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# Characterization of sludges — Hygienic aspects — Treatments

ICS 13.030.20

# National foreword

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TECHNICAL REPORT

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# CEN/TR 15809

November 2008

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English Version

# Characterization of sludges - Hygienic aspects - Treatments

Caractérisation des boues - Aspects hygiéniques - Traitements

Charakterisierung von Schlämmen - Hygienische Aspekte - Schlammbehandlung

This Technical Report was approved by CEN on 25 August 2008. It has been drawn up by the Technical Committee CEN/TC 308.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

**Management Centre: rue de Stassart, 36 B-1050 Brussels**



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## Foreword

This document (CEN/TR 15809:2008) 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 the practice and regulations in each member state.

This document gives general principles about hygienic aspects. Other guides on good practice for the use of sludge (Guides 2, 4, 5, 6, 7, 8) contain the specific recommendations based on the hygienic aspects described in this guide.

# Introduction

This Technical Report has been prepared within the framework of CEN/TC 308 on characterization of sludges. This document concentrates on hygienic aspects for good practice concerning treatment of sludge, but acknowledges that existing national regulations remain in force.

The use of sewage sludge on land is controlled within the EU by the sludge directive (86/278/EEC [1]) “on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture”. Regarding the purpose of the directive, it states:

— whereas the aim of this Directive is to regulate the use of sewage sludge in agriculture in such a way as to prevent harmful effects on soil, vegetation, animals and man, while encouraging its correct use;

Regarding hygiene, it requires:

— whereas sludge must be treated before being used in agriculture; whereas Member States may nevertheless authorize, on certain conditions, the use of untreated sludge, without risk to human or animal health, if it is injected or worked into the soil;

— whereas a certain period must elapse between using the sludge and putting stock out to pasture or harvesting fodder crops or certain crops which are normally in direct contact with the soil and normally consumed raw;

— whereas the use of sludge on fruit and vegetable crops during the growing season, except for fruit-tree crops, must be prohibited.

86/278/EEC defines 'treated sludge' as:

— sludge which has undergone biological, chemical or heat treatment, long-term storage or any other appropriate process so as significantly to reduce its fermentability and the health hazards resulting from its use;

EU Member States have enacted the directive into their national legislations with conditions that are no less stringent than the directive. In many cases they have more detailed treatment requirements than those written in the directive.

The European Commission has said repeatedly that 86/278/EEC, which was the first soil protection directive, has been a success because there have been no cases of adverse effect where it has been followed.

Sludge treatments and practices that control health risks can also affect odour; in the public’s mind they are linked.

When making choices in sludge management the hygienic aspects should be considered alongside the environmental impacts of the treatment such as energy use or emissions and the benefits of the final product.

## 1 Scope

This CEN Technical Report gives information about principles to be followed in different sludge treatment processes to reach specified hygienic requirements.

## 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 1085:2007, *Wastewater treatment — Vocabulary*

EN 12832:1999, *Characterisation of sludges — Utilization and disposal of sludges — Vocabulary*

CEN/TR 15473, *Characterization of sludges — Good practice for sludges drying*

EN ISO 22000, *Food safety management systems — Requirements for any organization in the food chain (ISO 22000:2005)*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 12832:1999, EN 1085:2007 and the following apply.

**3.1**
**Critical Control Point (CCP)**
step [in a process] at which control can be applied and is essential to prevent or eliminate a hazard or reduce it to an acceptable level

**3.2**
**HACCP (hazard analysis and critical control point)**
system that identifies, evaluates, and controls hazards which are significant for safety

**3.3**
**HACCP plan**
document prepared in accordance with the principles of HACCP to ensure control of hazards which are significant for safety in the segment of the chain under consideration

**3.4**
**hazard**
potential source of harm

**3.5**
**hazard analysis**
process of collecting and evaluating information on hazards and conditions leading to their presence to decide which are significant for safety and therefore should be addressed in the HACCP plan

**3.6**
**hygienic safety**
intended degree of safety

**3.7**
**hygienisation**
process that leads to reduced levels of pathogens in order to prevent infections, and their spreading in the exposed human, animal or plant population

**3.8**
**monitor**
act of conducting a planned sequence of observations or measurements of control parameters to assess whether a CCP is under control

**3.9**
**risk**
combination of the probability of occurrence of harm and the severity of that harm

**3.10**
**safety**
freedom from unacceptable risk

**3.11**
**validation**
obtaining evidence that the elements of the HACCP plan are effective

**3.12**
**verification**
application of methods, procedures, tests and other evaluations, in addition to monitoring to determine compliance with the HACCP plan

# 4 Hygienic considerations

## 4.1 General

Untreated sludge from wastewater treatment may contain different types and species of pathogens for humans, animals and plants. The occurrence of such pathogens depends on the type and origin of the raw materials and on the health situation with respect to the presence of diseases in the involved populations. This does not only apply to sewage sludge, but also to wastewater, biogas residues, animal manure and other organic fertilisers and compost of human, animal and plant origin. Environment *per se* is not sterile. Soil is more than a mineral support on which plants grow, it is an ecosystem with its own indigenous flora and fauna. Among this microflora are several potential pathogenic as well as toxigenic bacteria and fungi that can be found in varying concentrations such as *Listeria monocytogenes* or *Clostridium tetani*. There are also competitors and predators of the pathogens with which this guide is concerned. Hygienic considerations include aspects of microbiology, virology, parasitology and epidemiology.

