THE DELTA DRYER IN PRACTISE
PERFORMANCE OF A NOVEL, ENERGY-EFFICIENT DRYER FOR SLUDGE

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Abstract:

Thermal treatment of the fines fraction of contaminated dredging sludge is an attractive way to permanently destroy or immobilize the organic and inorganic contaminants. An important step prior to the actual process is to dry the mechanically dewatered sludge residue, which unfortunately costs a lot of energy. Within a project sponsored by Senter, Delft University of Technology and DHV developed a more cost-effective technique that uses vacuum drying to reduce off-gas and recycle part of the heat of evaporation. On the basis of promising results from computer simulations, a full-scale prototype was designed, and subsequently built by the Dutch engineering factories Van Tongeren Kennemer and Stramproy Contracting. This prototype has been tested, adapted, improved, and fitted with various sensors. At the moment process data are being collected for different sludge types.

Introduction

Yearly, huge amounts of sludges are formed in water purification, soil cleaning, dredging activities, mining and many other industrial processes. Since considerable parts of these sludges are contaminated, storage requires large areas and is therefore problematic. The Dutch national policy, based on public and political awareness of this problem, is to discourage disposal and to stimulate further treatment. The treatments involve destruction or immobilisation of the contaminants and, in most cases, yield a useful product that can be applied as a building material or for the production of green energy. [1,2]

An important step prior to the actual treatment processes is to dry the sludge to approximately 90% dry solids. As mechanical techniques are capable of dewatering to a maximum of only 20-50% dry solids, the utilization of thermal drying techniques is unavoidable. These techniques unfortunately, are very energy consuming and expensive. In order to make the treatment of sludge more attractive, the department of Applied Earth Sciences of the Delft University of Technology and DHV Environment and Infrastructure worked together and formulated ideas for a new drying technique. The resulting concept, called Delta dryer, has internationally been patented [3].

In a project subsidized by Senter (agency of the Dutch ministry of economic affairs) the Delta dryer concept and accompanying technology are being developed further. Up to now, fundamental research and laboratory experiments have been done, resulting in a detailed description of the processes inside the dryer. Based on this physical model simulation software has been written, which enables the user to simulate the drying behaviour of all kinds of sludge types and investigate influences of design specifications and process parameters. Encouraged by the promising simulation results (with simulated energy consumptions far less than existing drying techniques) DHV and the University of Delft have started cooperating with Van Tongeren Kennemer and Stramproy Contracting with the aim to design and construct a full-scale prototype installation. This research prototype has been finished, has been equipped with various sensors, and is presently being tested and optimised. Newly gained insights will be used to define the Delta dryer’s final configuration, adapt the physical model to real life circumstances, and enter the next phase towards commercialisation.

Drying as Part of Sludge Treatment

Figure 1 shows different processing routes for contaminated sludge. The first step usually consists of sand separation by means of hydrocyclone or sedimentation processes, followed by a mechanical dewatering stage of the residual fines fraction. Whereas the sand is often clean and useful for civil engineering projects, the dewatered cake is still contaminated at this point. The cake can of course be disposed in a landfill. However, this is not the most attractive option since it occupies large sites that must be monitored and maintained for indefinitely long times. The better alternative is to thermally dry the mechanically dewatered cake. For mineral sludges, the next (and last) treatment step involves a process of sintering or cold immobilization. During sintering the contaminants are partly evaporated, destroyed and enclosed into a hard granular product or bricks. Cold immobilization means that the dried cake is mixed with cement, which chemically binds some of the contaminants and locks up other substances from the outside. In either case, the end

product can be sold as a building material [4]. For sludge types with a high organic content, the thermal drying treatment is also beneficial as it increases the calorific value and makes the cake more suitable as a fuel in power plants.
Unfortunately, the high energy consumption of the thermal drying step contributes significantly to the total costs of sludge treatment. According to TNO/KEA-consult, at least 3-6MJ is needed to remove 1kg of water with presently available drying techniques.

