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Characterization of sludges — Good practice for sludges drying

ICS 13.030.20

British Standards

National foreword

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This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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TECHNICAL REPORT

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CEN/TR 15473

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ICS 13.030.20

English Version

Characterization of sludges - Good practice for sludges drying

Caractérisation des boues - Bonne pratique pour le séchage des boues

Charakterisierung von Schlämmen - Gute fachliche Praxis zur Schlammtrocknung

This Technical Report was approved by CEN on 27 August 2006. It has been drawn up by the Technical Committee CEN/TC 308.

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Foreword

This document (CEN/TR 15473:2007) has been prepared by Technical Committee CEN/TC 308 “Characterization of sludges”, the secretariat of which is held by AFNOR.

The status of this document as CEN/TR has been chosen because much of its content is not completely in line with practice and regulations in each member state. This document gives recommendations for good practice concerning the drying of sludges, but existing national regulations remain in force.

Introduction

All the information of this CEN Technical report constitutes a framework for the process of drying sludges.

Various Directives will apply to thermally dried sludge products depending on the use to which they are to be put. These Directives include Directive 86/278/EEC(see [1]) for recycling to land, Directive1999/31/EC (see [2]) for disposal to landfill and Directive 2000/76/EC (see [3]) for incineration and energy recovery and Directive 94/9 for equipment intended for use in potentially explosive atmospheres (see [4]).

This document should be read in the context of the requirements of these Directives and any other relevant regulations, standards and codes of practice, which may prevail locally within Member States.

1 Scope

This CEN Technical report describes good practices for sludge drying and it is one of a series on sludge management options. It gives guidance on

- drying processes;
- characteristics of dried sludge products;
- recycling or disposal of dried sludge products.

from **urban wastewater treatment** plants.

Sludges of other origin, like sludge from water supply or industrial treatment plants are not in the exact scope of this CEN Technical Report, however the handling of most of these sludges will comply to a large extent with the leads given in this CEN Technical Report.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1085, *Wastewater treatment – Vocabulary*

EN 12832, *Characterisation of sludges – Utilisation and disposal of sludges –Vocabulary*

CR 13714, *Characterisation of sludges – Sludge management in relation to use or disposal*

CEN/TR 13767, *Characterisation of sludges – Good practice for sludges incineration with and without grease and screenings*

CEN/TR 13768, *Characterisation of sludges – Good practice for combined incineration of sludges and household wastes*

CEN/TR 15126, *Characterisation of sludges – Good practice for landfilling of sludges and sludge treatment residues*

3 Terms , definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document the terms and definitions given in EN 1085, EN 12832 and CR 13714 apply and also those given in:

Directive 91/271/EC (see [5]) concerning urban wastewater treatment;

Directive 75/442/EC (see [6]) the waste framework directive as amended by Directive 91/156/EC (see [7]);

Directive 99/31/EC (see [2]) on the landfill of waste;

Directive 86/278/EEC (see [1]) on the protection of the environment, and in particular the soil, when sewage sludge is used in agriculture;

Directive 2000/76/EC (see [3]) on incineration;

Directive 94/9 (see [4]) for equipment intended for use in potentially explosive atmospheres;

Directive 99/92/EC (see [8]) on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres;

and the following terms and definitions apply:

3.1.1
adhesion or shearing phase

phase, which exists in a range of some 40 % to 60% dry residue content, where the sewage sludge changes its rheological behaviour. Within this phase there is a "sticky mass" whose treatment and transportation is to be given special attention. Above the adhesion phase the sewage sludge has, in many cases, depending on the drying equipment, a more crumbly/lumpy structure that makes it easier to handle

3.1.2

fully dried / partly dried sludge
sludge dried above 85% dry residue content is defined as “fully dried” and sludge of dry residue content below 85% as “partly dried”

3.1.3

convection dryer
drying system where the heat is transferred to the product by a gaseous medium which is in intimate and direct contact with the product

NOTE The evaporated water is thus mixed with the drying medium and the exhaust gases from the dryer consist of the drying gas including leakage air plus the evaporated water. Convection dryer can operate with direct or indirect heating.

3.1.4
conduction dryer
drying system where the heat is transferred through an intermediate heat transfer surface to the product

NOTE The medium, which supplies the heat to the product, is never in direct contact with it. The total exhaust gas amount leaving the dryer is the evaporated water plus some leakage air. Therefore a conduction dryer is always operated with indirect heating.

3.1.5
solar dryer
drying system where the heat is transferred to the product by solar radiation

3.1.6
combined drying system
system, which uses both principles, convection and conduction in the same dryer

3.1.7
hybrid drying system
system that consists of a combination of a conduction dryer and a convection dryer

3.1.8
direct heating
off gas from the burner is in contact with the drying product

3.1.9
indirect heating
heating loop is crossing a heat exchanger

3.2 Abbreviated terms

BOD Biological Oxygen Demand

COD Chemical Oxygen Demand

HAZOP Hazard and Operability Studies

LCV Lower Calorific Value

LIT Layer Ignition Temperature

LOC Limiting Oxygen Concentration

MEC Minimum Explosion Concentration

MIE Minimum Ignition Energy

MIT Minimum Ignition Temperature

MPOC Maximum Permissible Oxygen Concentration

PLC Programmable Logic Controller

RTO Regenerative Thermal Oxydizer

SCADA System Control, Alarm and Data Acquisition

VOC Volatile Organic Carbon

WWTP Waste Water Treatment Plant

4 General

The drying of sewage sludge is a complex process but it can contribute to the need for increased disposal security for sewage sludge. With dried sewage sludge, a wider potential customer market can be approached than for liquid or dewatered products. It can be recorded that the range of those willing to accept sewage sludge can be expanded if one offers dried sewage sludge. In any case, the opportunity for marketing sewage sludge can be extended considerably which, in turn, represents an additional security for disposal and/or utilisation. The overview of thermal dryer types is given in Figure 1.

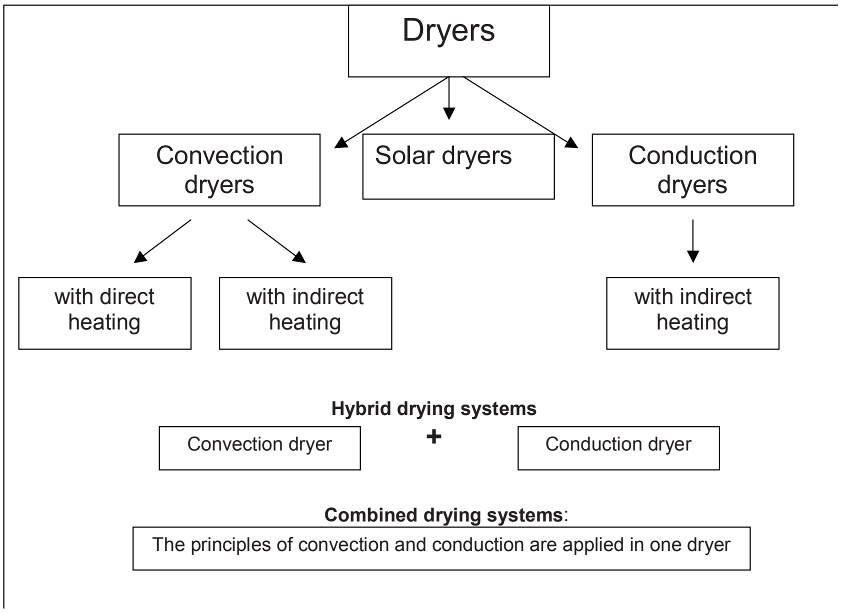


Figure 1: Overview on thermal dryer types

Thermal drying of sludge can result in the following advantages for almost all outlet routes:

- Substantial minimisation of the bulk of sludge for disposal. Thus 1 t dry residue of sludge at 90% represents 1,1 t actual or wet mass of sludge for disposal, but 1 t dry residue of sludge at 5% represents 20 t wet mass of sludge for disposal. Minimisation of sludge mass and volume by thermal drying results in savings in transport costs, which can be a major component of disposal costs.

- The removal of water leaves a thermally dried sludge product with a lower calorific value (LCV) (about 10 MJ/kg to 15 MJ/kg, depending e.g. upon the extent of pre-treatment), which can be used for thermal recycling.

- The thermally dried sludge product has favourable properties, as it is usually handable and storable, which lends flexibility to operations.

- For recycling to agriculture, in particular, there is the advantage that thermal drying is an ‘advanced treatment process whereby the dried sludge product gets sanitised and effectively free of pathogens at the end of the process.

Whilst the thermally dried product has definite advantages over other types of sewage sludge, there are some reservations (Brown and Jacobs, 2001 (see [9])) about the thermal drying process as follows:

- High capital cost (see 7.2.1);

- High operating cost, mainly energy consumption (see 7.2.1);

- Safety issues, particularly risk of fire and explosion (see clause 8);

- Technology can be complex and needs some well trained operators (see 7.3);

- The thermally dried product can be re-infected by micro-organisms and as a result of rewetting odour can be released after storage dependent upon the conditions of storage.

The thermally dried sludge product can reach a dry residue content up to about 95% mass fraction. In most instances thermal drying of sludge will aim to achieve a dry residue content of more than 50% in order to avoid the adhesion or shearing phase.

5 Treatment process description

5.1 General

There are numerous designs of thermal drying equipment available on the market and many of these have been adapted from other industries and used for sewage sludge drying. Few have been designed specifically for sewage sludge.

The equipment can be classified into four main groups defined by the drying process:

- Conduction dryers;
- Convection dryers;
- Combined or hybrid drying system;
- Solar dryers (radiation dryers).

5.2 Conduction dryers

5.2.1 General

A conduction dryer is a drying system where the heat is transferred through an intermediate heat transfer surface to the product.

The medium, which supplies the heat to the product, is never in direct contact with it. The total exhaust gas volume leaving the dryer is the evaporated water plus some leakage air. Therefore conduction dryers are always operated with indirect heating.

5.2.2 Disc dryers

Disc drying plants are - dependent on their shape - in a position to dry sewage sludge, both partially and completely. With this, complete drying is made possible using a mixing machine placed before the dryer. Here, a part of the already dried product is mixed with the dewatered sludge and thus overcoming of the adhesion phase is achieved outside the dryer. Plants for full drying, as special structures, are also used by which the return admixture takes place in the input area of the dryer.

Wear problems and dried sludge behaviour (fines and dust) have contributed to the decline in use of disc dryers for full drying. In the majority of cases, disc dryers are used to dry sludge up to a dry residue content below the shearing phase (for an auto thermal incineration).

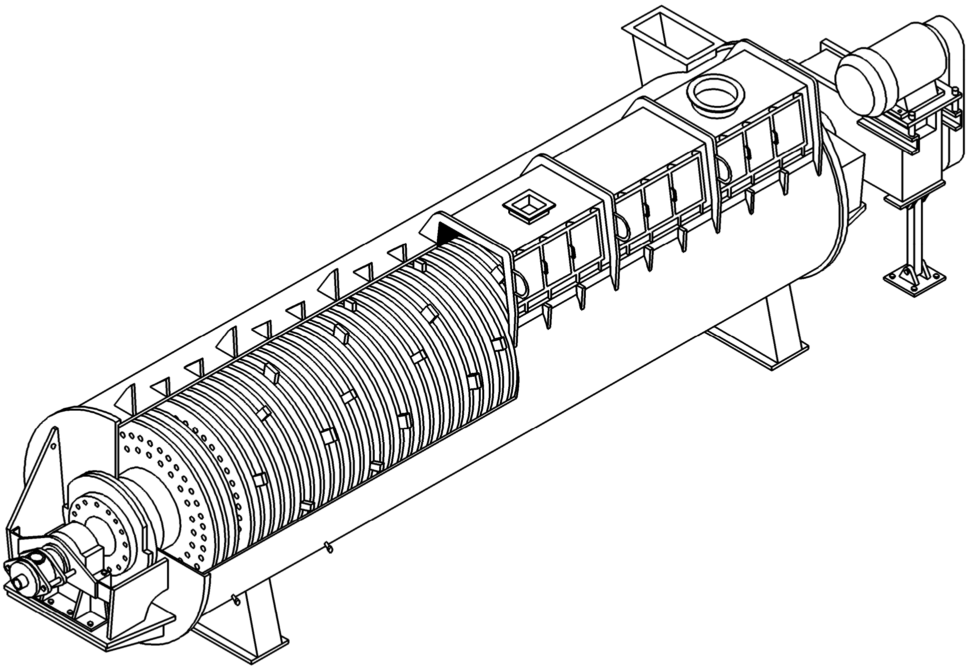


Figure 2: Disc dryer[1)]

The disc dryers (see Figures 2 and 3) are constituted of:

- A stator or body
- A rotor composed of a hollow shaft with hollow discs shaped as plates and welded on it.

A heating fluid crosses the rotor, either saturated steam up to approximately 1 MPa (10 bar) or thermal oil, which transfer thermal energy to the dewatered sludge, through the disc's surface. A process variant can additionally have the stator heated. The thermal oil (or steam) is heated in a boiler, usually fired with fossil fuel or biogas.

Vapours exhaust from the superior dome of the dryer, which should be correctly designed for effective transfer to a cyclone or a scrubber (partial drying at 45 %). As the residence time of the sludge in this type of dryer is rather large (around 1h), the vapours are usually highly polluted. However, one advantage of an indirect conduction dryer is that the volume of polluted vapours is small and kept separated from the flue gases of the energy source.

Due to the slow rotation of the rotor (circumferential velocity approximately 1 m/s) the sewage sludge is well mixed and a new interface for drying is continuously created. The requirements of the start-up condition are, met with the design of the drive.

Transport paddles, by which the sewage sludge is transported axially in the dryer, are additionally mounted on the rotor discs. However, in order to dry past the sticky phase, it is necessary to recycle some dry product upstream.

1) This dryer is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report and does not constitute an endorsement by CEN of this equipment. The manufacturer has given the authorisation to reproduce the scheme included in SIL documentation.

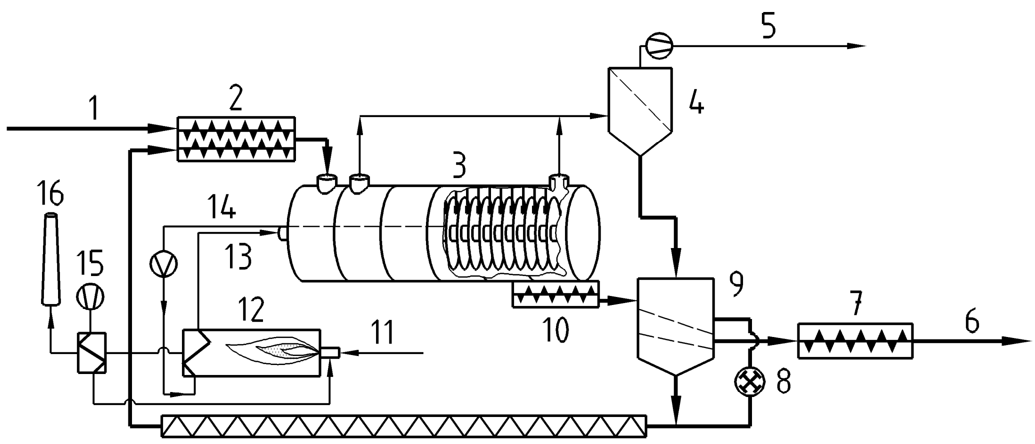
The dryer discs are subjected to high wear and corrosion loads, which should be taken into account through the selection of suitable materials or appropriate wear reserves, and in terms of maintenance and life time. Particularly stressed areas can additionally be armoured. The rotor has a considerable mass so that reverse-bending stresses also need to be accounted for.

Through the small separation of the discs it is possible to create a large surface area for heat transfer- related to the dryer volume. This means that disc dryers can be made very compact. The following specific evaporation performances have been documented (ATV-DVWK 2001 see [10]):

- With full drying plants of approximately 7 kg to 10 kg H_2O evaporated / (m^2.h) and
- With partial drying plants of greater than 11 kg H_2O evaporated / (m^2.h)

The degree of drying of the product is, as a rule, set via the input sludge quantity, which is proportional to the filling level of the sludge in the dryer and to the ratio of return, mixed dried material. To control the filling level and maximise the contact surface with the sludge, either pressure pick-up cells or gamma radiation level detectors are used.

