
"But," her supervisor adds, "at least we now have a much better idea of how to go about the manipulation of sharpness, lightness and chromaticity. We have also demonstrated that the printed results are much improved by compensating for the limitations of reproduction device at the image-processing stage."

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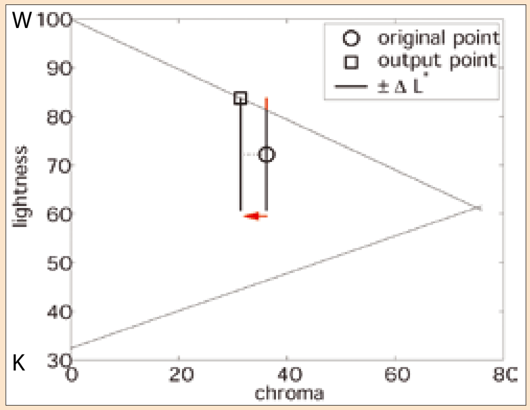
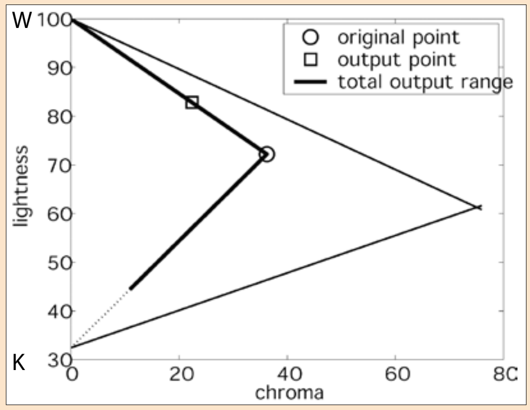
Dr. Judith Dijk now works at the TNO Physics and Electronics Laboratory (TNO-FEL), The Hague.

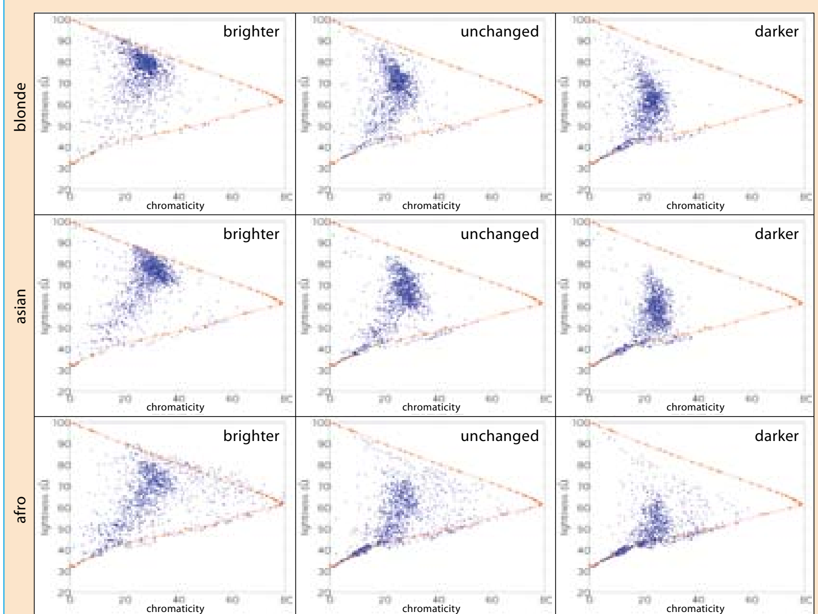




Overstepping the gamut boundaries as a result of image-processing operations can also be prevented by means of an adaptive (as opposed to fixed) reduction of chromaticity. In this operation, sharpening, lightness is more important than chromaticity. The lightness of the colour point indicated by the circle has to be increased (moving the line upwards), which brings it outside the gamut. The chromaticity is reduced (moved to the left) so that the resulting colour (indicated by the square) will remain within the gamut after setting the desired lightness .

An alternative strategy to remain within the gamut is to obtain the desired changes in lightness by mixing in white (W) or black (K).

A demonstration of the method outlined in the previous figure. On the left is the original, slightly blurred image. In the centre is the result of traditional sharpening to a level that remains within the gamut. On the right is the result of the new method, which uses adaptive reduction of chromaticity to achieve even higher levels of sharpness (look at the eyes and the corner of the mouth).

