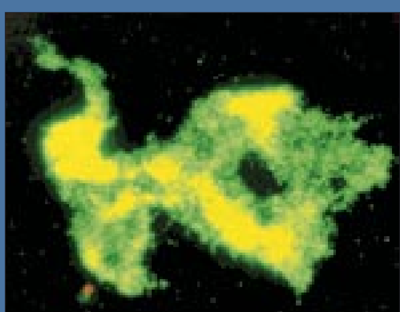
New drying method turns sludge into a useful product at a fraction of the normal cost

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.

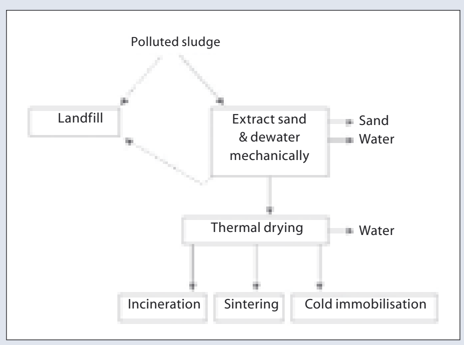
Dredging The Delta Dryer was initially developed to dry dredgings. The Netherlands have a long tradition of dredging and lead the world in dredging technology. Small wonder, since the country itself has had a dredging problem for many centuries. Its waterways, the lifeblood of its economy, keep silting 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.

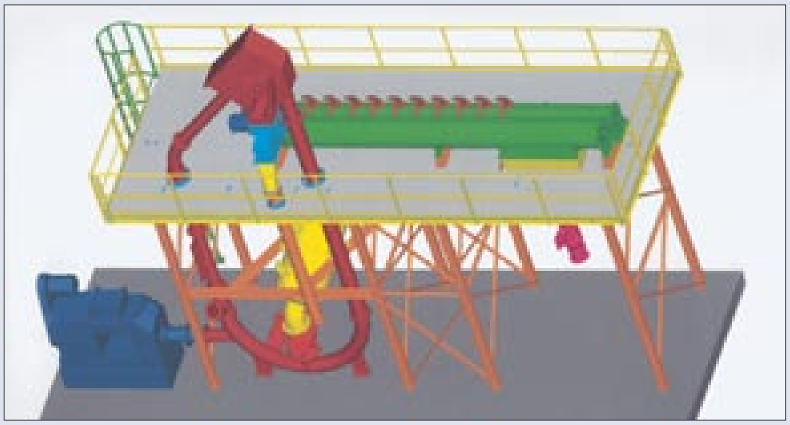
The treatment of waste water produces a continuous flow of organic sludge. In 2001 all 635 waste water treatment plants in the Netherlands together produced 187 million kilograms of dried sludge. In the same year the 389 Dutch sewage treatment plants produced 345 million kilograms of dried sludge. In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

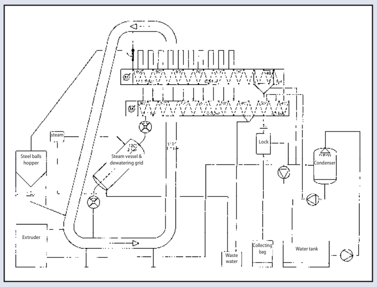
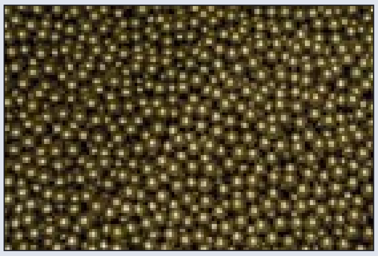
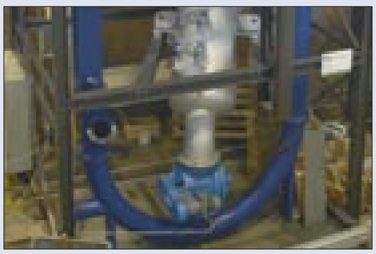


Diagram showing the operating principle of the thermal dryer. The hot steel balls take about 2.5 minutes to go around the machine once.

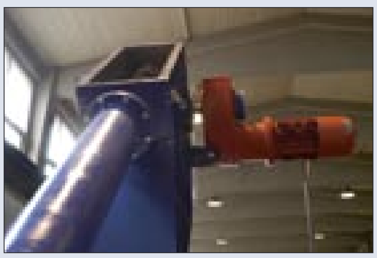
The test rig has found a temporary home at the Stevin I Laboratory of the Civil Engineering subfaculty. The semi-dried sludge from Urk harbour is delivered in big bags. An extruder then squeezes it into the installation like a big sausage.



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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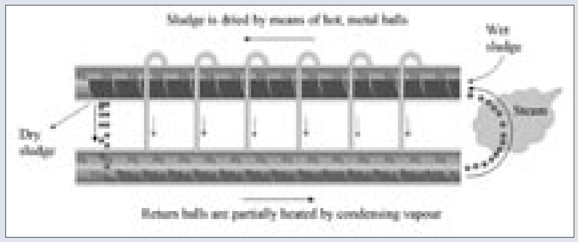
From the elevator the mixture of steel balls and sludge enters the upper of a pair of screw conveyors. During the one minute it takes to pass the mixture through the 7-metre long conveyor the sludge gradually dries. At the end of the screw conveyor the dry sludge is removed from the balls and is fed 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.