In practice, for a daily start up and shut down, the operational flexibility of disc dryers is difficult to manage because of the high energy heat stored in the heating medium. As there are permanently large sewage sludge quantities with varying degrees of dryness in disc dryers, a quick shutdown of the plant is not possible. Consequently, there is a danger that sewage sludge can bake on to the discs (particularly with a sudden removal from service and extended standstill periods). Therefore several hours are to be allowed for start-up and closedown procedures so that disc-drying plants are best operated continuously.



Key

1 Dewatered sludge
2 Mixer
3 Disc dryer
4 Solids separator
5 Exhaust vapour treatment
6 Dry material
7 Cooler
8 Grinder
9 Sieving plant
10 Feed screw
11 Oil/gas
12 Burner
13 Steam
14 Condensate
15 Air feed
16 Exhaust gas

Figure 3: Disc drying plant for full drying[2)]

5.2.3 Paddle dryers

These dryers are composed of a horizontal body, in which two shafts are rotating in opposite directions. Each shaft bears special paddles, of wedge-shaped type. The paddles of the first shaft are staggered, in relation to the second one.

The main difference with a disc dryer is in the design of the paddles and the high torque, which allow complete drying without dry sludge feedback.

2) This is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The ATV-DVWK has given the authorisation to reproduce this scheme included in document ATV-DVWK 2004, see [11].

The dewatered sludge to be dried is fed at one extremity of the dryer and flows out to the other extremity, carried in part by the rotation of shafts and inclination of the dryer.

The heating medium (steam or thermal oil from the boiler) is fed simultaneously to the dryer shell, the shafts and the paddles.

The vapours escape to a lateral condenser. There is a little control air swept in.

The body, shafts and paddles are manufactured with special and resistant steel. The surface of the paddles and body are quite smooth.

Typical features of a paddle dryer are:

- Low shaft rotation speed (about 10 tr/min), in order to limit the risks of wear;
- Good homogeneity of temperature in the sludge bulk, which allows a good control and avoids a local overheating;
- The paddle construction and the smooth surface enables self cleaning and an excellent thermal transfer (up to 20 kg H_2O evaporated /(m^2.h);
- For full drying, there is no need for any back mixing of dried sludge; the shearing phase is overcome by kneading action;
- It can accommodate possible variations of sludge dry residue content;
- The high residence time (up to 4 h) is effective for pathogen reduction.

The operation of paddle dryers is similar to disc dryers, but special attention is required to control the plastic phase, which can move along the dryer when different sludges are processed.

5.2.4 Thin film dryers

Thin film dryers consist of a horizontal stator with double walled cylinder and an internal rotor. The heat energy in the form of saturated steam or thermal oil is fed to the dryer via the double jacket of the cylinder.

Two kinds of thin film dryers can be differentiated:

- Total indirect dryer;
- Mixed dryer with an internal fluidised effect for sludge transportation.

a) **Thin film dryer with mechanical transportation of sludge** (see Figures 4 and 5)

The function of the internal rotor, with its welded-on distributor and transport elements, is to build up and spread the dewatered sewage sludge in a 5 mm to 15 mm thick layer on the inner circumference of the stator. In this manner a continuously renewed contact interface is ensured and sludge is exchanged very intensively at the heated wall.

The design of the rotor provides a spiral shaped carrier for the dried material along the heating surfaces as far as the discharge side. A continuous blending and breakdown of agglomerates, which could possibly form in the adhesion phase, is achieved through the freely moving pivoted flaps of the rotor. The rotor can be matched to various sludges by changes to the paddles (rotor design) during stoppages.

By using a special blade configuration fitted on the rotor, sludge is exchanged very intensively at the heated wall. These blades have different functions as:

- Feed transfer elements. These pieces transport the sludge from the feed point into the heated area, they are located at the dryer inlet;
- Twisted transportation elements. They have the function of conveying the sludge through the dryer at slow or high speed;

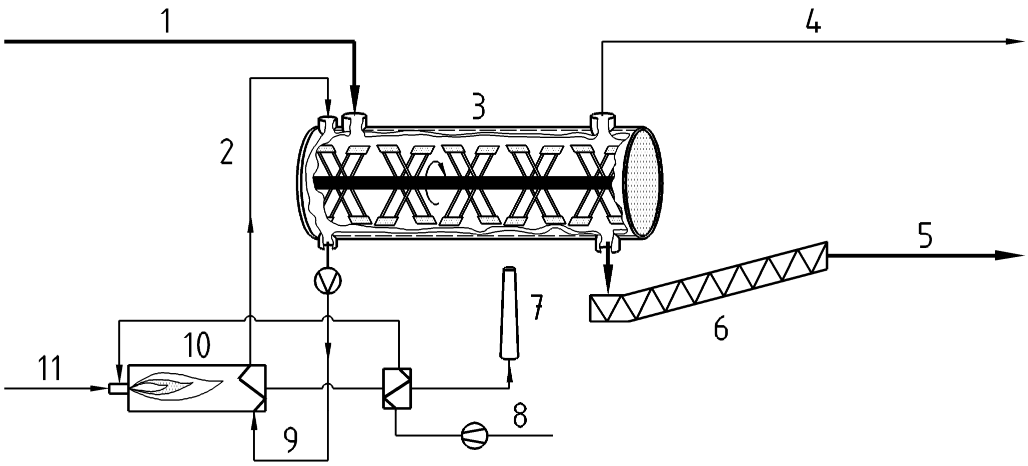
- Cleaning elements which remove the sludge from one area of the heated wall and push it to an another area to continuous mixing;
- Back return blades to improve the residence time in the dryer.

The sludge is continuously fed into the dryer at one end, where the feed blades of the rotor distribute the pasty slurry onto the heated wall. The subsequent mixing and transport blades carry the sludge in a highly mixed manner in a spiral path on the heated surface, thus accomplishing the required evaporation of water. Sludge retention time is in the range of 4 min to 10 min and can be adjusted by using various combinations of blades.

NOTE Thin film dryers do not tolerate fluctuations in the quality of the dewatered cake that is fed into them, which makes them inappropriate for sludge treatment centres.

The rotor can be driven at different and adjustable rotation speeds.

The sludge, after drying, is released from the dryer in a form of granules or coarser particles, at a temperature between 80 °C to 95°C. This is then loaded, via a spiral screw, for example into containers.



Key

1 Dewatered sludge
2 Steam
3 Thin film dryer
4 Exhaust vapour treatment
5 Dried sludge
6 Cooler
7 Exhaust gas
8 Air feed
9 Condensate
10 Burner
11 Oil/gas

Figure 4: Thin film dryer plant[3)]

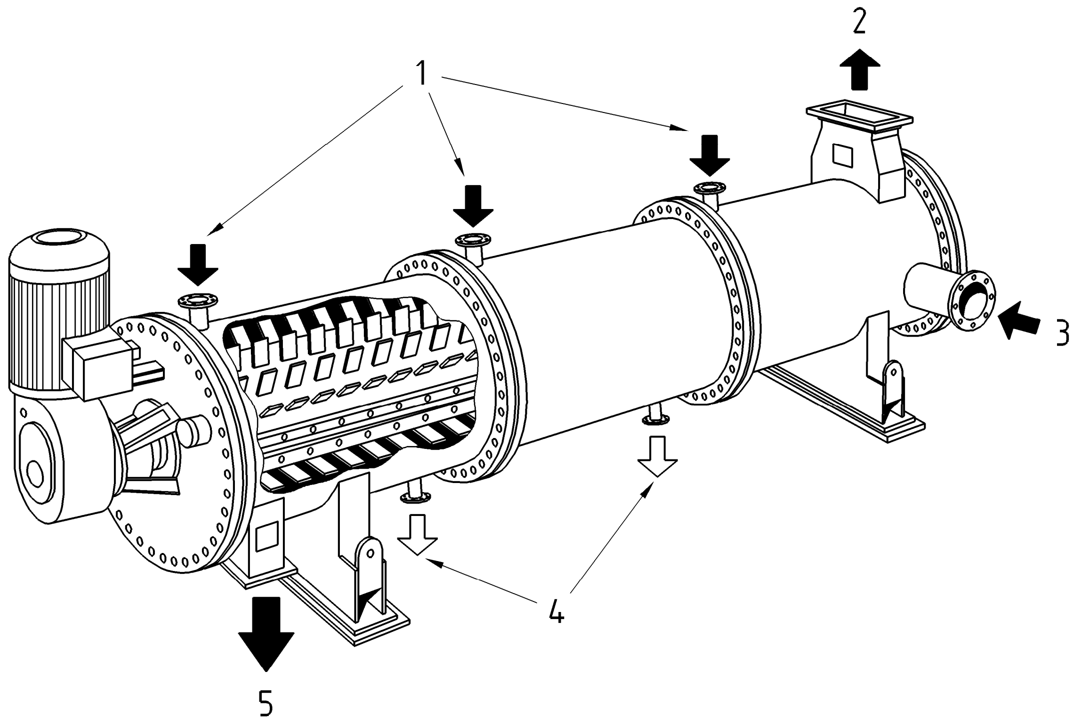
3) This is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The ATV-DVWK has given the authorisation to reproduce this scheme included in document ATV-DVWK 2004, see [11].

Basically both a partial and a full drying are possible with a thin film dryer. Its thermal efficiency is excellent (very high coefficient of thermal conductivity W/m^2), thanks to the good transfer of energy through the surface, that ensures high specific drying rate in the range of 25 kg H_2O evaporated / (m^2.h) to more than 100 kg H_2O evaporated / (m^2.h). However, the mechanical power necessary to overcome the shearing phase of sludge is higher, in comparison to systems utilizing a back mixing of dried sludge.

Operating with higher degrees of drying far above the adhesion phase, vaporisation no longer takes place in a thin layer but in a form of bulk material drying in which the contact surfaces reduce significantly. From this results a smaller heat transfer so that larger heating surfaces are necessary. With degrees of drying of up to approximately 65 % dry residue content one shall reckon with a specific evaporation performance of 25 kg H_2O evaporated / (m^2.h) to 35 kg H_2O evaporated / (m^2.h). With higher degrees of drying the necessary evaporation performances are to be considered as economically critical.

Thus, thin film dryers are mostly used for partial drying of sludge up to 65 % dry residue content and sometimes for small units (500 kg H_20 evaporated (m^2/h) to 1000 kg H_20 evaporated (m^2/h) for full drying (85 % dry residue content to 90 % dry residue content).

Start-up and shut-down can be carried out without problem in approximately 1 h, as only relatively small quantities of sewage sludge are present in the dryer (ATV-DVWK 2001 see [10]).



Key:
1 Steam
2 Vapour
3 Wet sludge
4 Condensate
5 Dried sludge

Figure 5: Thin film dryer plant 4)

Relevant to the degree of drying with thin film dryers is the dry solid content of the input sludge and the quantity of sludge supplied. The rate of rotation of the paddles influences the product structure and, as a rule, is not changed during operation. As thin film dryers are used mainly for partial drying, small variations of the final dryness can be accepted so that, following a single setting of the operational parameters, a further control is not absolutely necessary (Franke, Günther 1993 (see [12])).

To sum up, a thin film dryer operates at higher tr/min than either disc or paddle dryers, and with a much shorter residence time. With no recycling of dried sludge, most of the thin film driers in industrial operation reach a final dry residue content of 55 % to 65 %, versus 90 % for paddle dryers. Disc dryers without recycling are limited to 40 % to 45 % final dry residue content.

b) Thin film dryer with an internal fluidised effect

The principle of the thin film dryer has been associated with the fluidisation one. This allowed the development of a "turbo-dryer"5)

The turbo-dryer is a combined dryer, which associates the twin effects of conduction and convection drying with a carrier gas. It is one of the few dryers, which use this method of heating. In the dryer, the sludge film, in contact with the heating body, is constantly renewed; so the sludge area, exposed to the airflow and to the wall area, is increased.

The drying process deals with a closed loop circuit. Dried sludge is removed from the vapour stream, in an isolated cyclone locked at the inferior part, by a rotary valve.

The thermal conductance ratio is high. Low air volumes are introduced into the loop and the absence of back mixing of dried sludge leads to an optimisation of the energy transfer. The construction materials (protected paddles) shall be very resistant to wear, because the peripheral tangential velocity is quite high (≅ 30 m/s).

The high rotation speed of the rotor requires a perfect equilibrium; a breakdown or the wear of paddles are drawbacks that can cause damage. Maintenance and control require specialized staff. Carrier gas fluidisation and mechanical action of the rotor contribute to the fragmentation and division of granules of dried sludge, especially if the mechanical resistance of the granule is too weak, leading to the formation of fines and dust, which necessitate a downstream re-agglomeration with a pelletizing machine.

5.2.5 Others

a) Multi-tray dryers

The vertical multi-trays dryers are indirect dryers[6)].

It consists of hollow trays, constructed one above the other inside a cylindrical shell. The trays are heated with thermal oil running in a closed loop path.

Dewatered sludge is pumped to a coater. In the coater, dry sludge granules are thoroughly mixed with the incoming dewatered sludge. The granules, coated with wet and sticky sludge are fed to the top of the dryer. The back mixing of dried sludge is used to avoid the problem of the “sticky phase”. The back mixing of granules of small size optimises the drying, because the developed surface of granules is important and consequently, the contact frequency, between granules and the trays heated surface is increased.

The coated sludge granules fall onto the distribution device located at the upper section of the dryer in order to be spread over the top tray. By means of a raking mechanism fitted to the central and vertical rotating shaft, the wet granules are slowly moved over the upper tray and pushed from the centre of the dryer to the outer edge from where they fall onto the second tray. The continuously rotating scraping arms move the sludge back from the outside to the inside of this tray from where it falls onto the next tray. By this operation, granules of sludge are smoothly transported from tray to tray and dried. This transport operation avoids dust formation and the rolling movement over the trays give the sludge particles round form.

Energy transfer for water evaporation is introduced into the drier by means of hot thermal oil flowing through the hollow trays; the oil is heated in a thermal oil generator.

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4) DAS thin film dryer is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The manufacturer has given the authorisation to reproduce the scheme included in SMS (BUSS) documentation.

5) Turbo dryer as thin film dryer can be manufactured by VOMM Company. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment.

6) SEGHERS-KEPPEL sludge hard pelletiser, which relies on dry sludge recycling, is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment.

At the lower part of the dryer, dried pellets exit and are transported upwards in a bucket elevator to a small separation hopper. One fraction is separated and recirculated to the coater while the remaining part is cooled before being stored in the final dried product silo. To get an efficient cooling, one vibrating fluidised bed system is used to cool the pellets to a temperature lower than 40°C. This device ensures the production of dustless homogeneous pellets. Exhaust gases shall be treated before release into the atmosphere.

The dryer and the back mixing equipment are sealed and kept under a slightly negative pressure (10 mm to 20 mm water column) by means of a self-adjusting fan. The dryer is crossed by a minimal quantity of air (less than 10 % of the vapours stream) and the water evaporation is boosted by the chimney effect of the dryer. The oxygen concentration is around 2 % to 3 %, so that self-ignition of sludge is avoided.

Vapours are cooled in a condenser, which is flushed with treated water; afterwards, the mixing is released to the Waste Water Treatment Plant (WWTP) to be treated again.

Non-condensable gases can be destroyed in the flame of the generator or treated in a bio-filter.

The operator can control, thanks to inspection hatches, placed at the level of each tray, the behaviour of granules and quickly notice an abnormal operation.

Wearing by abrasion is limited to the scrapers, which are easily inter-changeable, and corrosion can be controlled by the manufacture of dryer bodies in stainless steel.

The consumption of mechanical energy, for the rotation of the central shaft, is low. From this point of view this dryer is very efficient.

b) Linear screw dryers

The linear screw dryer is sometimes used to replace the segmental disk dryers. It avoids the pre-drying operation (thin film dryer) and allows an end product with dry residue up to 90 %, with mechanical advancing of sludge.

Only the screw shell is heated.