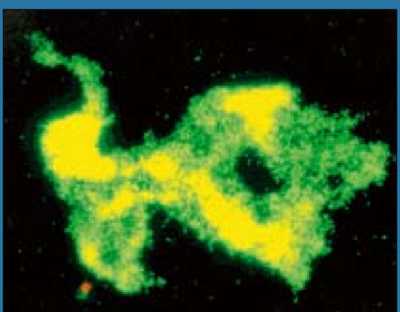


The homogeneity of the distribution (the differentiation) of colours in the pink flag (facial colouring) turns out to be a measure of the quality of portraits like the ISO image of the three musicians on page 17.

New drying method turns sludge into a useful product at a fraction of the normal cost

Hot balls dry sludge

Each year some 25 million m³ of mineral sludge are dredged from rivers, canals and harbours in the Netherlands alone, twenty percent of which is polluted. The unpolluted sludge is usually dumped at sea. The remaining five million m³ may only be dumped in a few selected landfill locations, at considerable cost.



A sludge flock, photographed at the Delft Laboratory of Fluid Mechanics. Sludge consists of a collection of small particles, including clay, fine sand, organic material, and a lot of water, and if the dredgings came from anywhere near the sea, silt. The clay particles give sludge its characteristic properties, which differ from, say, sand. The clay particles are cohesive, so when they meet they tend to stick together. The size of a flock varies from a few dozen to many hundreds of micrometers (see also Delft Outlook 2003.2).

In the late nineteen-eighties the processing of mineral sludge from soil remediation projects and dredgings was still too costly. So the Slufter, a 260 hectare basin that can hold 150 million cubic metres of sludge, was created at Europoort near Rotterdam. Each year, some 3 to 5 million tons of dredgings are added to the 50 metre deep reservoir.

BY DAP HARTMANN

Rivers, canals, harbours, domestic and industrial water treatment plants, factories. They ar e all sources of sludge. Each year 25 million tons of sludge are produced in the Netherlands alone. Five million tons of this sludge are polluted and cannot be dumped without further treatment. Processing all this sludge is a costly business and drying constitutes a major part of the process.
Guus van Gemert, a doctorate student in the faculty of Applied Earth Sciences, is currently testing the Delta Dryer, a revolutionary sludge dryer developed at TU Delft. The immense device moves 125 tons of hot steel balls around every hour, in the process turning two tons of dredging sludge into 1000 kilos of dry granules and a cubic metre of water, all at a quarter of the current cost of drying sludge.

At Stevin I, one of the large laboratories of the subfaculty of Civil Engineering that also houses long-term structural timber tests, a large test rig of the subfaculty of Applied Earth Sciences has found a temporary home. The reason for the presence of this stranger in the home of civil engineering testing is that it is simply too large to be accommodated in any of the Applied Earth Sciences facilities. The device, a sludge dryer designed at TU Delft, is the subject of a Ph.D. research assignment of Guus van Gemert. After graduating in Materials Science, in March 2002 Van Gemert started his research on the Delta Dryer, a project for which he appears to be ideally suited.
Van Gemert: “What I like best about it is the combination of laboratory work, design and hands-on mechanics. I am not the kind of person who can sit at his desk all day working on a computer. Fortunately, my research offers plenty of variety. First of all, my job is to get the Delta Dryer up and running. It should have been operational a couple of months ago but due to technical glitches we are now behind schedule. Once I’ve got it working I can start carrying out measurements on the machine in operation and collect data that I can use to refine the computer simulation model. Finally, I want to determine the relevant sludge properties so we can use them as the basis for predicting the behaviour of the Delta Dryer.”
Van Gemert likes variety and does not shirk his work. Today may find him dressed in a dirty pair of jeans adjusting a set of flange bolts with a no. 52 ring

spanner, tomorrow he might be in the lab studying the rheology of a sludge sample. Because there's more to sludge than meets the eye. For example, Van Gemert has measured its hygroscopic properties (i.e. the fraction of water that is bound to the sludge solids) as well as its heat-transfer kinetics (how does the transport of heat progress from the balls through the sludge to the outside world).