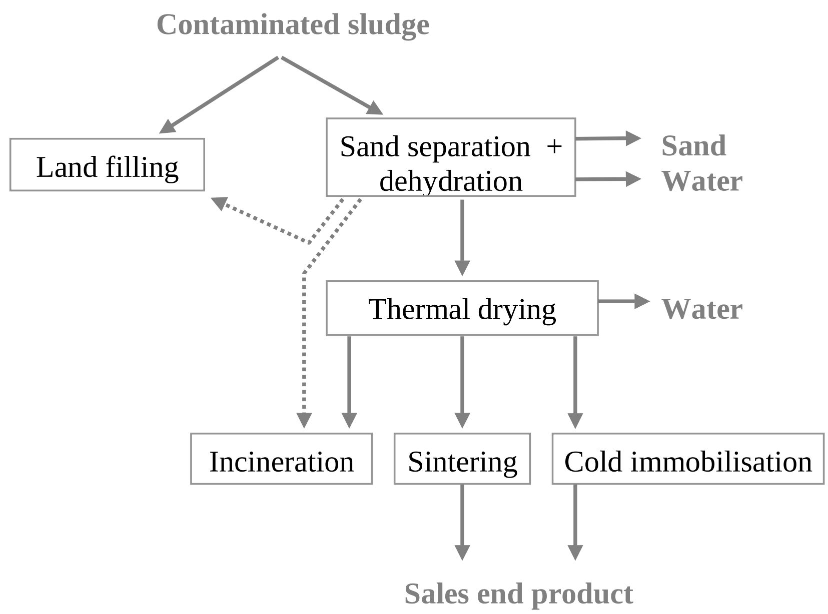

Figure 1: Different processing routes for contaminated sludge.

The Delta Dryer Concept

A major cost reduction for the thermal drying step is conceivable as existing drying concepts still show enough room for improvements. Most dryers, for example, use more energy than is actually needed to evaporate the water from the sludge. In addition, some of them use air to carry away the water vapour, which necessitates a large air cleaning installation in order to separate the volatiles, odours and fine dust that are carried away as well. Finally, several dryers are susceptible to the way in which the sludge transforms from a pumpable material, through a sticking phase into a solid. In that case, extensive mixing of sludges from different sources is often required to achieve constant characteristics of the input material.

The Delta dryer concept was developed with the aim to overcome the disadvantages of existing dryers. It has resulted in an installation in which the sludge is mixed with hot, steel balls and dried in a vacuum atmosphere. The steel balls will enhance the transfer of heat to the sludge, and make sure that the flow behaviour of the total mixture doesn't change much when the sludge passes through the sticking phase. The absence of air avoids the problem of air cleaning and allows for drying to very low end temperatures, e.g. 40°C to 50°C, so that the dried product is released with little smell and without the risk of spontaneous combustion. Moreover, the vacuum gives the opportunity to recycle part of the heat of evaporation by making the vapour condense on a heat exchanger.

The thermodynamics of the Delta drying process can be compared to the production of fresh water out of salt water by means of multiple stage flash evaporation. Figure 2 schematically shows the main parts of the installation and explains how the process works. First, the wet cake is brought into the installation and mixed with hot, metal balls. The mixture is fed into a screw conveyer, where it occupies only half of the volume of the pitches, dividing itself into alternating packages of solids and vapour. During their transport, these packages gradually dry up and cool off, as the sludge water evaporates into steam and escapes through vapour bridges. At the end of the screw conveyer a condenser and vacuum pump get rid of remaining sludge water and small amounts of air, after which the dried cake is separated from the balls and removed from the system. The balls are put into a second screw conveyor and transported back to the start of the process. As this second conveyor is connected to the first conveyor via vapour bridges, the return balls are now step-by-step reheated using steam that was formed in the first conveyer. Because of this efficient reuse of the heat of evaporation, only a small additional heating stage is needed before the balls are hot enough to be mixed again with wet sludge.