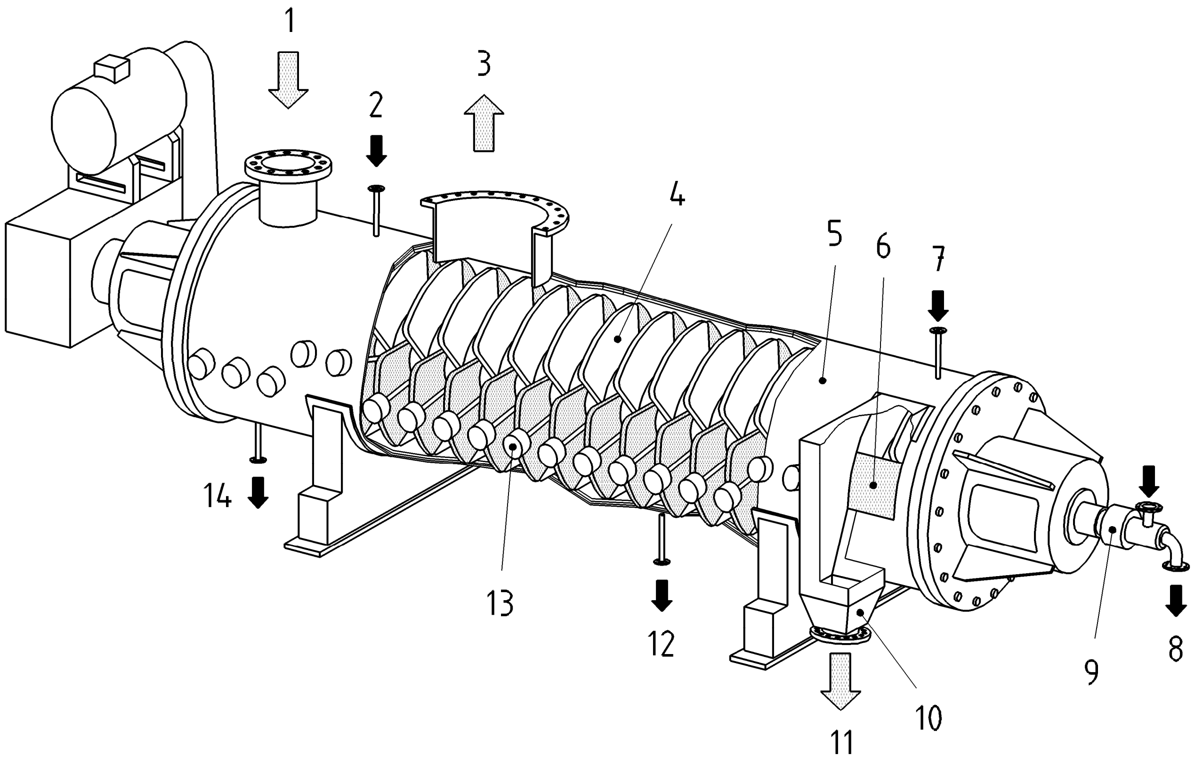
Investment cost is clearly less than a segmental disk dryer (about 3 times cheaper), but the range of evaporation is limited to several hundred kilograms of water per hour.

c) Combination of thin film and disc dryers

Combinations of thin film and disc dryers are used exclusively for full drying. The main advantage of this is the problem-free transit of the adhesion phase using thin film dryers is used. The drying process is then interrupted with a dry residue of approximately 55 % to 60 % as, from here, thin film dryers function uneconomically. The partially dried sludge is then fed directly to a disc dryer for full drying. The disadvantage of the arrangement of two drying machines is compensated by avoiding the need to return product for reprocessing and therefore in this way, the disc dryer can be sized significantly smaller for the same throughput performance. The peripherals here correspond with the single case (ATV-DVWK 2001, see [10]).

Segmental disc dryers

Segmental disc dryers (see Figure 6) are a variant of disc dryers. Segments are staggered on the shaft. The system is a total indirect dryer, composed of a trough-like shell and of a rotor equipped with blades.



Key

1 Wet sludge
2 Heating medium
3 Vapour
4 Agitator
5 Jacketed vessel
6 Weir
7 Heating medium
8 Heating medium
9 Rotary joint
10 Side discharge
11 Dried sludge
12 Heating medium
13 Breaker bars (option)
14 Heating medium

Figure 6: Segmental disc dryer [7)]

Due to its long retention time, the dryer is ideally suited for further processing downstream from the thin film dryer. Consequently it is often used as a second step of a dryer line, after the thin film dryer.

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7) ROVACTOR dryer is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The manufacturer has given the authorisation to reproduce the scheme included in SMS documentation.

To avoid wear of the plant, various components have to be made of materials such as tungsten carbide.

d) Bundle pipe dryer

The dryer (see Figure 7) consists of two parts:

- one rotary unit: the rotor;
- one stationary casing for the rotor.

The rotor consists of a cylindrical shell with end plates and hollow collars. The end plates are manufactured with open axial tubes rolled in the tube plates. The collars are provided with roller rings. On one of the collars, a chain sprocket is placed outside the roller ring. The casing consists of a cylindrical chamber with holes for the collar of the rotor. On each side of the casing, there is a connector for the heat transfer medium to enter and leave the dryer.

As the rotor is smaller than the inside of the casing, the flue gases pass through the tubes and around the shell of the rotor. In this way, all surfaces of the rotor, as well as parts of the collar inside the casing are heated by the gaseous medium. This implies that all surfaces in contact with sludge are effective heating surfaces. No condensation is therefore possible.

A tubular rotary bundle pipe dryer is heated by an indirect transmission system. The indirect system enables drying in an atmosphere of super heated vapours that minimises the risk of overheating the end product, dust explosion and fire. Incondensable gases in direct contact with sludge are minimised so that exhaust gases are practically limited to those arising from combustion of fossil fuel.

Figure 7: Bundle pipe dryer [8]

The mechanically dewatered sludge is back-mixed with dried material and continuously fed to a bundle pipe dryer. Biogas or fuel is combusted to generate flue gases (400°C) that are drawn through the dryer and transferred by indirect way to the sludge mix.

After drying, the main part of the gases are blown back to the hot gas generator. The remainder of the gas is sucked through an air pre-heater to control a slight vacuum in the flue gas system. It is then discharged to the atmosphere after treatment if this is required by the control authority.

The venting air is used to transport contaminated water vapour away from the dryer. The air is subsequently treated in a cyclone to remove dust, which is screwed back into the feed end of the dryer.

The moisture is removed from the air in a condenser that includes high-grade heat recovery via an indirect lamella plate system. Sometimes, a direct scrubber is installed on plants if no primary heat is required.

Finally, the air is blown to an indirect air pre-heater. Here energy from the off gases is transferred to the venting air prior to recirculation to the dryer for the combustion of odours and bad smelling gases.

[8] PLEQ bundle pipe dryer is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The manufacturer has given the authorisation to reproduce the picture of PLEQ bundle pipe dryer.

The back mixing is adjusted by actions of rotor dryer speed, dew point of vapours, drying inlet gases temperature and fraction of sweep air from the heat exchanger (loop energy recovery).

Evaporation capacity of commercial tubular rotary driers can be in a quite wide range from 100 kg H_2O/h to 8 000 kg H_2O/h.

5.3 Convection dryers

5.3.1 General

A convection dryer is a drying system where the heat is transferred to the product by a gaseous medium which is in intimate and direct contact with the product.

With convection dryers the evaporated water is thus mixed with the drying medium and the exhaust gases from the dryer consist of the drying gas including leakage air plus the evaporated water. A convection dryer can operate with direct or indirect heating.

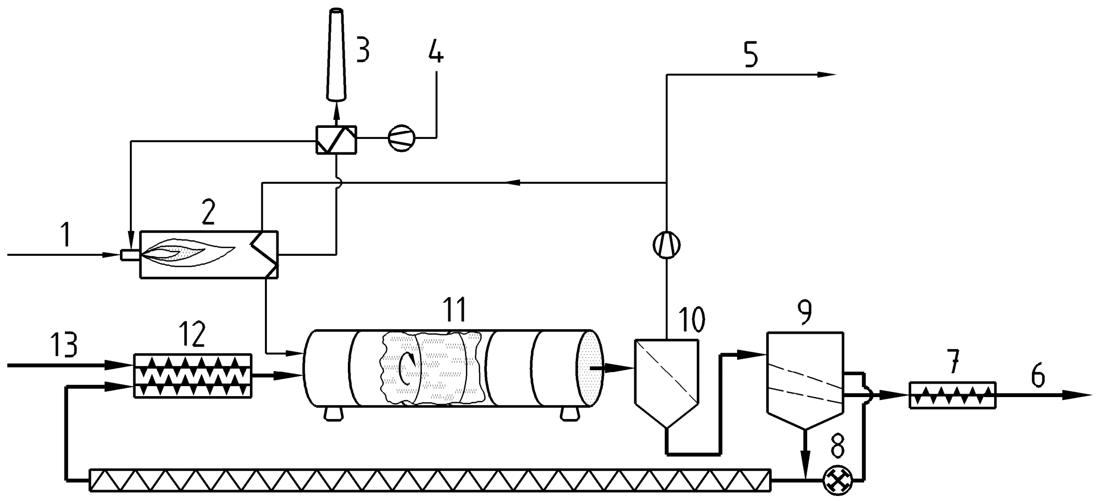
For all convection dryers, the sludge feed has to be prepared either by back mixing to reach dry residue content above 60% or the sludge is to be extruded to a cylinder shaped material.

Although some belt dryers can be operated with cold air, most industrial driers use warm air, which is produced with a burner.

For safety considerations it is required to have a limited oxygen concentration in the warm gas. This can be realised by recycling a part of the exhaust gas.

5.3.2 Drum dryers

Drum drying plants (see Figure 8) are employed exclusively for full drying. To avoid the sticky phase, the sludge is fed at around 65% dry residue content by recycling of dry sludge into a mixing machine. In addition the mixer provides a granulation, which is relevant for the dried product quality.



Key

1 Oil/gas
2 Burner
3 Exhaust gas
4 Air feed
5 Exhaust vapour treatment
6 Dried sludge
7 Cooler
8 Grinder
9 Sieving plant
10 Solids separator
11 Drum dryer
12 Mixer
13 Dewatered sludge

Figure 8: Drum drying plant (indirect heating)[9)]

The actual drying takes place in a permanently rotating one or three pass drum. Transport through the drum, depending on the type of heating gas flow, is by guide blades together with the degree of filling of the drum or through an inclined position of the drum. A large quantity of warm air is circulated through the drum by the main transport fan and helps carry the smallest particles.

Direct or indirect heating, as explained above, produces the warm air. A proportion of the circulation air, equivalent to the amount of combustion air, shall be exhausted from the system, which shall be maintained under a slight depression. If no prior condensation has been made, this exhaust air carries the evaporated water away.

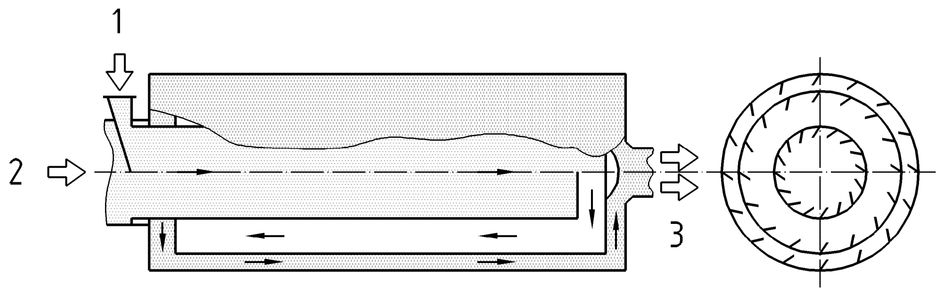
The process gas is separated, via a solids separator (bag filter or cyclone), from the dried sewage sludge, which is then fed to a sieving plant. The coarse granule is crushed in a grinder and fed to the mixer with the

9) This is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The ATV-DVWK has given the authorisation to reproduce this scheme included in document ATV-DVWK 2004, see [11].

sieved-off fine material. The dried material is taken direct from sieving and appears in a granule spectrum corresponding with the choice of sieve.

Control of the process takes place primarily via the gas temperature at the exit of the dryer which is proportional to the dry residue content of the existing dried material the upstream mixer machine is fundamentally responsible for the self-adjusting granular structure (ATV-DVWK 2001,see [10]). A more detailed description is given below for the case of a three pass drum dryer with direct heating.

A three pass drying drum (see Figure 9) consists of three cylinders, inserted into each other, and has a common shaft. In the innermost cylinder, the wet sludge is pre-dried.



Key

1 Blended sludge

2 Heated air

3 End product dried granules

Figure 9: Three-pass drum dryer[10)]

Due to the high temperature of the gas coming from the burner (400 °C to 600°C, according to drum size and capacity), evaporation takes place and causes a sudden drop of the hot gas temperature.

By turning the drying drum slowly and by conveying the material forward in the air current, the sludge passes from the inner cylinder into the central cylinder and then into the outer cylinder. From this last cylinder, the dried sludge leaves the drum automatically with the air current, just in time to avoid an overheating of sludge.

The radiation heat of the inner cylinder is absorbed by the central cylinder and then by the outer cylinder. There is little heat loss except radiation from the outer cylinder to atmosphere.

After leaving the drying drum, the dried material is carried by the large flow of flue gases to a pre-separator and then to a polycyclone. In these units, the hot humid air is separated from the dried sludge.

The flue gases (90°C) leave the polycyclone through a large fan and the moisture is released in a condenser supplied with industrial cooling water. The cooled circulation air goes back to the generator where it is heated up to the required operating temperature. This allows an adjustment of the oxygen content in the drying loop to less than 12%, which is an important safety feature. Vapour condensates are discharged with cooling water at a temperature < 35°C to the Waste Water Treatment Plant (WWTP). Condensation heating can be used for heat recovery.

The dried material (coarse granules) passes to the screen via rotary valves and a collecting screw. By means of a sieve device, granules are divided into three fractions.

10) DDS dryer is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report and does not constitute an endorsement by CEN of this equipment. The manufacturer has given the authorisation to reproduce the scheme included in ANDRITZ documentation.

- large granules > 4 mm to 5 mm;
- standard granules: usually from 2 mm to 4 mm;
- lower granules < 2 mm.

The standard granules are discharged into silos via an elevator. Large granules are crushed and go to the return silo. If the returned quantity is insufficient, some of the standard granules are transported automatically to the crusher, then to the return silo.

In general drum dryers are used for evaporation capacities from 3 000 kg H_2O/ h to 8 000 kg H_2O/ h.

5.3.3 Fluidised bed dryers

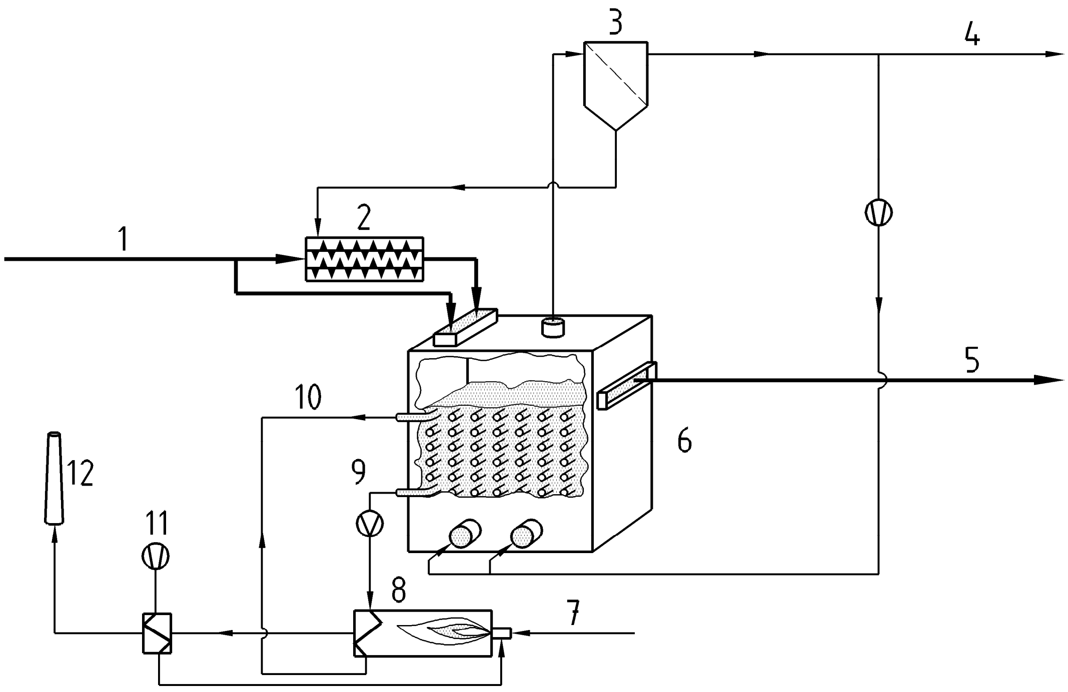
Fluidised bed dryers (see Figure 10) are indirectly heated convection dryers and are used for full drying. The fluidised bed dryer is the only device with which the dryer - with the exception of external blowers - has no moving parts. The principle of the fluidised bed dryer is based on the injection of turbulent air/gas until a fluidised bed has formed. With this the granules are held in suspension and intensively blended.