Bedlam Initially, the move to the large Civil Engineering laboratory went without a hitch. The company of Van Tongeren Kennemer delivered two of its giant Spaans screw conveyor and Stramproy machine builders supplied the other components. Bolting everything together resulted in an impressive test rig measuring 12 metres in length and 8 metres in height with a real catwalk and its own access ladder. But when the machine was switched on for the first time all hell broke loose. The noise of tens of thousands of balls (the kind you find in ball-bearings) crashing against steel pipes is unimaginable. And that is precisely what the other people working in the building thought. The protests became so loud that a rule was introduced forbidding the testing of the Delta Dryer with balls before 5.30 p.m. The complaints are justified of course, but they don't make the work any easier.

Radioactive waste Steel balls are a perfect medium for transferring heat. In 1985 three Japanese researchers had already come up with the idea of using hot, steel balls to dry sludge (or radioactive waste in their case). They applied for and received a patent for the idea, but their invention solves only half the problem. The question remains of what to do with the water that evaporates from the sludge? Just carrying off the vapour wastes a lot of energy, which is why the Japanese patent never grew into a commercial application.
A method called multiple-stage flash evaporation is often used to extract drinking water from sea water. Sea water is heated until the water evaporates (the salt remains) and the water vapour is then turned into condensate. The heat produced by the condensation process is then reused very efficiently. The best way of doing this is by reducing the pressure in a number of stages. The technology is used on a large scale commercially.
Dr. Peter Rem, lecturer and researcher in the Raw Materials Technology section of the Applied Earth Sciences subfaculty, combined the two technologies and designed the Delta Dryer (Delta stands for DELft Technische Aardwetenschappen, the Dutch name of the subfaculty). The project came about as a result of an enquiry from Aldert van der Kooij of DHV Consultants who wanted to know whether a more efficient method could be devised for drying sludge. The initiative recently earned him the Public's Choice Award at the Engineer of the Year awards ceremony. The real prize though is the Delta Dryer itself.

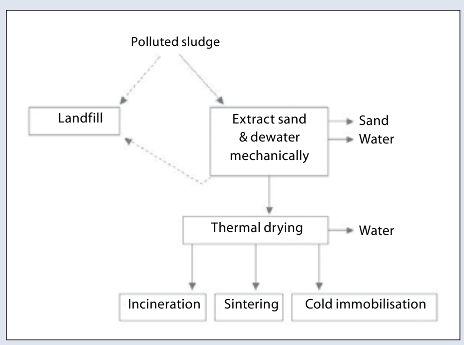
Dredging The Delta Dryer was initially developed to dry dredgings. The Netherlands have a long tradition of dredging and lead the world in dredging technology. Small wonder, since the country itself has had a dredging problem for many centuries. Its waterways, the lifeblood of its economy, keep silting up and the only remedy is to physically remove the sludge. Each year 25 million m³ of sludge is dredged in the Netherlands, some 20% of which is polluted in one way or another. That instantly creates a new problem: where to put the stuff? Unpolluted sludge is usually dumped at sea but this cannot be done with the polluted portion. Since processing dredgings is a very costly affair enormous depots were built to store the sludge. In the late nineteen eighties, the Slufter, a 260 hectare hole 50 metres deep was excavated in the Maasvlakte area to the west of Rotterdam and sludge has been pouring into it ever since. The original idea was to use the facility to store polluted sludge from the direct vicinity of the port of Rotterdam. Some years ago the depot was opened up for polluted sludge from other regions. Three to five million tons of polluted sludge goes into it each year. With a total capacity of 150 million cubic metres the Slufter will be filled in another 10 to 15 years. Of course, one could simply dig another hole and repeat the process, but a much better idea is to process the sludge into building materials. For all possible processing routes, water had to be removed first, which until now was too expensive a process, costing about one euro for every percent of water removed from a ton of sludge. With the Delta Dryer sludge can be dried at acceptable prices; some estimates say less than € 0.30 for each percent of water per ton.

Sludge depot in Amsterdam for dredgings from harbours and small waterways.