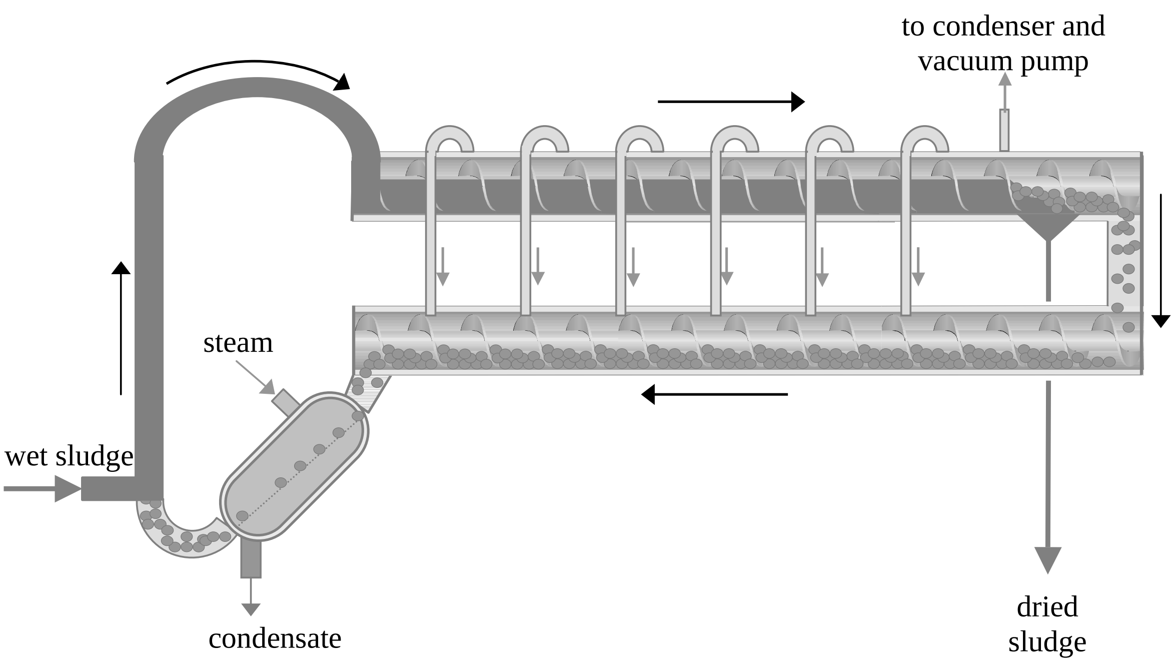

Figure 2: Schematic representation of the Delta dryer, showing a closed circuit of metal balls. At the left side the balls are mixed with wet sludge. In the upper conveyor the mixture dries up and cools off, whereas cooler return balls are stepwise reheated by sludge vapour in the lower conveyor. At the end of the lower conveyor the partially reheated balls are fed into steam vessel.

Full-Scale Prototype

According to simulation results with realistic input data, the Delta dryer should be able to consume only 1-2 MJ per kg of evaporated sludge water, which is a lot less than the 3-6MJ in standard thermal dryers. A full-scale research prototype has been built, to prove that these energy consumptions are also feasible in practise. Figure 3 shows a photograph of the installation.