A fluidised bed dryer consists of a three components housing:

- wind box or plenum at the lower section with the nozzle plate for uniform gas distribution;
- middle section where the actual position of the fluidised layer is;
- free board to recover sludge particles in the upper section.

As with drum dryers, some dry sludge feedback is necessary. The granulation device forms the sludge granules. Blending wet feed sludge with back dried sludge, available as dust and screened fines, produces strong granules, stable throughout the drying process and as such remaining in the final product. The type of granulator device is determined by the rheological properties of the dewatered sludge, as well as by the required characteristic of the final dried product. Sometimes, an atomisation device directly into the fluidised layer produces free flowing wet granules.

Gases, moved by a powerful fan, flow through the sludge blanket, fluidise it and carry the evaporated water out. Energy for water evaporation is applied through the submerged heated tubes located inside the sludge fluidised bed.



Key

1 Dewatered sludge
2 Mixer
3 Solids separator
4 Exhaust vapour treatment
5 Dried sludge
6 Fluidised bed dryer
7 Oil/gas
8 Burner
9 Condensate
10 Steam
11 Air feed
12 Exhaust gas

Figure 10: Fluidised bed drying plant[11]

Wet sludge granules drop from the top into the layer. Fines are picked up by the fluidising gas, discharged from the fluidised bed, collected in the suction hood and carried to the gas-cleaning cyclone. These fines particles are then removed from the gas stream. Dried, dust free sludge exits the fluidised bed device through a weir to a final separation before storage.

The gas input through fluidizing nozzles in the lower dryer area serves primarily for the production of the fluidised bed and for the removal of the released exhaust vapours. Removal of already dried sewage sludge with the gas flow is prevented by a turbulent air layer free zone (freeboard) in the upper area of the dryer

[11] This is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report and does not constitute an endorsement by CEN of this equipment. The ATV-DVWK has given the authorisation to reproduce this scheme included in document ATV-DVWK 2004, see [11].

where the entrained sewage sludge returns again to the fluidised bed due to gravitation. Fine dust particles are separated in a downstream cyclone and fed to the wet sludge input using a mixer. Baking within the dryer is not possible as the wet sludge applied at the top falls directly into the fluidised bed and there rapidly forms a stable surface. The circulation gas is fed to a condenser and returned into the dryer via a blower. Due to this concept only small quantities of exhaust gas are formed which can be fed further, for example, via a bio-filter.

The input of heat into the dryer takes place via pipe lengths in the fluidised bed. These operate in a similar manner to immersion heaters and are fed with either saturated steam or thermal oil. Through the short contact time of the sewage sludge with the heating rods, these can be operated at a high temperature. Baking and excessive wear on the heating rods are not unlikely as the fluidised bed, with moderate particle velocities, provides self-cleaning.

The dewatered sludge is structured by the fluidised bed and is removed laterally from the dryer as a product with granule sizes from approximately 1 mm to 5 mm. As the product is produced dust free it can be transported to a silo without further sieving.

Fluidised bed dryers can easily be controlled via the temperature in the flow bed. A controlled, rapid and simple start-up and shutdown are possible. For this, first the heating and then the wet sludge supply are shut off. In the case of an emergency shutdown no critical operational conditions occur due to the low temperature level. The dryer can be started up again later without further measures.

Fluidised bed dryers, with a predetermined heat input, are regulated by the input sludge quantities that a temperature of 85° C is set in the fluidised bed. This results in a dry residue content of 95 % in the product (Otte-Witte 1989, see [13]; Sixt 1994,see [14], Huschka 1991,see [15]).

Advantages of fluidised bed dryers are:

- constant temperature across the cross-section;
- behaviour of the granules in the fluidised bed which is similar to that of a fluid;
- constant pressure loss with varying flow rates (ignoring the fluidising nozzles pressure loss);
- improved heat and substance transport through combined conductive - (to the steam pipes located in the fluidised bed) and convection drying through the heated turbulent air/gas.

In particular, the last named is used for sewage sludge drying plants to reduce the energy consumption so that very compact construction results.

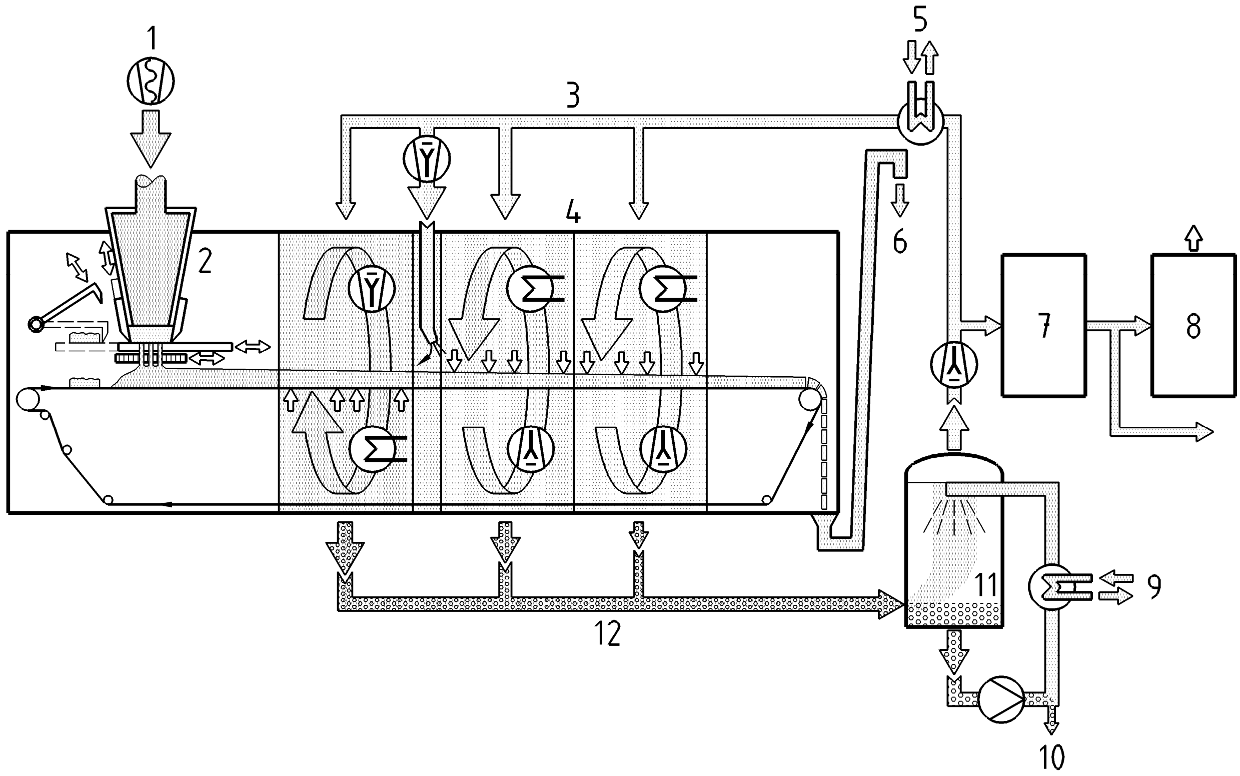
5.3.4 Belt dryers (see Figure 11)

Belt dryers belong to convection drying systems. They can dry dewatered sewage sludge directly through the adhesion phase to a dry residue content of above 90 %.

In the majority of industrial dryers, the wet sludge is distributed on the belts by extrusion: the sludge is pressed across the holes (6 mm to 10 mm in diameter) of cylindrical dyes disposed across the belts. The dry residue content of the incoming sludge shall be sufficient (greater than 20%) for the “spaghetti” like strands to form a porous mat and the compaction of sludge shall be particularly controlled. Lasers can control the thickness of this mat. Sludge, after drying, will usually have an oblong form, with porous aspect, diameter 3mm to 5 mm.

For drying, the sewage sludge is transported through the dryer chambers on one or more perforated conveyor belts across which a flow of warm gases circulates. This gas can be cold air or warm flue gas from a burner. The temperature therefore varies between ambient temperature and 180°C and the residence time of the sludge and the size of the dryer vary accordingly.

The choice of construction materials and the way to treat the escape vapours are also very dependent upon the operating temperature. This explains the rather large number of manufacturers of such dryers, all having made different technological choices.



Key:

1 Wet sludge

2 Pelletiser

3 Circulation air supply

4 Dryer

5 Heat recovery circulating air

6 Container

7 Scrubber

8 Combustion in heater unit

9 Cooling water

10 Condensate

11 Condenser

12 Circulating air exhaust

Figure 11: Belt drying plant (indirect drying)[12]

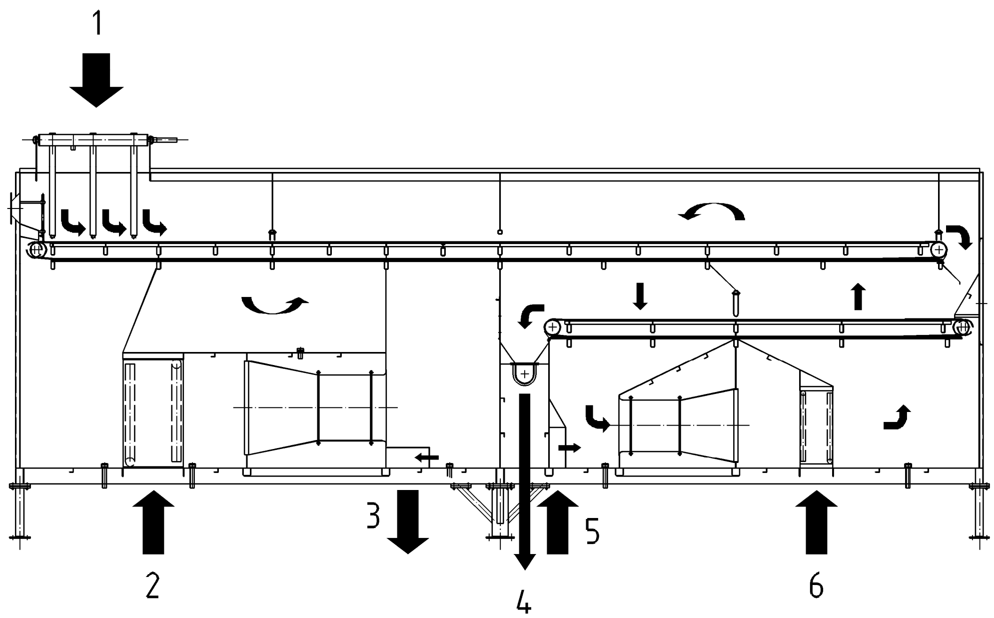
[12] DORNIER dryer is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The manufacturer has given the authorisation to reproduce the scheme.

The size of the dryer is dependent upon the temperature. A dryer for 1,5 t/ h of water evaporation can be 45 m long, but the civil engineering cost is usually low. The width is between 1 m and 3 m, and some space is saved by having at least two belts on top of one another, travelling in the same or opposite directions. The belts are made of perforated stainless steel or of plastic screen, according to temperature.

The “oven” is divided into several drying chambers, 3 to 14 in high temperature dryers, sometimes followed by a cooling section. For lower temperatures, the number of drying chambers is usually two to three, according to capacity. Air-tightness at both ends of the dryer is important for odour control.

One technology (see Figure 12) consists of a cabinet, which is built up as a reinforced, closed steel construction.

The dryer is fitted with two drying belts. The belts are of the wire belt type and are made from stainless steel. The first belt, where the sludge is deposited, moves at a speed of approximately 0,5 m/min. The other belt, on which the sludge from the first belt is unloaded with a solid content of approximately 50 %, moves at a speed of approximately 0,1 m/min. With a dry residue content of more than 50 % when unloaded from the first belt, the sludge has passed the sticky phase, and the unloading can take place without problems.



Key

1 Dewatered sludge, dry residue content 10 % to30 %

2 Thermal oil as heat source

3 Wet circulation air from condenser

4 Dried and treated sludge, dry residue content > 90 %

5 Dry circulation air from condenser

6 Warm water as heat source

Figure 12: Belt drying plant[13]

[13] BIOCON dryer is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The manufacturer has given the authorisation to reproduce the scheme.

The dryer is fitted with standard ventilators for the circulation of the drying air in three transversal open passages. While in operation, the dryer is kept at a sub-pressure of minimum 50 Pa by means of an exhaust ventilator. The exhausted air is applied as combustion air for the boiler's burner to avoid smell problems.

In the condenser, the wet drying air is washed in final effluent from the WWTP.

The drying air is cooled down to below the dew-point temperature in order that the vaporised water from the sludge is condensed.

The drying air leaves the condenser in a dried and cleaned condition through the bottom of the condenser. Before the drying air is led back to the drying installation, it is re-heated in the exchanger with heat from the condensate.

The final effluent and the condensate is mixed in the condenser and led out from the bottom of the condenser.

The condenser can be supplied with an energy recovery installation. The amount of recovered energy depends on the capacity of the drying plant.

Where the start-up is executed with a cold thermal oil and water system, it will last 1 h.

There are three possibilities available for the control of the belt dryers. These are the input sludge quantity, the conveyance rate of the belt and the heat energy supplied. Sludge quantity and conveyance rate determine the layer height on the belt. The individual blower per chamber regulates the amount of hot gas supplied so that a defined temperature is set in each chamber (Born, 1992, see [16] Huschka, 1991, see [15] and Sixt 1994, see [14]).

For high temperature dryers, the speed of the belt, the energy quantity provided to the different zones, and adjustment of temperature set points, define the end dry residue of sludge.

For low temperature dryers, the air temperature is kept constant. As the humidity of the air in the last chamber is well correlated with the sludge final dry residue content, its measurement can be used to adjust the speed of the belts and/or the flow of the extruders.

Belt dryers have an excellent flexibility to obtain variable dry residue content of the dried sludge. Low temperature dryers can have difficulties in reaching a dry residue content higher than 85%.

5.3.5 Cold air dryers

Preliminary dewatering is required for drying in a cold air dryer. In addition, the dewatered material shall be crushed.

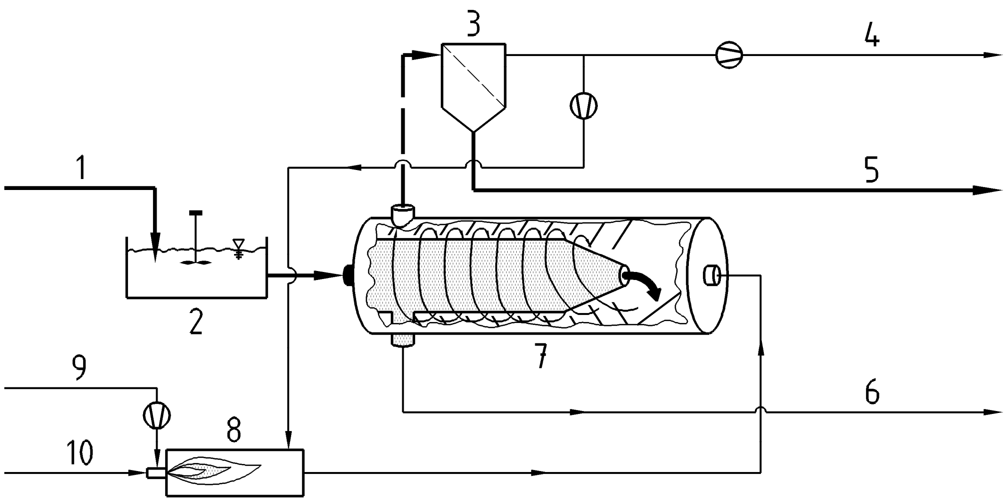
The material to be dried is supplied continuously so that a 3 mm to 5 mm high loose pile results. This remains for approximately 1 h to 1,5 h in the dryer and is subjected continuously to a large quantity of ambient air. Dependent on the respective design of the structure, it is possible to dry a sewage sludge volume flow of approximately 2 m^3/h to 8 m^3/h to a dry residue content of 70 % to 90 %. As the principle of the cold air dryer is based exclusively on the natural drying potential of the ambient air, large quantities are necessary in order to achieve the described result. Furthermore, with an air temperature lower than 10° C and a relative humidity greater than 80 %, preheating of the ambient air becomes necessary (ATV-DVWK 2001, see [10]).