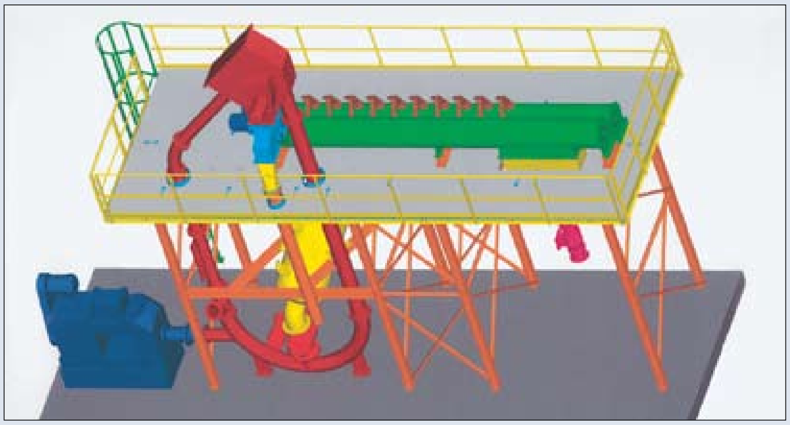
The treatment of waste water produces a continuous flow of organic sludge. In 2001 all 635 waste water treatment plants in the Netherlands together produced 187 million kilograms of dried sludge. In the same year the 389 Dutch sewage treatment plants produced 345 million kilograms of dried sludge. In addition, 166 million kilograms of dried sludge were produced by various industrial waste water treatment plants.

Once the organic sludge has been extracted from the waste water it is mechanically dewatered until it contains approximately 25% dry matter. Until a few years ago the sludge could still be spread on land, but these days local authorities also face steep disposal costs. Today most of the organic waste is incinerated. The remainder is either dumped in landfills or composted (see also http://www.rivm.nl/milieuennatuurcompendium/nl/i-nl-0154-04 .html).

Close-up view of dried mineral sludge from Urk harbour. The sand was removed from the sludge, which was then mechanically dried. The dry matter content is 50 percent.



Process diagram showing sludge processing options.
The Applied Earth Sciences faculty developed the Delta Dryer to make thermal drying much cheaper and more efficient.



CAD drawing of the Delta Dryer test rig, a thermal dryer 8 metres high and 12 metres long, based on an idea of researcher Dr. Peter Rem.

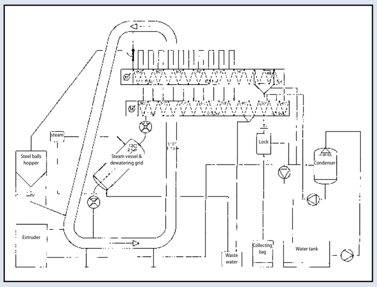
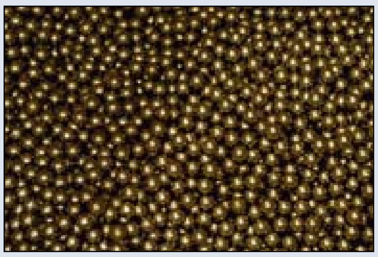


Diagram showing the operating principle of the thermal dryer. The hot steel balls take about 2.5 minutes to go around the machine once.

The test rig has found a temporary home at the Stevin I Laboratory of the Civil Engineering subfaculty. The semi-dried sludge from Urk harbour is delivered in big bags. An extruder then squeezes it into the installation like a big sausage.



The steel balls, which were bought from the factory, are 12 millimetres in diameter.

On the left the sludge sausage is pushed into the elevator where a chain fitted with discs takes over the transport. In the diagonally suspended steam vessel the balls are heated up to approximately 120 °C under a pressure of 2 bar. At the lower end of the vessel the balls pass through a lock to be added to the sludge in the elevator.

The powerful electric motor of the elevator drives a chain fitted with discs that transports the mixture of balls and sludge upwards through a pipe. In this way, 35 kilograms of material is moved through the machine every second, with 99% of the weight being accounted for by the steel balls. Even so, the 1% of sludge is good for production of 1000 kilograms of dried end product per hour.

With the inspection cover of the elevator removed the chain and discs are clearly visible. The diameter of the discs is a few centimetres less than that of the pipe so a large proportion of the balls will continuously fall down through the pipe. The turbulent behaviour of the balls ensures that they mix well with the sludge and so can transfer as much heat as possible.