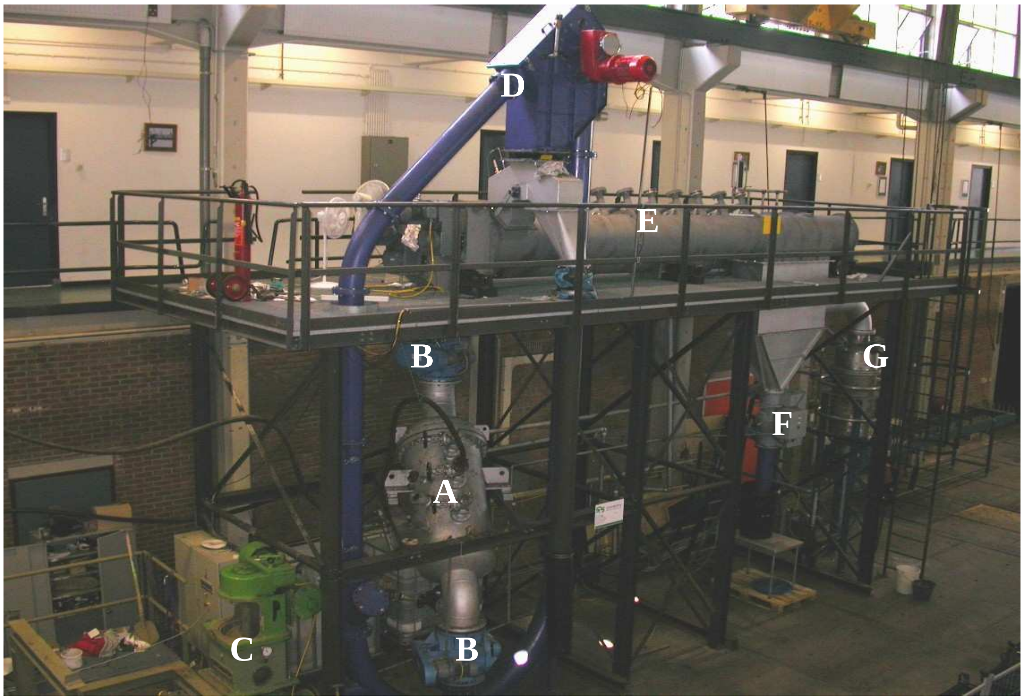

Figure 3: The prototype consists of a steam vessel (A), two rotary sluices (B), an extruder (C), an elevator (tube chain conveyor) (D), two screw conveyors (E), a vacuum sluice (F), a condenser (G), a vacuum pump, and a water pump. Except from the screw conveyors, these are all more or less standard components.

The prototype has a theoretical capacity of 2 tons of sludge per hour (approximately 50% dry solids) and moves around 125 tons/h of metal balls in a closed vacuum circuit. These balls are heated in a steam vessel to a temperature of 120°C. At the same time, their rolling movement over a sloping dewatering screen creates a large centrifugal force that is sufficient to reduce the condensed water film to an acceptable thickness. After passing a rotary sluice and entering the bottom part of the elevator, the hot balls meet the wet sludge that is pressed into the installation by a clay extruder. The elevator brings the sludge and metal balls up to a screw conveyor and creates a turbulence in which the balls and sludge extensively mix.

Inside the conveyor a high water vapour pressure causes the sludge water to evaporate into steam. The vapour is carried away through vapour bridges and (partly) to a spray condenser, allowing the mixture to dry up and cool off while it is being transported. At the end of the conveyor the dried sludge (now 90% dry solids at ~50°C) is removed from the balls by a rotating grid and carried away via a sluice system to big bags. The balls are washed with sprinkler water and brought back to the steam vessel by means of a second conveyor. This second conveyor is positioned perpendicular to the first conveyor and connected to the other ends of the vapour bridges. Consequently, the hot sludge compartments are repeatedly brought into contact with facing colder compartments, allowing the sludge vapour to flow through the vapour bridges, condensate, and reheat the return balls. Then, the partially reheated balls pass a second rotary sluice and enter the steam vessel again.

Major influences on the Performance of the Prototype

In the ideal situation, the compartments of both conveyors are well isolated from each other, while every flash of the multiple stage evaporation process brings two facing compartments to perfect thermodynamic equilibrium. Having a fair number of vapour bridges and no leaks to the outside (except from the input of cold sludge and output of warm, dried material), such a hypothetical dryer would easily consume less than 0,5MJ per kg of removed water. And of this 0,5MJ only a fraction is actually needed to disappear into a heat sink (condenser) to keep the drying process going.

In practice however, the drying process will never reach such high efficiencies for several reasons. First of all, the porous balls beds and the gap between the screw blades and the conveyor hull allow vapour to escape in longitudinal direction of the conveyors. This does not only reduce the effective number of vapour bridges, but also generates an unnecessary large heat leak towards the condenser and vacuum pump. Previous simulation results [5] have shown that it really helps to place a brush on top of the screw blades and obstruct these leaks. Those tricks however have not been implemented in the prototype (yet). For similar reasons of simplicity, the prototype uses standard rotary sluices to bring the balls from the steam vessel to the elevator and vice versa. As a result some steam will leak through the rotary sluices, condensate onto the wet sludge in the elevator, and waste energy.