5.3.6 Flash dryers

The process consists of spraying finely pulverized dewatered sludge at counter current in a high temperature upward gas stream. The most usual equipment are refractory lined steel towers to which the heated off gases (which shall be greater than 800 °C) are introduced. These exhausted gases are generated either from combustion of municipal waste or industrial waste, or furnace with fuel, wasted oil, digestion gas, dried sludge.

The process (see Figure 13) is an example of a flash dryer. Dewatering and drying are carried out in the same machine. The thin slurry supplied can be brought directly to a dry residue content of 50 % to 95 %. In this way no preliminary dewatering of the sludge is necessary. As, however, the process reacts sensitively to variations of dry residue content of the input, the thin sludge is fed to the dryer via a homogenising tank to achieve a consistent feed. The drying of the sewage sludge takes place directly upwards from the adhesion phase for reasons of the concept given below. Plants, which operate according to this process, are very compact in construction.

Liquid sludge is mechanically dewatered by the centrifuge, which is part of the dryer. The high velocity of the disintegrator fitted round the diffuser explodes the dewatered sludge into small particles, which are dispersed in the heating gas. The concentrate is fed to the sewage treatment plant with the exhaust vapour condensate. The dewatered sewage sludge is transferred to the solids discharge as a fine granule product by means of a deflector plate and is then subjected to the hot gas stream.



Key

1 Thin slurry
2 Homogenizing tank
3 Solids separator
4 Exhaust vapour treatment
5 Dried sludge
6 Centrifuge liquid to sewage treatment plant
7 Flash dryer
8 Burner
9 Air feed
10 Oil/gas

Figure 13: Flash drying plant[14]

The outer chamber of the centrifuge circulates a hot gas stream that is produced by a generator. This is sucked in the opposite direction to the axial transport direction of the centrifuge and leaves the dryer, together with the dried sewage sludge, in the area of the thin slurry. Drying takes place within a few seconds. The necessary quantity of heat is fed into the circuit via combustion gas. An inert atmosphere is achieved through the circulation action of the drying gas with an appropriate moisture level from the water evaporation and the supplied combustion gas.

[14] CENTRIDRY process is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The ATV-DVWK has given the authorisation to reproduce this scheme included in document ATV-DVWK 2004, see [11].

The exhaust vapours are fed over a cyclone using cellular wheel sluices in which the dried sewage sludge is separated from the gas flow. The resulting product has a relatively broad granule spectrum. Furthermore the exhaust vapours are sucked out using a blower and fed to the exhaust vapour treatment. The exhaust gas can be discharged into the combustion chamber (ATV-DVWK 2001, see [10]) or treated for odour in a bio filter.

Temperature, pressure, through-flow, filling level and rate of rotation of the centrifuge are all used for control .A rapid start-up and shut-down of the plant is possible since there is only a limited volume of sludge within the process.

The temperature of the heated drying gas is intentionally limited to low temperature (< 380°C), in order to avoid the potential risks of ignition, odours and technical problems of centrifuge operation.

The mesh size of the dried sludge is extremely small (below 1 mm size), depending essentially on the origin and nature of sludge to be treated.

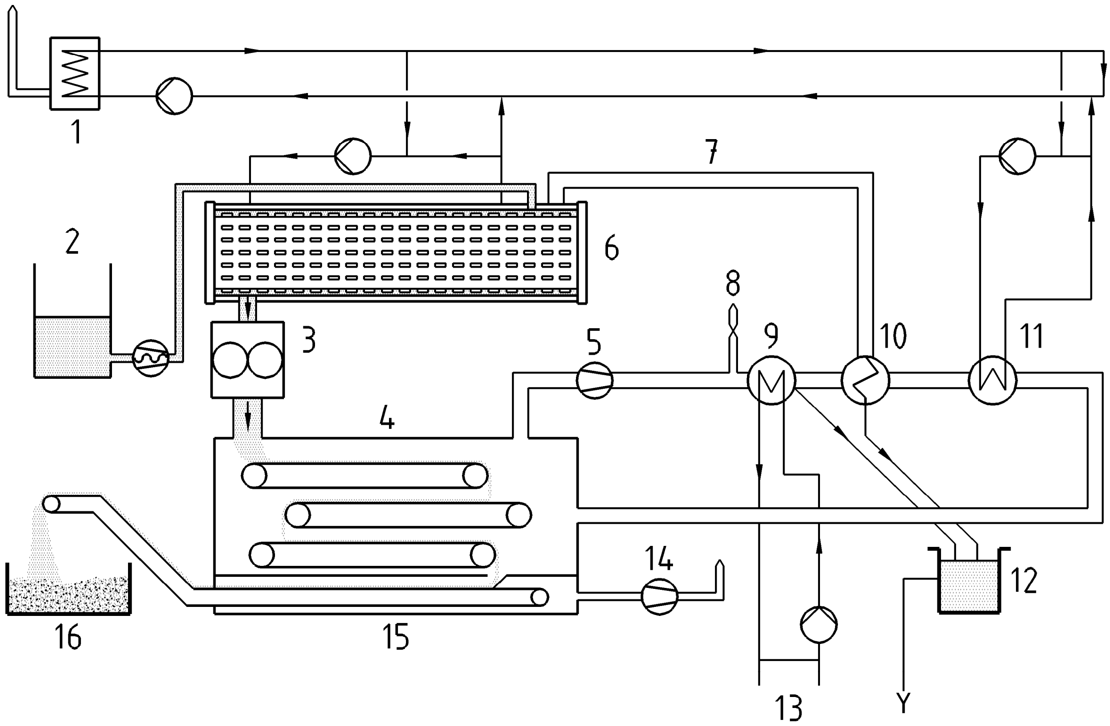
These installations are limited to small evaporative throughput: 200 kg H_2O/h to 1 000 kg H_2O/h.

5.3.7 Hybrid processes

The hybrid drying process combines two drying principles: conduction and convection.

The combined drying process (see Figure 14[15]) is very recent (1996 – 1997). The drying principle combines two drying functions, in the same process. These two combined drying systems are conduction and convection types. This approach to sludge thermal drying is very new. The technological functions are well known, but never used in series. An internal energy recovery loop and a dust free dried material are the strongest features of this process.

[15] INNOPLANA process is an example of a suitable design of thermal drying equipment available commercially. This information is given for the convenience of users of this CEN Technical Report….and does not constitute an endorsement by CEN of this equipment. The manufacturer has given the authorisation to reproduce this scheme included in Figure 15.



Key

1 Oil heater
2 Dewatered sludge dry residue content 10 % to30 %
3 Chopper, dry residue content 40 % to 50 %
4 Belt dryer
5 Fan
6 Thin-film evaporator
7 Vapours
8 Exhaust air treatment
9 Cooler
10 Condenser
11 Re-heater
12 Condensate tank
13 Heat bypass
14 Cooling air
15 Cooling belt
16 Dried sludge (granulate dry residue content 90 %)

Figure 14: Combined belt drying process

Sequence 1 (Conduction drying)

The first step by conduction drying is a thin film dryer, which operates ideally in the range of dry residue content of 18 % to 50%. The dryer is heated with thermal oil produced by a generator. Moulding – i.e. granulation – of the sludge is easiest if the sludge remains plastic and contains between dry residue content of 40 % and 50 % according to the different types of sludge.

Sequence 2 (Extrusion)

The chopper fitted between the first stage and the second stage shapes the plastic material into granules looking like “spaghetti”. Various different sizes of choppers can be selected to suit the intended use of the final product. This apparatus or “chopper” is made up of a perforated curved screen, in front of which turns a screw or blade that compresses the plastic sludge.

Under the chopper, “spaghettis or worms” of sludge fall by gravity onto a pivoting conveying belt forwarding the materials in the belt dryer.

Sequence 3 (Convection drying)

The second drying step is a belt dryer, heated with a hot air closed loop system. Hot gases are transported under the lower drying belt from where the dried sludge is released. The belt dryer is manufactured with 2 or 3 tiers of belt, related to the evaporative water throughput; it achieves drying up to dry residue content of 90 % at 95 %.

To improve the overall efficiency, this process recovers energy for second stage heating from the water condensation produced from the thin film dryer.

The condensed vapours from the first phase indirectly reheat a closed loop system for the second stage of drying. The exhausted air from this phase is then subjected to condensation prior to being reheated for the first phase of the process.

Only 650 kWh of thermal energy is required per tonne of evaporated water. This represents energy savings of 30 % to 40 %.

The process sets new standards of drying plant safety (explosive atmosphere); the operational temperature of the second step plant is below the ignition limit thereby ensuring safe conditions. Granule is largely dust free and vapour condensate release is an extremely low load to the WWTP.

5.4 Solar dryer

Solar/ventilation drying plants, while varying in process technical features are, in practice, to a large extent similar.

A typical process consists of an area sealed from the subsoil, and covered with a greenhouse construction using highly transparent sheets of glass. The drying process takes place in this formed space. Through solar radiation, the space is heated up, dependent on the weather conditions and thus the water capacity of the air is increased. As a rule this air is passed outside via upward exhaust shafts. Control can take place by opening and closing apertures. Exchange of air can be improved using ventilators.

Drying time is essentially dependent on the air temperature in the drying plant, the water saturation of the outside air and the rate of exchange of the air within the system (Kassner 2002, see [17]).

In order to turn the sewage sludge to encourage the drying process within the plant, an advancing cylinder with spiral shaped shovels on it, mounted on rails, can be used. As an alternative, conveyor belts, which are arranged at different heights, can be employed to achieve turnover and mixing by being operated several times a day.

Depending on the regional climatic conditions, an evaporation rate of 500 kg H_2O / (m².a] to 950 kg H_2O / (m².a] is possible in Central Europe. Varying evaporation rates depending on weather conditions and the time of year need to be taken into account. In Central Europe one may reckon that about 70% of the evaporation might be gained during summer time. Hence during winter times sludge shall be stored.

The energy demand for the process set-up can be roughly estimated about 25 kWh/t evaporated water (Kassner 2003, see [18]).

Solar/ventilation dryers can achieve a dry residue content of more than 85 %. Special treatment of escape vapours is not usually essential. The need for odour scrubbing of the exhaust air is a site-specific issue.

6 Drying plant ancillaries

6.1 General

In a drying plant, the dryer is the central piece of equipment, but several functions shall be met:

- Storage of wet sludge;
- Treatment of escape vapours;
- Treatment of odours;
- Pelletisation of dried sludge;
- Storage of dried sludge.

There is a big difference between drying plants operated within a Waste Water Treatment Plant and “central” drying plants treating sludges from several WWTPs. In the latter, the storage of wet sludge needs to be planned. Also, the treatment of escape vapours which require large amounts of water to be discharged need to be given special attention.

Wet sludge storage will not be described in detail. It can entail some high costs if several silos are needed. The cost will include truck unloading pits, transfer pumps, water drains, odour treatment and the feeding of the dryer. In such a plant, the cost of the dryer may be only 50% of the total investment cost, especially when one accounts for all the civil engineering, buildings, roads, landscaping and the cost of engineering studies and permitting.

Permitting is not treated in detail in this report, as it is very dependent upon country and region. But some national regulations may require limits on VOCs or sulfur dioxide (SO_2). In most dryers, the sludge itself is not heated to more than 100°C, the organic matter is not volatilized and heavy metals are not or only minimally transferred to the gas phase.

6.2 Treatment of escape vapours

The vapours, which are removed from the dryer during its operation, are a mixture of air and water vapour, polluted by dust, VOCs and ammonia. The degree of pollution of this mixture depends upon the temperature inside the dryer, the residence time of the sludge and the quality of the sludge. The treatment of escape vapours is therefore very dependent upon the upstream drying process. According to the type of dryer, this treatment will include:

- Separation of the dry granule and dust;
- Cooling and condensation of water vapours;
- Cooling water treatment;
- Odours treatment for air that will be discharged.

6.2.1 Separation of the dry granule and dust

With convection dryers the dried product is transferred outward, together with the escape vapours, from the process and is separated before condensation. Here cyclones or dust filters are used and care shall be taken to ensure that the dew point in the device is not exceeded. Exhaust vapours from conduction dryers generally do not need a specific treatment for particulate removal. If cyclones or dust filters are used subsequently then this will be to reduce the return loading to the sewage treatment plant.

A big difference between convection and conduction dryers is in the quantity of air carried. In a drum dryer evaporating 3 tons of water per hour, the airflow is around 30.000 Nm^3/h. However, once the pellets are separated, 50 to 75% of this flow is recycled through the dryer, and only 10.000 m^3/h is exhausted. The humidity of this air depends upon the location of the condenser. Some manufacturers cool the totality of the flue gases in order to have a rather dry flow across the drum, whereas some others install the condenser to treat only the exhausted air.

In a conduction dryer of the same size, for example a paddle dryer, the amount of air extracted and treated for release is around 5 000 Nm^3/h, and it is mostly (more than 80%) water vapour.

6.2.2 Cooling and condensation of water vapours

For all types of water evaporators, the heat needed to condense the water is the same (the quantity needed for air cooling is small in comparison). According to the desired outlet temperature, the need is roughly 10 m^3 to 30 m^3 of water per ton of water evaporated.

In WWTPs, this amount of water is easy to obtain and it can be discharged at the entrance of the treatment plant, though the extra pollution load should be taken into account. However, if the water shall be discharged to a municipal sewer network, there are some restrictions on temperature and pollution, and the cost is such that the amount should be minimized and therefore only the evaporated flow is sent back after some treatment.

Condensation of the escape vapours is therefore done either by direct injection of cold water in large quantities or by a tube condenser in which water circulates in closed circuit and is cooled by a cooling tower.

In the first case a large quantity of water is sent back for treatment to the WWTP. In the second case only a small amount, corresponding to the evaporated water of the dryer, has to be treated.

As the escape vapours still have a relatively high heat potential, utilisation of the energy via heat recovery should be provided for indirect digester heating or sludge warming before dewatering.

The dried and cooled air shall be treated for odours before being discharged (see 6.2.3).