Vapour bridges

Essentially, the Delta Dryer pumps steel balls around in a continuous process. The fact that sludge is added to the balls is neither here nor there to the machine. At the lower end of the machine, superheated steam is used to heat up the 12 mm diameter balls to about 120 °C. Using spin dryers and band filter presses, the sludge has already been mechanically dewetered as well as is possible up to about 50% dry solids. In this state the material, which has the consistency of potting soil, is fed into an extruder that squeezes it into the machine in the form of a 20 cm thick sausage to join the hot balls. A massive chain with horizontal steel discs attached to it drags the sludge/balls mixture upwards through a pipe. The pipe of this elevator is completely filled with balls. Since the discs are slightly smaller than the diameter of the pipe balls are continuously raining down. This avalanche of steel balls ensures that they mix well with the sludge. The temperature of the mixture at this point is approximately 100°C. The elevator acts as a buffer to ensure a constant supply of balls. At the top of the pipe, the sludge/ball-bearing mixture is fed into a seven-metre-long horizontal screw conveyor with a diameter of 50 cm that revolves once every two seconds. The tolerance between the screw and its wall is only a few millimetres. What the screw does is to divide the mass of steel balls into separate compartments. The heat of the balls causes the water to evaporate from the sludge. The water vapour is then extracted through vapour bridges, ten of which have been fitted to the top of the screw conveyor along its length.

At the end of the screw conveyor the temperature has dropped to about 60°C. Any remaining water vapour is trapped by a condenser. The dredgings have now been dried and are encrusted on the balls. A grid of steel rods cleans the dried sludge from the ball-bearings and the dry sludge granules then drop through an airlock (the entire process takes place in a low-pressure environment) into a large collection bag. The balls are rinsed clean and then enter a second screw conveyor mounted parallel to the first one and running in the opposite direction. The screws are interconnected through the vapour bridges. The sludge vapour condenses onto the balls to reheat them. When they reach the end of the return screw the balls have reached a temperature of 90 °C. They then drop through a lock onto a grid to shake off the condensate. At this point the superheated steam raises the temperature of the balls to 120°C, completing the cycle. This is the great strength of the Delta Dryer: it uses a continuous process, with sludge entering the machine at one end and water and dry granules leaving it at the other. The Delta Dryer moves around 35 kilograms every second, 99% of which is accounted for by the steel balls, so in fact the machine moves practically nothing but balls. All they do is pick up some dirt en route in the form of dredgings, which gets dried and removed. Another benefit of the closed system is that there is no escaping gas or smell, which eliminates its need for a large air treatment unit. The end product consists of granules that contain less than 10% water and can be sintered into a basalt-like material suitable for applications such as road construction foundations.

It was Dr. Rem who came up with the principle of the Delta Dryer, calculated the vapour pressures, energy flows and other parameters, and developed the machine on paper. Some of the sub-processes could not be tested in the laboratory, however. It was impossible to build a scaled-down version of the Delta Dryer because some properties do not lend themselves to scaling. For example, the compartments in a screw conveyor need to be full sized in order to achieve sufficient separation to maintain the required pressure gradient along the length of the screw. On a smaller scale the loss of pressure would be too great and the process would cease to work. It goes without saying that a full-scale machine is a costly affair, but thanks to funding by Senter (part of the Dutch Ministry of Economic Affairs), and the willingness of Van Tongeren Kennemer (who manufacture the Spaans screw conveyors) and Stramproy Contracting (responsible for the other components and the assembly) to supply at cost price, the full-size prototype was built. In exchange, Van Tongeren Kennemer and Stramproy have been granted the exclusive right to supply all future Delta Dryers for the next two years on commercial terms. A percentage of the revenues will be returned to TU Delft, so everybody will be happy. It could well become a lucrative business, for in addition to dredgings, the Delta Dryer will soon be able to dry other types of sludge as well, including sewage sludge, paper sludge and sludge produced during soil remediation. The machine might also be suitable for use in the food-processing industry, although in that case a stainless steel version will probably have to be built.

Valuable data It is a slow process, but each week brings the project closer to completion. The current prototype of the Delta Dryer is capable of moving the balls around without problems. The steam and low-pressure processes have also been tested. The drying process will soon be tested using just water, and then artificial sludge will be tried. Each time the process will move a small step forward until finally the machine will be fed real dredgings. That is when Guus van Gemert will start collecting valuable data. The machine has been temporarily fitted with pressure gauges, flow meters and thermocouples to measure a range of essential variables at a number of different points in the screw conveyors. The collected data will provide insight into the leakage flows between the various compartments, and into the way the pressure, moisture content and temperature vary. Armed with the data, Van Gemert will then optimise the computer model simulating the Delta Dryer. Once the properties of a type of sludge are known in advance the model can be used to make useful predictions about the behaviour of the real machine. The assembly of the Delta Dryer caused a few problems.