The efficiency of a flash stage also depends on the pressure difference between two facing screw compartments. Normally, vapour pressure differences are the logical consequence of temperature differences. But if the sludge has been dried substantially, this is not always the case. According to literature [6] and laboratory experiments, the hygroscopic nature of partially dried sludge can make local vapour pressures drop well below the equilibrium vapour pressure at that temperature. This effect particularly occurs at the last vapour bridges where, unfortunately, temperatures are relatively low and pressure gradients per unit of temperature drop are already smallest. That’s why the last vapour bridges will in practise contribute only very little to the efficiency of the prototype installation.

Furthermore, the presence of vapour pressure differences on itself is neither a guarantee for vapour transport. Serious accumulation of non-condensing gasses can level out the overall pressure gradients and stop the drying process. For this reason, air leaks into the installation are kept as small as possible. At the input side, the clay extruder acts as a seal between the open air and the vapour atmosphere inside the installation, whereas the output of dried sludge goes via a vacuum sluice. Air that has yet managed to leak into the system and gasses that are formed during the drying stages are collected at the point of lowest pressure (i.e. the condenser) and removed by a vacuum pump.

Finally, the process efficiency of a flash stage will never reach the highest level, because in practice, it just takes to much time for two facing compartments to reach thermodynamic equilibrium. Several heat resistances will evoke temperature gradients between the compartments; especially when the sludge has already been dried partially and broken away from the balls. Keeping the drying rate at an acceptably high level automatically implies that temperature gradients become higher, less heat is reused, and energy consumption increases. On the other hand, just lowering the capacity does not necessarily benefit the efficiency of the prototype either, since it increases the vapour and heat leaks per unit of dried material.

Test Program and Present Situation

Several tests on the individual components were carried out in the design phase of the prototype installation. Problems regarding the input of wet sludge were taken care of, the dewatering behaviour of rolling balls was verified, and the removal of dried sludge from the balls was examined. In the assembled state the components together revealed new problems. Many leaks had to be sealed to make the machine sufficiently airtight. And several adjustments appeared necessary in order to streamline the balls transport through the installation and minimise the risk of ball accumulation or jamming in the moving parts.

More recently, the installation has been insulated and a steam unit has been coupled to the steam vessel, initiating a new test program. The experiments of this test program focus on the thermal performance of the prototype and usually start with the removal of air from the installation by means of steam injection. Then, the balls are transported through the installation and heated as they pass the steam vessel. The condenser and vacuum pump are switched on, and the process control parameters are tuned in order to achieve adequate drying conditions. Presently, the activities emphasize on drying just ordinary water, which is being sprayed onto the hot balls at the top of the elevator. This is for practical reasons. Soon, a simple, artificial sludge will replace the water, after which standard sludge types like dredging sludge, coal sludge and sewage sludge will be dried.

As part of the investigations, the conditions inside the dryer are monitored with sensors. A V-cone flow meter with ultra-low response time measures and calculates vapour mass flows through the vapour bridges. Thermometers and thermocouples have strategically been placed in output streams, and several pressure transmitters are to reveal the pressure gradients in length direction of the conveyors. Initially, the gathered information is applied to support process control. In a later stage, the acquired data will be coupled to simulation results and will help adapting the simulation model to real life. This improved simulation model will then be able to carefully predict influences of design specifications, sludge properties and control parameters on the performance of the Delta dryer.

Conclusion

As the thermal drying step contributes significantly to the total costs of sludge treatment, new, enhanced dryers should be simple, consume less energy, and bring less volatiles to the air than existing techniques. The Delta dryer concept meets these requirements by mixing the sludge with metal balls in a vacuum atmosphere and by recycling part of the heat of evaporation. According to laboratory tests and simulation results, energy consumptions will lie in between 1 and 2 MJ per kg of evaporated sludge water. The exact value depends on the magnitude of vapour and air leaks, on the hygroscopic nature of the sludge, and on the rate at which heat and vapour migrate through the sludge.

To investigate the practical feasibility of the concept, a full-scale research prototype has been built and put into use. At the moment this prototype is extensively being tested. Despite some delay, clear progress is being made, and first drying experiments will be completed soon. After that, the research program will concentrate on the processing of various sludge types, including dredging sludge, paper sludge, coal sludge and sewage sludge. A future pilot operation plant has been planned in order to investigate the installation's reliability and wear resistance, as well as possibilities for further improvements.

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