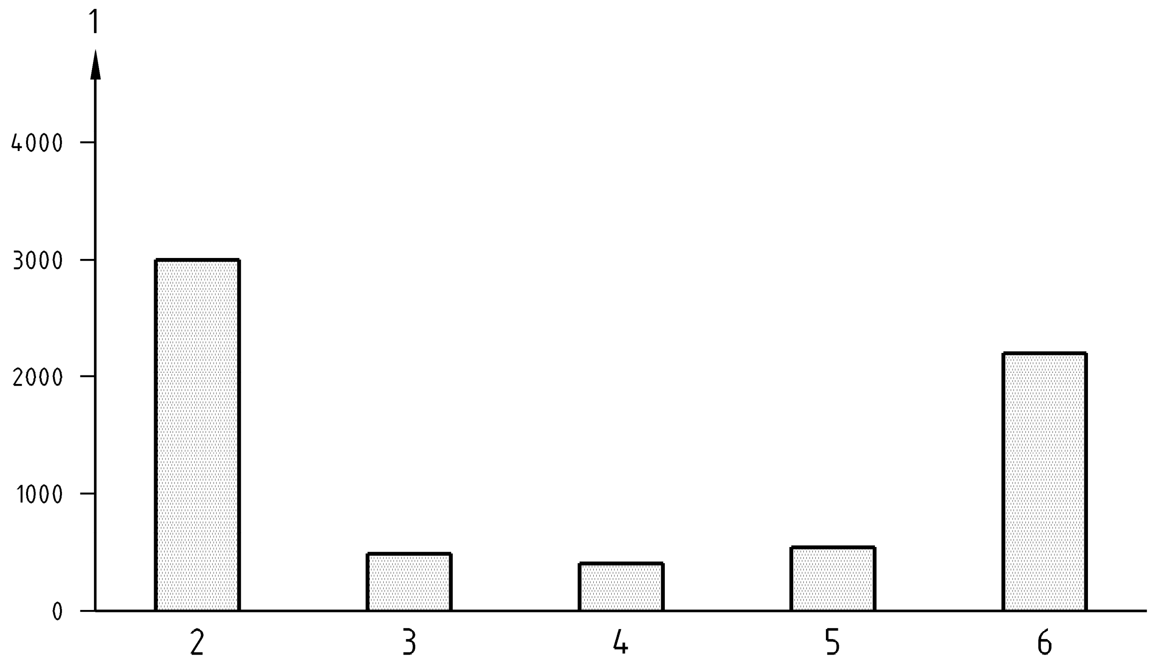
6.2.3 Cooling water and condensate treatment

The loading of the vapour condensate is dependent on the pre-treatment of the sludge (e.g. anaerobic or aerobic stabilisation) and the granule temperature during the drying process. The concentration of ammonium in the condensate rises with increasing heating of the sludge during drying.

With conduction drying, the ammonium concentration is significantly above that of convection drying. The maximum ammonium loading of the water vapour condensate according to a German survey is shown in Figure 15, whereby the variation range, even with stationary dryer activity, is considerable (belt dryers are not considered).

The vapour loading with BOD_5 and COD is only indirectly dependent on the dryer type, rather is almost exclusively determined by the dust content of the vapour. Fluidised bed dryers without downstream dust removal have very high COD vapour condensate loadings of up to 7,000 mg/l. With this system one should not dispense with dust separation.

As the amount of condensate itself makes up only approximately 10 % of the concentrate/filtrate quantity of the sludge even with full drying, the significance of the reverse loading of a sewage treatment plant from the vapour condensates is to be rated as small. This, however, does not apply for central drying facilities in which the sludge from several sewage treatment plants is dried, but the vapour condensates flow only to the local sewage treatment plant (ATV-DVWK 2001, see [10]).



Key

1 Maximum ammonium reverse loading (mg/l)

2 Fluidised bed dryers

3 Drum type dryers

4 Thin film dryers

5 Thin film/disc dryers

6 Disc dryers

Figure 15: Maximum measured ammonium concentrations in vapour condensate according to operators' information (ATV-DVWK 2001, see [10])

6.2.4 Odour treatment

The non-condensable parts of the vapour, which are ejected with the air from the condenser, have to be treated separately. Technical process for this include bio/compost filters, bio washers, absorption/adsorption facilities and thermal oxidation.

An effective means of destroying VOCs is incineration (thermal oxidation treatment) at a temperature above 800°C. In some facilities equipped with conduction dryers, the non-condensable gas is sent back to the boiler. This is possible because the volume of non-condensable gas is small with conduction drying. This system can be used as well with convection dryers with indirect heating.

However, these systems have limitations in their efficiency and can bring corrosion in the burners. In the case of strong regulatory limitations on VOC emissions, dryers are equipped with thermal oxidation systems. There are two different types of system, the recovery systems (the gas is preheated in an exchanger before entering a combustion chamber) and the regenerative systems (known as RTO). Their principle of operation consists of heating alternately two refractory-lined chambers with the hot gases from a burner, then passing the gases to be treated through these chambers.

The investment cost of such systems is high and there is some additional operating cost for fuel but all the odours are removed and, in addition, there is no production of flue gas plumes.

Besides the exhaust gas from the dryer, many fans are used in a drying plant, for dedusting or removal of odours to keep the working place healthy. The air, which is collected, is sent to bag filters, and after dedusting, some of it can be sent to the main odour treatment, which shall be sized adequately.

6.3 Pelletisation of dry products

Thermally dried sludge products normally take the form of granules or pellets, the latter being made by a pelletiser attachment, which the dried sludge passes through as the last stage of the process. Dried sludge can be fluffy and dusty before it is pelletised. Maintenance of pelletisers can be important because they are subject to high wear.

Direct dryers usually don't need post-pelletisation, since a granule produced by the dryer, either because of recirculation (drum and fluid bed dryers) or upstream granulation (belt dryers). Only if the product is not hard enough (raw primary sludge) is it necessary to use another pelletiser downstream.

For agricultural use, a range of approximately 2 mm to 3 mm is thought preferable. Where a pelletiser is fitted to the end of the drier it can be adjusted to give the preferred size of pellet. Pellets can be controlled by addition of water. The use of the product shall be considered when making any chemical additions (see clause 9).

6.4 Transport and storage of dry products

With transport and storage of the dry products the extent of drying, in particular the granule size and the product temperature, should be taken into account. Partially dried sludge should be treated principally as thickened sludge (e.g. exhalation).

In partly dried sludge biological activity can restart. This can lead to a rise of temperature so that safety aspects and odour problems need to be considered. For protection against explosion and fire see clause 8. With fully dried sludge there can be considerable development of dust depending on the drying process. Dependent upon the nature of the product covered containers could be necessary for transport. The possibility of self-ignition due to creation of explosive atmospheres in storage or transport shall be addressed. The conditions are to be taken into account by careful operational management (no heat due to friction). Long storage times in silos should be avoided as caking can occur.

For many operators conventional bucket conveyors have proved not to be suitable for the transport of the dried sewage sludge. Abrasion problems occur in these, particularly in the area of the chains. With pneumatic transport blockage problems can be experienced due to the high fibre component in the dried product. Corrosion and abrasion in the silos and on the conveyance units are to be countered by a suitable choice of material like stainless steel, ceramic etc.

If cloth filters are employed for dust separation frequent transition through the dew point is to be avoided so that the filters do not clog prematurely. If appropriate management of the operation cannot prevent this, additional heating can be installed. With the employment of heat exchangers for vent condensation attention shall be paid to prior dust separation as otherwise depositing and encrustation can occur (ATV-DVWK 2001,see [10]).

7 Operation

7.1 General

This clause gives a brief overview of variable costs (energy and other consumables) and elements to assess fixed costs through availability, maintenance and staffing.

Energy costs usually represent the largest part of the operating cost of a thermal dryer, and numerous data are available. There is not much need to review the other variable costs such as cooling water (it is usually available at low cost in a WWTP and can be treated also at low cost. Some chemicals may be needed to lower ammonia in the flue gases, and compressed air is used for pneumatic transport and bag house cleaning. One important item can be liquid nitrogen used to inertize the dry product storage silos.

7.2 Energy ranges

7.2.1 Requirement for thermal energy

The theoretical energy requirement for the evaporation of one tonne of water is, at normal pressure, 627 kWh. In addition, there are 93 kWh for the heating of the water from 20 °C to 100°C and 14 kWh for the heating of the solid material. Direct heat losses represent slightly more than 100 kWh, 20% via the surface of the dryer and 80% due to the efficiency of the energy conversion.

This represents a total of around 834 kWh / t H_2O evaporated. In practice, some specific consumption data can be found in a study by GDF (Gaz de France) and ADEME (1998) [19]:

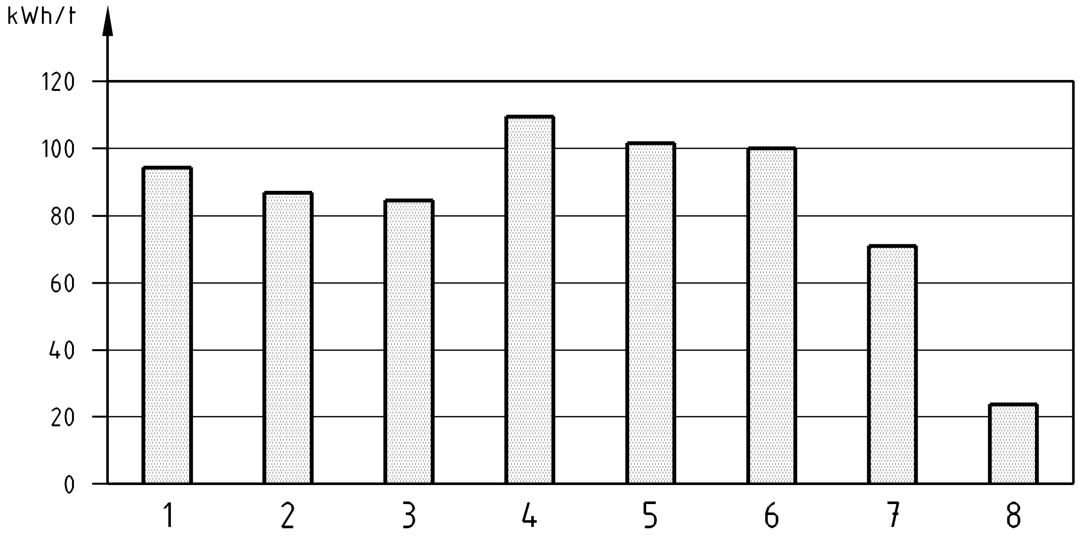
- Disc dryers: 855 kWh / t H_2O to 955 kWh / t H_2O
- Paddle dryers: 800 kWh / t H_2O to 885 kWh / t H_2O
- Thin film dryers: 800 kWh / t H_2O to 900 kWh / t H_2O
- Belt dryers: 950 kWh / t H_2O to 1140 kWh / t H_2O
- Direct drum dryers: 900 kWh / t H_2O to 1100 kWh / t H_2O
- Combined dryers: 950 kWh / t H_2O to 1050 kWh / t H_2O

This last number is representative of drum dryers with no or little flue gases recirculation. It is well known that in this scheme, between 30 % and 40% of the input energy can be lost in the flue gases. For modern equipments, this loss can be strongly reduced by recirculation, and the average thermal need is between 930 kWh / t H_2O and 1000 kWh / t H_2O (see for example Hassebrauck and Ermel, 1996 [20]). This heat loss is still large compared to conduction dryers, which nearly always have smaller thermal energy needs.

The latter factors can be modified through optimised planning and design. As these are nevertheless only about 10 % of the energy input, there remain practically no possibilities for energy saving with sludge drying. Basically, for the optimisation of the overall process the upstream dewatering machine - centrifuge or chamber filter press - should have as high as possible solid matter separation. For economic and technical reasons there are, however, limits set (ATV-DVWK 2001, see [10]).

7.2.2 Requirement for electrical energy

With the drying of sewage sludge, electricity is required primarily for the driving of drying equipment. In addition, there are many ancillary units, e.g. for the transportation of sewage sludge, treatment of exhaust vapours or for the boiler plant. Figures for usage for the overall system vary between 70-kWh/ t H_2O and 110-kWh/ t H_2O water vaporised (Figure16). Basically the requirement for electrical and thermal energy increases with higher sewage sludge dried content.



Key

1 Flash dryer
2 Fluidised bed dryers
3 Drum type dryers
4 Thin film dryers
5 Thin film/disc dryers
6 Disc dryers
7 Belt dryers
8 Solar dryers

Figure 16: Requirement for electrical energy for the vaporisation of 1 t of water in various drying plants (ATV-DVWK 2001, see [10])

7.3 Availability and maintenance

Before going to availability and maintenance, it is important to give a few words about staffing, since it is closely related.

Most industrial manufacturers of dryers provide an automatic computerized supervision system (SCADA) which are an essential feature, as they usually include sequential programmable logic controllers (PLC), which control plant start-up and shutdown, and manage all the alarms.

If a good part of the safety of the plant relies upon SCADA, the next big question is the need for posted staff. A lot of wastewater treatment plants are not manned during the night, because the biological processes are not subject to rapid change. Similarly, in conduction dryers, the residence time of the sludge is usually of the order of 4 h and they can be stopped automatically in case of problems.

Direct dryers have smaller reaction time (of the order of half an hour) and the back mixing is controlled visually quite often, which means staffing in 3 shifts is essential. Also, large drying plants receiving sludge from different WWTPs also need round the clock watch. With a good SCADA system, the operators can spend most of their time on daily maintenance, especially of all the sensors, which keep the supervision effective.

Availability of dryers if often given by the manufacturers as 8 000 h per year (96%). This is very ambitious, and the learning curve to reach it can be a year or more, according to the efficiency of the manufacturers' starting team. The issue is very different in a plant operating 6 or more dryers than in a plant with a single dryer, where provision shall be made to store or dispose of wet sludge during stoppages.

Most of the large dryers necessitate at least one long stop (two weeks once yearly or one week twice) for major maintenance. The nature of this maintenance is very dependent upon the type of dryers: indirect disc or paddle dryers are sophisticated mechanical pieces, which need lubrication and tight clearances to avoid thermal fluid leaks. Belt dryers also need periodic tensioning and alignment of the belts.

Abrasion and wear are the most common sources of non-availability of a dryer, whatever its type is. For disc and paddle dryers, the choice of material is essential as the discs are subject to thermal stresses and wear at the same time (plus corrosion if steam is the heating medium). The change of a worn paddle requires opening the dryer and lifting the main shaft, which is usually very heavy. For direct drum dryers, the wear problems are more frequent in the dry sludge recycling circuit shredder, vibrating screen and in the mixer. A certain quantity of spare parts shall be kept, but their cost depends very much on the dryer type.

Dry sludge conveyors (or pneumatic transports) are a source of wear for all kinds of dryers. Many sensitive spots (elbows) are reinforced with special steels or ceramics.

Weekly stops shall be planned, mainly for cleaning (dust accumulations in circuits, or even hardening wet sludge in dead zones of the dryer). They do not need to be very long, but the time of stoppage (and cooling) plus the time of re-starting can strongly influence the availability.

Non-availability of driers due to shut downs and maintenance can cause considerable problems with the continuous production of raw sludge. To overcome this some best practice guidelines have been developed:

- Include substantial redundancy/over-capacity in the plant design by including at least two or more parallel dewatering and/or drying lines with the number and capacity of the lines configured so as to allow, ideally, up to 100% of the design throughput to be maintained even with one of the process units unavailable.
- Include substantial buffer storage capacity upstream of the drying plant – liquid or cake having an overall storage capacity equivalent to at least 3 days throughput of the drying plant.
- Establish a fully integrated team of appropriately qualified and well-trained site based personnel with the technical and financial resources to deal immediately with all operational and maintenance –related issues associated with the plant.

8 Safety considerations

8.1 General

Depending on the design of the plant there is potential for a dust explosion to occur in the main dryer, dust collection and handling plant, pellitiser and final product discharge plant. Once dried, material in the plant can also self heat leading to ignition and a slow burn which may be accelerated with the ingress of additional air into the plant. Dried product in storage may also self ignite and storage silos need to be specially designed and monitored. Additionally transportation needs to be considered, as some products may not be suited to bulk transport because of fire risk.

Fully dried sewage sludge is similar to a solid fuel, and as such shall be stored with precautions. Being organic in nature, the dried sludge can warm up during storage, and dried sludge silos, like grain silos, shall be specially designed and monitored.

The main European regulations are the Directive 94/9/EC (see [4]) concerning equipment and protective systems to be used in potentially explosive atmospheres and the Directive 99/92/EC (see [8]), which deals with the minimum health and safety requirements that, shall be satisfied in a production site.

8.2 Fire and explosion risk in sludge drying plant

In a sludge drying plant, there are two main risks specifically linked to sludge:

1. A risk of fire, mainly linked to self heating of the dried sludge storage;

2. A risk of explosion, which can happen when a spark inflames a dust cloud, or when coming in contact with a hot surface.

Not withstanding the risk of natural gas explosion in the boiler house of the dryer, gas explosions due to sludge can occur in two cases:

3. If dried sludge stands for a long time in an airtight atmosphere, in contact with a warm surface, it can smoulder and generate some explosive gases like carbon oxide (CO) by pyrolysis.