Van Gemert: “This is not what you would call a ‘plug and play’ machine. The various components have all been separately tested, modified and approved, but put them together and you are in for a few surprises. Which is only to be expected with steel parts moving all those balls around. It only takes one in every million balls to go the wrong way to cause a serious problem. The screw conveyors are now working well, but in the early days they would seize on balls caught between the screw and the conveyor tube. The noise was terrible. For the same reason the locks have been tested, taken apart and improved a number of times. The chain elevator transporting the steel balls to the top of the machine also caused a few problems. The elevator was produced in Germany according to our specifications. It worked perfectly at the factory, but then someone decided it could do with some ‘improvement’, with the result that the chain has already come off the drive sprocket four times. Each time we had to call in people from Germany to repair it.”

All these things held up the process even more, not just because the mechanics had to come from 500 kilometres away, but also because of the noise problems mentioned earlier. The mechanics would work evenings to solve the problems but then had to wait till the next morning before they could consult their company, only to have to wait until the evening again before they could continue their work. Following a similar completion stage, in which the installation was made airtight, the steam supply has been connected and the research part of the project can begin.

Glue phase Van Gemert is confident that the machine will eventually dry dredging sludge without any problems. “When you extract water from sludge, at some point you enter what is known as the glue phase, when the sludge becomes extremely sticky and would normally end up in a single big lump. Because our mixture contains 99% steel balls, however, the properties of the ball-bearings outweigh those of the sludge. Consequently, the balls will not really be bothered by the glue phase of the sludge. I do not expect any problems with that.”

The unique combination of two proven technologies will result in a sludge dryer that uses far less energy than traditional methods. The difference is due to the fact that the energy is reused very efficiently. The energy cost is only € 10.00 per ton of extracted water, which is about a quarter of what conventional thermal dryers consume. The capacity of the prototype is two tons per hour. This means that 1000 litres of water are removed from 2000 kilograms of dredgings every hour, leaving 1000 kilograms of dry granules. The current machine includes no facility to use the heat from the waste water, but future Delta Dryers will probably be able to recover energy from the hot water.

A buyer has also been found for the prototype. If everything goes according to plan, Deutsche Steinkohle AG (DSK) will be using the Delta Dryer to dry coal sludge from the middle of 2005. Coal mining produces a lot of stone dust. Although it can be separated rather well from the fine fraction of coal by means of flotation, a wet coal slurry is formed in the process. The Delta Dryer will be used to process the waste flow into a useful product.

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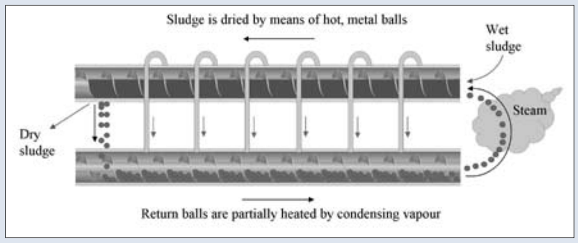
From the elevator the mixture of steel balls and sludge enters the upper of a pair of screw conveyors. During the one minute it takes to pass the mixture through the 7-metre long conveyor the sludge gradually dries. At the end of the screw conveyor the dry sludge is removed from the balls and is fed though a pressure lock into big collecting bags waiting below the test installation. The balls then pass into the second screw conveyor to be returned to the steam vessel.



Schematic diagram of the heat recovery process. Packets of the hot balls/sludge mixture are transported to the left in the upper screw conveyor and release water vapour in the process. As the mixture passes the vapour bridges, the water vapour escapes to packets in the opposing lower conveyor containing colder balls on their return journey. As the vapour condenses onto the returning balls, these are heated in stages to a temperature of 90 °C.

At the end of the first screw conveyor, before the point where the sludge and the balls are separated from each other, the excess vapour is fed into a large condenser. The condensate it produces is then used to wash the steel balls.

Due to the low pressure in the machine the sludge granules have to pass a pressure lock before they can be collected in big bags.

After leaving the second screw conveyor, the preheated balls pass through a pressure lock and enter the steam vessel. At a pressure of 2 bar, the steam raises the temperature of the balls to 120 °C, completing the cycle.

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