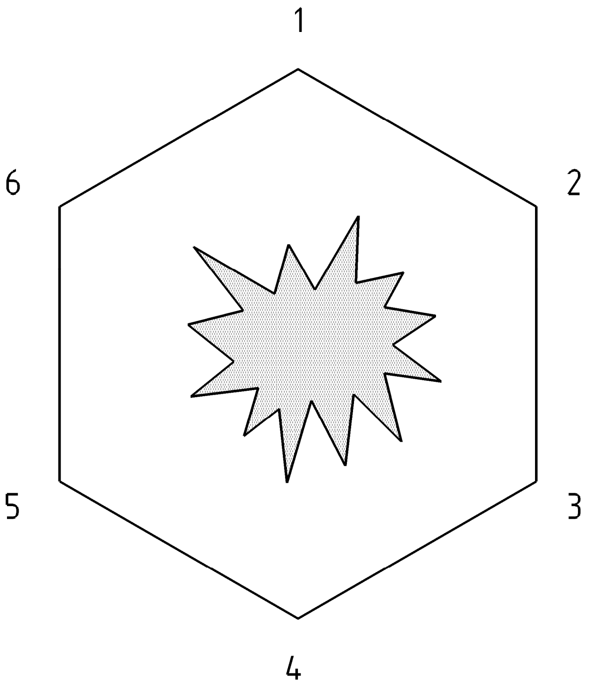
4. Wet sludge, in anaerobic conditions, can produce biogas (methane (CH_4) with traces of H_2S), which can explode, even though the biggest risk for the workers is suffocation.

Risks 1 and 2 should be limited by a careful design of the equipments (dryers, silos…), whereas tight operational procedures will reduce risks 3 and 4.

8.3 Sludge characterization with respect to explosion risks

Different conditions, summarised in Figure 17, need to be satisfied for a dust explosion to be set off. A fire needs a fuel (the dry sludge), some oxygen and an energy source. To become an explosion, the fuel will be dispersed (dust), the concentration will be within limits and there will be some confinement.

Laboratory tests are used to try to reproduce explosion conditions in closed vessels such as calorimeters or Hartmann bombs, in order to determine the critical parameters for different products such as coal, grains or dry sludge.



Key

1 Ignition source
2 Dust concentration
3 Oxygen
4 Confinement
5 Combustible dust
6 Dust cloud

Figure 17: Dust explosion hexagon ('see [20] and [21])

Among those parameters, the dust granulometry is important and dust pellets are much more difficult to ignite. A dust explosion can be started when a sufficient dust concentration (minimum explosion concentration (MEC)) is present in a confined space with enough oxygen (limiting oxygen concentration (LOC) under which an explosion is not possible). The explosion is set off by a source of energy characterized by a minimum ignition energy (MIE).

The explosion can also start if a dust cloud comes into contact with a hot surface at a temperature greater than the minimum ignition temperature (MIT). A layer of dust can also be set on fire if it is deposited on a hot surface, the temperature of which is higher than the layer ignition temperature (LIT), which decreases when the thickness of the layer increases.

Once an explosion is started, it can be characterized by the highest pressure attained (P_{max}) and by the speed at which it is attained. The explosion constant K_{st} is used in nearly all countries. If K_{st} is lower than 20 MPa m s^{-1} (200 bar m s^{-1}), the explosive dust is classified as ST1, which is the case of most dried sludges (ST2 implies K_{st} between 20 MPa m s^{-1} and 30 MPa m s^{-1}, whereas ST3 is for K_{st} greater than 30 MPa m s^{-1} (300 bar m s^{-1}). In Germany, a burning number (BZ, from 1 to 6) (ATV-DVWK 2001, see [10]) is also used.

These tests are done in specialised laboratories such as the Fire Research Establishment in the UK, INBUREX in Germany or INERIS in France (see [21]). In the Table 1, are given values compiled from the bibliography which show that sludge dust, like granule dust, is “explosive” at lower temperatures than coal.

Table 1: Examples of safety characteristic values of dried sewage sludge

		Sludge	**Sludge**	**End-product ground**	**Sieved-product > 1mm**	**Municipal sludge**	**Municipal sludge**	**Coal**	**Wheat flour**
Source		HSE	VDI	ATV	ATV	Pollet [22]	Pollet [22]	HMFI	HMFI
MEC minimum explosion concentration	g/Nm^3	60	60 to 500			60	125	55	50
LOC limiting oxygen concentration	% volume fraction	5 to15	16 to17			5 to 8	15		
MIE minimum ignition energy	mJ		490 to 735				420 to1300	55	50
MIT minimum ignition temperature	°C	360 to 550	360 to 510	450			460	610	380
LIT layer ignition temperature	°C	160 to 375	230 to 430	260	260	230 to 250	250		
P_{max} highest pressure attained	MPa	0,6 to 0,9	0,66 to 0,77	0,65	0,31	0,64to 0,71	0,77	0,59	0,64
K_{st} explosion constant	MPa m s^{-1}	5 to 20	3,6 to10, 4	7,9	0,6	8,8 to 9,7	11,2 to15, 7		
Classification		ST1 [(a)]	BZ3 to BZ5 [(b)]	ST1 BZ3	BZ3		BZ4		

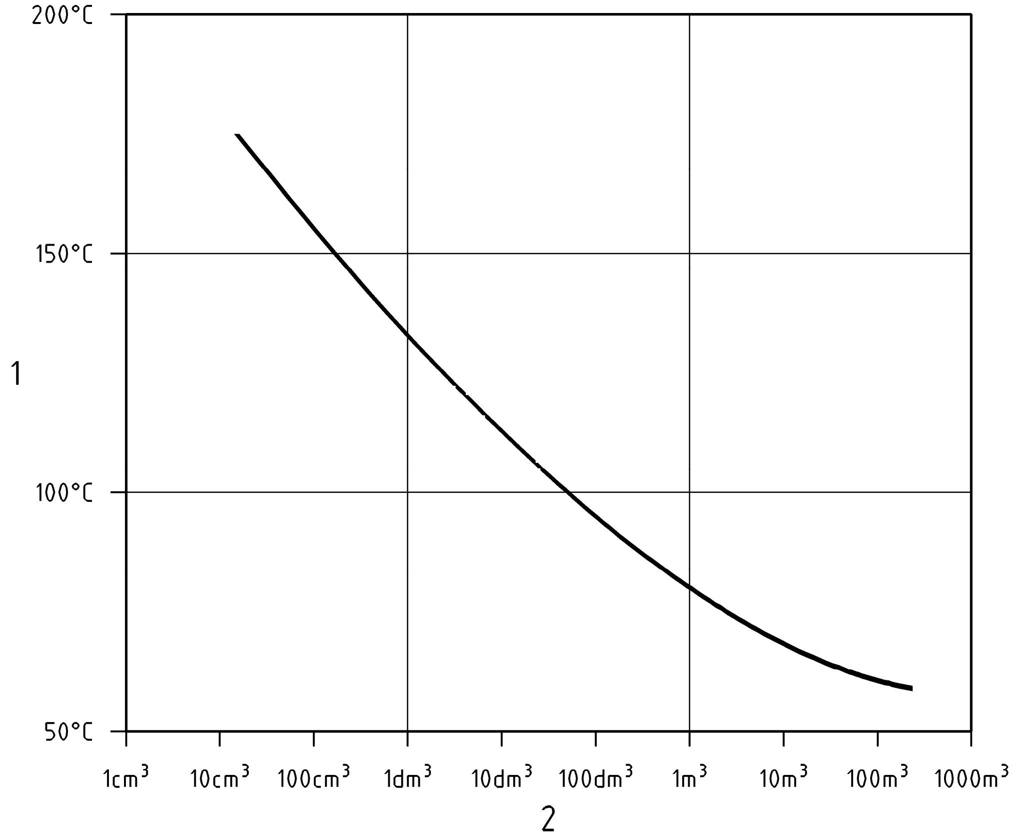
(a): ST = dust explosion class
(b): BZ = assessment value

As some dispersion is seen in the tests, much standardization work is still needed. The CEN/TC 305 "Potentially explosive atmospheres-Explosion prevention and protection" is in charge of standardization in this field, with EN 14034-1 to 4 [23]. Those methods are also given in the reports IEC 61241-2-1 to 2-3[24] published by the International Electrotechnical Commission, which edits standards for all electric equipments, including those with special protection against explosions.

8.4 Self heating of dried sludge

The majority of organic materials tend to oxidize spontaneously in air. This is particularly the case with dried sludge granules. The reaction is slightly exothermic and takes place very slowly at normal ambient temperature. However, the heat losses through the granules by conduction are relatively slow because the granules act as an insulator. There is therefore a critical temperature above which the temperature increases in the mass, in turn increasing the speed of the reaction and causing the granules to catch fire (Frank – Kamenetskil, see [25]).

INERIS and other laboratories such as the BRE (Building Research Establishment) perform tests in cubical wire mesh baskets of different sizes put in ovens which are then heated and maintained at a given temperature (isothermal heating) to determine a critical temperature at which combustible powders reach self-ignition as a function of volume. An example of such a curve is given on Figure 18 where the critical temperature is plotted as a function of storage volume. Rather than volume, one can use other characteristic parameters, such as a volume to surface ratio or a cube half-size.



Key

1 Self-ignition temperature in °C

2 Volume of dust

Figure 18: Self-ignition temperature of cylindrical sewage sludge dust piles (ATV-DVWK 2001, see [10])

Figure 18 shows that for the sizes of silos used (larger than 1 000 m^3), the critical temperatures are about 50°C.The storage silos of the large US drying plants are maintained at less than 40°C. It should be mentioned that recently there is some evidence in UK that self-ignition can occur at 50°C on volumes of much less than 100 m^3.

In practice, these data are used in the design of silos, where one chooses a slender shape (small radius, large height) in order to facilitate the cooling through the walls. Those silos will always have vents, which are calculated as a function of P_{max} and K_{st}.

8.5 Principles of plant safety

Risk assessment should involve identifying the hazards present in the working environment or arising out of the work activities. Risk assessment should be reviewed typically annually or when there is a significant process change. The risk assessment needs to identify the relevant hazards from the material given its likely condition in different parts of the plant. Once the plant is operational a review of the original risk assessment should be carried out with particular emphasis on likely operator interventions e.g. blockage removal. A risk assessment should be carried out for reasonably foreseeable contaminants e.g. petrol which could enter the plant. Similarly it should include measures for the removal of 'ignition sources' such as metal or stones, which could cause a spark.

The risk assessment will include an assessment of where explosive atmospheres may form. These zones will then be used as a basis for selecting electrical and other equipment.

Besides the storage area, general safety measures shall be applied across all the plant. Risk assessment studies (Hazard and Operability Studies (HAZOP)) shall be carried out and employers shall classify areas where accumulations of combustible dust and gases can occur, as prescribed by the 99/92/EC Directive [8].

It should be remembered that the risks of a fire or explosion can be reduced by:

- Avoiding a flammable atmosphere;
- Inerting;
- Avoiding ignition sources.

If those are not sufficient, protective measures shall be taken in the design of the plant to avoid propagation of a fire or an explosion:

- by providing explosion relief venting (on the granule silos in particular);
- by providing fire-fighting systems (water, CO_2, etc.);
- by providing fire containment systems;
- by separating the different parts of the plant with fire barriers.

8.6 Safety of operation

The most important aspect of safety in operation is to keep low oxygen content in the dryer itself. The maximum permissible oxygen concentration (MPOC) should be 2% under the limiting oxygen concentration (LOC) measured for the sludge. This safety margin may need to be increased if for instance the response of oxygen sensors is slow, or the detector head is remote from the place where the oxygen content starts to rise. When selecting an oxygen sensor system it is important that the supplier confirms its suitability for use at elevated temperatures, high humidity and with the likely contaminants present. A crucial point of operation is during shut down and start-up in particular after a short shut down when the LOC could potentially be breached. This should be addressed in the risk assessment.

Oxygen sensors (as well as CO and CH_4 sensors) in appropriate places shall be monitored and automatic shut down actions taken in case of values being exceeded. More generally, detailed start-up and shutdown procedures should be followed. Even after long stoppages, there exist some risks of explosion due to smouldering of sludge that has remained in stagnant areas. Suitable procedures should be in place to prevent smouldering such as stabilising by the addition of water or fresh sludge. Of particular concern are places inside the drier where dry material is left to build up. Over time such material absorbs more heat and with an increase in oxygen levels may rapidly start to burn.

Temperature monitoring of many parts of the plant is also essential. The dry sludge will be cooled at the exit of the dryer to less than 50°C and careful monitoring will be made of its temperature in all transport circuits and in the storage silos. All these circuits will be kept under negative pressure by a ventilation system that will allow the dust to be collected in a sleeve filter and a silo. It is sensible to avoid opening them, especially after an emergency shutdown. The dust shall of course be sucked out before personnel enter the circuits for servicing or maintenance work.

The operators should maintain the plant clean and avoid dust build-ups, especially around such areas as granulators, crushers and sieves. During their inspection rounds, they should also check that no spark is emitted by worn out conveying belts, or bearings. There should be no abnormal temperature increase due to friction.

A high level of training is imperative for all new operators and supervisors. This training shall cover emergency situations and refresher training and emergency exercises should be included for all staff. Suitable protective clothing should be provided particularly to minimise contact with dried sludge dust.

9 Characteristics of dried sludge products

9.1 Dried solid content

Depending on the drying process, dried sludge can reach a dry residue content up to 95 %. If dry residue content is below 85 % (except for well digested sludge) possible risks of fermentation and smells should be considered. In a range of 65 % to about 75 % of dry residue content sludge is to be considered as a non-storable material. Drying processes with back mixing of dried sludge can lead to sludge with dry residue content > 90 %, whereas, with some other drying processes without back mixing, dry residue content could be managed below 90 %.

9.2 Form of dried sludge

The form of dried sludge depends very much on

- origin and nature of sludge to be dried (primary, activated, humus, co-settle sludge, digested or non digested);
- drying process focused on the dryer technology;
- process operation.

Table 2: Examples of possible forms of dried sludge subject to the origin of sludge and the type of dryer

Origin and nature of sludge to be dried	Drying system	Dryer type	Final product
Primary raw sludge	Conduction	Thin film + segmental disk dryers (2 stages)	Fluffy material. Bulk density 200 kg/m^3 to 230 kg/m^3. Pelletizing is required, because the raw material cannot be used as it is produced
Primary raw sludge	Conduction	Paddle dryer	Fluffy material. Bulk density < 200 kg/m^3. Pelletizing is required, because the raw material cannot be used as it is produced
Non digested sludge: blend of 70 % primary sludge and 30 % biological activated sludge	Conduction	Thin film + segmental disk dryers (2 stages)	Fluffy material with granules. Bulk density = 350 kg/m^3
Digested sludge: blend of 50 % primary sludge and 50 % biological activated sludge	Convection	Drum single pass	"Hunting lead" material aspect – icy bright surface – bulk density = 650 kg/m^3 to 750 kg/m^3 – granule size = 2 mm to 4 mm after classifier
Non digested sludge: blend of primary, biological and chemical sludge	Conduction	Thin film + segmental disk dryers (2 stages)	Fibres and granular material aspect –different forms – bulk density = 450 kg/m^3 to 550 kg/m^3
Digested blended sludge	Conduction	Disk dryer	Very tiny particles < 250 µm – bulk density = 850 kg/m^3 to 900 kg/m^3
Digested blended sludge	Conduction	Multi-tray dryer	Ovoid form and dull surface granules – bulk density = 780 kg/m^3 to 820 kg/m^3 – particle size of granules = 1 mm to 5 mm
Blend of primary and chemical sludge	Conduction	Fluidised bed dryer	Material with very irregular aspect – particle size = 2 mm to 8 mm.

Dried sludge can also be classified in accordance with some usual forms:

Pre-formed dewatered sludge up to 30 % of dry residue content: "black-pudding", "chipolatas", and "spaghettis".
Pre-dried sludge 30 % to 40 % of dry residue content: sticky and gummy material.
Pre-dried sludge around 50 % to 60% of dry residue content: sludge lump – shearing phase.
Pre-dried sludge: 58 % to 65 % of dry residue content: flakes shape – granule material looking as gravel and stone.
Partly dried sludge below 90 % of dry residue content

Fully dried sludge above 90 % of dry residue content (see Tables 2 and 3):

- High bulk material: ragged hay, smashed cotton
- Dusty and fines material: powder
- Blending of dust, fines and granules – angular shape with very hard and dry sludge granules
- Granules with a very narrow mesh size - icy bright surface looking like "shooting lead" – no dust
- Large particle size granules, - dull and porous surface, ovoid form - no dust
- Granules with high spherical form and non ovoid form – no dust

Reconstituted dried sludge with dry residue content > 90 % comes as pellets or aggregates.

Table 3: Optical description of some dried sludge dry residue content at 90 %

Material description –	Particle size measurements	Remarks
Fines particles and dust only	< 250 µm	Dust are classified as particles particle size < 63 µm (flight)
Smooth granules – spherical granules – hard material	0,5 mm to 1 mm – homogenized figures	No dust – previously screened material
Material with frozen bright surface – micro-balls	2 mm to 4mm – homogenized figures	No dust – previously screened material
Granules with a small and rough sticks shape.	Diameter 4 mm to 7 mm/ Length 10 mm to 25 mm	No dust– end material can be cut at adjustable length.

Colour and presence of litter in sludge depends on waste origins and treatments. By anaerobic digestion, and with presence of iron sulfur, sludge becomes very dark and black, whereas raw sludge will have a grey colour.

Liming treatment for chemical stabilization tones down the colouration (lightens).

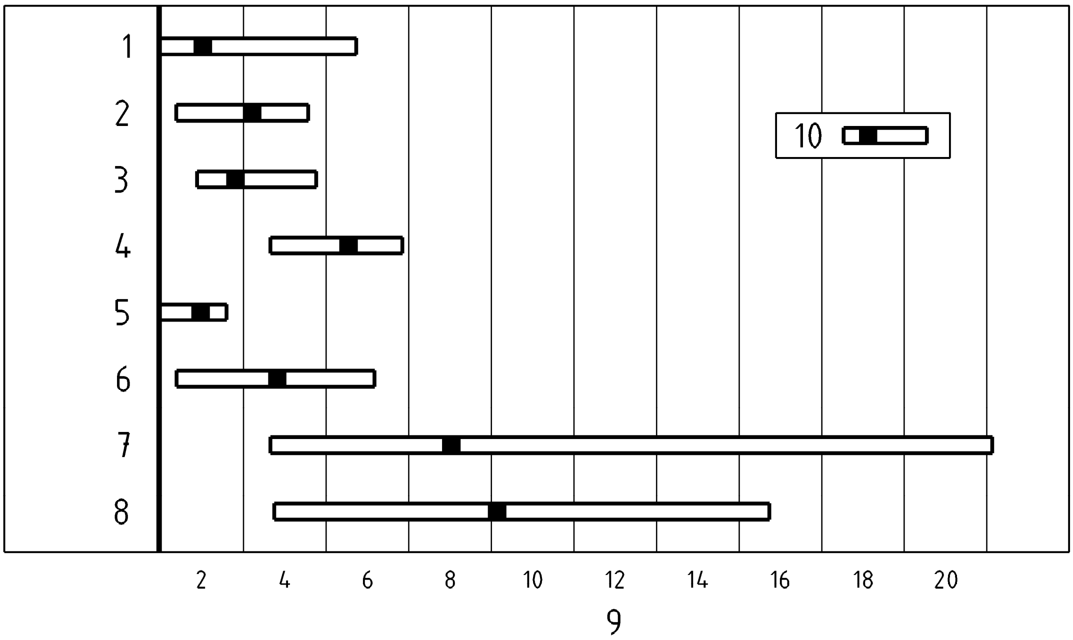
9.3 Bulk density

The range of densities may vary from 350 kg/m^3 to 900 kg/m^3 .The average is about 650 kg/m^3. Bulk density is exceptionally high for very tiny granules of non-organic sludge content. At the opposite, it is weak for a dried sludge produced from dewatered extruded material (350 kg/m^3). Raw primary sludge that contains fibres will always have a bulk density very inferior to digested sludge. Thus, the value of 350 kg/m^3 can be measured for thermally dried undigested sludge, which can be a loose fluffy material.

The exact density of sewage sludges is site specific and can be predicted only in broad terms. After manual compaction, the bulk density often rises up to 10 %.

9.4 Corn granule spectra of dried sludge

Figure 19 shows that the granule spectra, dependent on drying method, can be subject to a wide range of variation. This, in most cases, can be limited by additional sieving.



Key

1 Disc dryer
2 Drum type dryer
3 Fluidised bed dryer
4 Thin film dryer
5 Flash dryer
6 Thin film/disc dryer
7 Belt dryer
8 Solar dryer
9 Granule diameter in millimetres
10 Granule spectrum and mean value

Figure 19: Corn granule spectra of fully dried sewage sludge (ATV-DVWK 2001, see [10])

9.5 Hardness

Hardness or resistance of granules to crushing is dependent on the granulation process.

Successive coatings of wet sludge on dried sludge germs lead to improved hardness of the granules; it can exceed the 50 N, a value generally obtained for chemical fertilizers.

The evaluation of the granules hardness is sensitive. We refer to the works of *CEN/TC 260/GT2 «Determination of crushing resistance ».* As an alternative measurement, one can use a pellets crushing method.

9.6 Durability

The deterioration of sludge granules, during transport, loading and spreading operations can compromise final utilizations; operators require high durability.

Some tests are used in the fertilizer industry as a standardized method for the pellet durability.

9.7 Water sorption

Generally, dried sludge granules that have a high bulk density and a weak porosity don't tend to absorb water. Whereas, dried porous sludge composed of cellulose fibres will re-absorb the ambient humidity.

In order to estimate water sorption, it is necessary to determine the sludge behaviour with the rate of fibres test, as often used in the paper industry. The measurement of dried sludge water sorption has not been fully conducted. It can be observed, after several months of storage in free air, that dried sludges tend to create a crusty layer protecting the sludge granules beneath.

Icy bright sludge granules should have less water sorption than fibrous sludge or those, which have high specific surface area.

9.8 Fluidity and handle ability for flowing and transportation

As the previous measurement of water sorption, there is no standardized method for dried sludge fluidity and handle ability for flowing and transportation. For high viscosity liquid, the flowing time is measured through a calibrated orifice; this method could be applied after a few fittings. The dried sludge granule form, the fibre content, the bulk density and particle size will have strong influences on fluidity and handleability when flowing from silo storage.

9.9 Smell

The thermally dried sludge product is usually odourless or nearly so. All dried sludges give some odour emissions, particularly if the sludge is re-infected by micro-organisms as a result of rewetting. Thus odour can be released after storage dependent upon the conditions of storage.

Emission of odour from dried sludge can also depend on:

- Waste water origin, sludge composition and treatment of sludge (e.g. anaerobic stabilisation);
- The drying process and dryer type (conduction or convection).

10 Outlets available

10.1 General

With dried sewage sludge, there is a wide range of potential outlets available. This is one important advantage of dried sewage sludge as, through this, disposal security is increased. The dried sewage sludge can be fed to various markets, such as:

- Agriculture;
- Land reclamation;
- Incineration, pyrolysis, gasification;
- Co-incineration (power plants, cement industry, brick industry);
- Land filling.

10.2 Recycling to land

10.2.1 General

Provided that benefits to agriculture or ecological improvement can be demonstrated, recycling to land is the preferred option for sewage sludge bio solids according to the waste hierarchy as given in the Waste Framework Directive 75/442/EC [6] as amended 91/156/EC [7]. The key tenet in support of land spreading is that it recycles nutrients and organic matter to the land, which would otherwise be lost in disposal to landfill or through incineration. Land spreading is therefore in accordance with the principles of sustainable development.

The particular advantages of thermally dried sludge products for recycling to land are:

- Thermal drying qualifies as an 'advanced' treatment process so the dried product presents negligible risk of pathogen transmission and is safe to use on the land with minimum restriction.
- Almost odourless.
- Consistent product in terms of biological, chemical and physical properties.
- Supplies nutrients in a more concentrated form than other types of sludge biosolids.
- Can be applied with conventional farm equipment e.g. a lime spreader.
- Handle able and storable with less need for storage space.
- Can be delivered and stored in fertiliser bags – 25 kg to 1000 kg.

The disadvantages are:

- The product can be dusty.
- Release of nutrients for crop growth may be slow if the product is of the hard granular type, which is slow to degrade in the soil.
- The product can become odorous on rewetting, especially if undigested.
- There is some risk of fire during storage.

Dusty, wet or sausage-shaped products are not always favourable for agricultural utilisation. Although one can eliminate some disadvantages using pelleting of the dried sewage sludge, the processing costs are increased through this. From the aspect of phosphate availability, a small grain size is to be sought for agricultural utilisation. Nevertheless, for spreading, a minimum granule size is important as otherwise the fertiliser is too easily blown away. In this respect corn sizes between 2 mm and 6 mm are required for this area of application and the dust portion shall be reduced to a minimum. In addition, importance should be placed on an extensively even granule size, so that an optimum spread with even distribution occurs. Granule sizes greater than 6 mm should be avoided. For storage and pourability abrasion resistance and uniform density are of significance.

It is recommended that spreading pattern tests be undertaken for each granule plant and repeated if there are significant changes in granule/pellet quality.

10.2.2 The fertilizing value of dried sludge

In their study of thermally dried sludge products, Sweet *et al.* (1996), see [26] undertook plant growth tests on dried and cake sludges and concluded as follows:

The plant growth tests showed that there were large significant differences in plant response between sludges applied at the same application rate. However, when the results were examined on the basis of the actual quantities of nitrogen applied there were few significant differences between the sludges.

On a mass for mass basis as supplied to the farmer, thermally dried sludge products would provide substantially more nutrients and organic matter than dewatered sludge cake.

The nitrogen in thermally dried sludge is as available for crop growth as that in dewatered sludge cake. The availability of nitrogen to ryegrass was broadly similar whether or not the thermally dried product was made from digested or undigested sludge.

It was suggested that the nitrogen availability of thermally dried sludge was taken to be 15% in the first year after application to the land (ammonium nitrate fertiliser = 100%) in temperate zones. For high temperatures in southern Europe nitrogen availability can be significantly higher. Furthermore hydrolysis of organic nitrogen in the dryer can increase availability compared with the cake. Similarly the P availability was estimated to be 50% (super phosphate fertiliser = 100%). An exception to this would be where the thermally dried sludge product is in the physical form of hard granules. Availability will be reduced if the granules or pellets do not break down readily in the soil to release nutrients. Plant growth response and phosphate uptake data suggested that there was no difference in phosphate availability to crops according to whether the phosphate was supplied in thermally dried sludge product or in the cake from which it was derived.

There would be further release of nitrogen and phosphate in subsequent years to the first year of application, which would be particularly beneficial to land reclamation operations, for example. The pelletisation process can be adjusted to optimise breakdown of the pellet and release of nutrients in the soil.

Smith et al (2000), see [27] reported laboratory incubation trials on nitrogen in thermally dried sludge products and sludge cake, which indicated that the nitrogen release from thermally dried sludge products could exceed that from the corresponding sludge cake. Their results showed also that the nitrogen content of the five sludge cakes they tested was in the range 4,4 % to 5,8,% of dry residue content compared with 3,5 % to 4,7,% of dry residue content for the corresponding thermally dried products, indicating a loss of nitrogen of about 20 % during the drying process.

10.2.3 Chemical composition variability

After a full thermal drying, (dry residue content ≥ 90 % to 95 %), very little direct variation of nutrient content due to dry residue content exists. This is not the case with a dewatered sludge.

For example, 1 t of sludge at 25 %, 4 % of P_2O_5 expressed to dry residue content, contains 10 kg of P_2O_5 /t of raw sludge. If dry residue content decreases until 20 %, the same amount (1 t of sludge) will only contain 8 kg of P_2O_5, so a difference of 20 %. By comparison, a dried sludge at 90 % of dry residue content will contain 36 kg of P_2O_5/t of raw material, and a variation of dry residue content of 90 % to 95 % will only lead an augmentation of 2 kg of P_2O_5, so a difference of 5 %.

The advantage of dried sludge is that it can be a complete phosphate fertiliser without the farmer having to add any Triple Super Phosphate (TSP). This again emphasises the contribution to sustainability.

In conclusion this is an important advantage for farmers who are looking for accurate rates of land spreading.

10.2.4 Bio availability of phosphorus

According to several studies (Switzerland, Scotland), made principally on digested sludge, it would appear that availability of phosphorus in the soil is slightly affected by the drying operation and temperature.

10.2.5 Bio availability of nitrogen

The major part of the easily assimilable mineral nitrogen is removed from sludge during the drying process, due to the high temperature of the vapour. Very few drying processes can fully limit the loss of ammonia.

Three phenomena lead to the elimination of ammonia nitrogen from dewatered sludge:

- drying temperature itself, as well as the temperature reached by sludge granules;
- back mixing ratio and the overheating of sludge granules;
- high pH of sludge due to lime conditioning.

It is also important to note that digested sludge has a higher mineral nitrogen content because of the reduction of the organic nitrogen percentage. A classification of sludge can be laid down as:

- Raw fresh sludge with activated sludge surplus. Some can contain up to 6 % of total nitrogen; and also some is being enriched with ammonium salts fertilizer;
- Digested sludge. The breakdown of organic nitrogen during digestion sequence decreases the organic nitrogen content and, consequently, the available nitrogen concentration of the dewatered/-dried product can be low;

Raw fresh sludge has a greater quantity of organic nitrogen than dried digested sludge. Losses of mineral nitrogen from raw sludge will be slightly reduced if there is no lime addition before or after dewatering and as well by a smooth temperature during sludge drying ; temperature of material during the drying ≅ 85 °C without back mixing.

10.2.6 Disintegration of granules in soil

Four main parameters influence the decomposition of granules:

- granule production process;
- origin of sludge and certain elements of their composition like fibres;
- climate and principally the amount of rain;
- nature of the soils.

Granules of small size (3 mm to 5 mm) are the best assimilated, compared to granules of 5 mm to 10 mm that react very slowly.

Trials have shown that dried sludges spread in the soil decompose more quickly than in certain soils where the rate of humidity is weak.

Observations on the decomposition of certain granules of dried sludge applied in autumn to the soils, followed by incorporation indicate that 6 to 8 months later, some granules remain. If the soil is saturated with water, granules become soft and are transformed into sludge in 45 days.

10.3 Thermal treatment , energy recovery and disposal

The lower calorific values (LCV) of digested sludge thermally dried products will range form about 10 MJ kg^{-1} to 15 MJ kg^{-1}. Undigested sludges can reach higher lower calorific values (LCV) up to 20 MJ kg^{-1} . The lower values for the digested products reflect loss of readily degradable organic matter as methane and carbon dioxide during the anaerobic digestion process prior to thermally drying. These lower calorific values (LCV) for thermally dried sludge products can be compared with those for hard wood at 19 MJ kg^{-1} and coal at 28 MJ kg^{-1}. Thermally dried sludge can substitute fossil fuel for incinerators, coal-fired power stations, cement works and in gasification and pyrolysis.

Thermal destruction or conversion processes are traditionally understood to be combustion or incineration. However a range of thermal processes, such as gasification and/or pyrolysis, are available for sludges resulting in different by-products which can be converted to energy or useful chemicals via processing stages.

The ash or slag from incineration of sludge, and other energy recovery processes, may be classed as ‘hazardous waste’ if it contains ‘dangerous substances’ in this case heavy metals. The concentrations of heavy metals (such as cadmium, mercury, lead, copper, nickel, zinc and chromium), which would cause either fly ash or bottom ash to be classified as hazardous, are not specified. Bottom ash has been used in various civil engineering applications, for instance as an under layer in road construction or in building block production. Fly ash from sludge incineration is likely to be classified as a hazardous waste in any event because of its caustic properties – pH value approximately 13. An important challenge for the future is to develop cost-effective ash treatment methods to produce products which are stable and safe in the long-term to be possibly recovered according to European and national regulations”.

The usual process engineering for thermal treatment of sludge are mono-incineration (fluidised bed, multiple hearth furnace) which is described in CEN/TR 13767 and co-incineration in (coal fired) power plants, waste and household wastes (see CEN/TR 13768) ,incineration plants or cement works.

The disposal to landfill is the least favoured option according to the waste hierarchy in the Waste Framework Directive 75/442/EEC [6] as amended 91/156/EEC [7]. It is described in CEN/TR 15126 for land filling of sewage sludge.

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