## 4.2 From concept to good practice

In the framework of HACCP concept, the intended field of application of sludge has to be defined, followed by the determination of the existence and the types of pathogens in sludges, as well as the identification of the possible ways of transmission to humans, animals or plants.

If the interpretation of this analysis (based on the level of risk for health in regard of the uses of sludges) demonstrates the need for treatment, the process should be capable of reducing the hazard to an acceptable level of risk by inactivating the selected pathogens to a defined extent. The treatment process should be validated by a representative indicator organism covering the types of pathogen identified.

## 4.3 Aspects of microbiology, virology and parasitology

Besides the indigenous microbiological flora and populations of viruses including protozooic and metazooic organisms, untreated sewage sludge may contain a variety of pathogens for humans, animals and plants as well as other undesired organisms which may present an environmental hazard. The species and numbers of indigenous flora as well as the pathogens and undesired elements depend on the origin and treatment of the wastewater. Basic data concerning the occurrence of bacterial, viral and fungal pathogens as well as parasites have been given in the past by several authors [2, 3, 4]. From this variety of bacterial pathogens *Salmonella* spp. are the most relevant since they can infect or contaminate nearly all living vectors from insects to mammals. Amongst the viral pathogens, noroviruses, enteroviruses and rotaviruses are the most relevant ones from the point of view of environmental risks. Special regard must be paid to the parasitic pathogens, not only to eggs of round- and tapeworms but to *Giardia lamblia* and especially *Cryptosporidium parvum*. Nearly all gut related pathogens of farm animals could be found in slaughterhouse effluents. Wastewater from households or industry containing plant material may contain plant-pathogenic viruses, fungi, bacteria, parasites and undesired weeds. This may cause an additional phytohygienic risk if untreated material is used in agriculture as a fertiliser [5]. However, in most cases, the concentration of the relevant pathogens in the sludge is moderate or small. Consequently, risk related treatment, storage and utilisation basically determines the hygienic safety of the final product.

The health of the population (humans, animals, plants) has to be taken into account both in the risk assessment and in establishing a HACCP-concept.

## 4.4 Aspects of epidemiology

The epidemiological aspects of sewage sludge mean that hygienic safety must be considered during all steps of treatment, transport, storage and utilisation. The right balance between the advantages of organic fertilisers based on sewage sludge and the requirements to achieve the degree of hygienic safety necessary for the intended application has to be made. Different European experiences with strategies for proper use of sludge show that epidemiological risks can be minimized.

Three aspects of hygiene have to be considered related to different epidemiological pathways:

— one aspect concerns the occupational health aspects in transport, storage, treatment and utilisation.

NOTE 1 The occupational health aspects are covered by Directive 2000/54/EC [6] and related national legislation, and are not covered in this context.

— the second aspect concerns two vectors: transmission of pathogens directly to susceptible hosts or indirectly via living and non living vectors (e.g. food, animal feed, or contaminated equipment).

NOTE 2 The direct or indirect transmission of zoonotic agents to farm animals is generally regarded as the most relevant risk factor of agricultural utilisation of untreated or insufficiently treated sludge. This direct relationship between fertilizing with sewage sludge and infection in cattle fed with forage after sludge spreading was first demonstrated for *Salmonella* [7]. The transmission of parasites was observed much earlier. *Transmission to humans via products based on sludge or containing insufficiently treated sludge by applying them to plants in househods or in home-gardens is a relatively rare event. The risk of infection of persons exposed to salmonellae after sludge application to farmland is minimal and no different from that of the nonexposed population [8].*

Indirect transmission to humans is of special importance, because the introduction of pathogens into the food chain via contaminated fertiliser leading to contaminated animal feed resulting in infection of farm animals or excretion of pathogens is of basic epidemiological significance. This is mainly due to contamination of meat and meat products during slaughtering and processing as well as contamination of plants and plant products by manure of animals excreting the above mentioned organisms. The risk of transmission of pathogens to human food by living vectors such as insects, rodents and birds from processing, handling and agricultural utilisation of organic fertilisers is also regarded as a risk factor [9].

— the third aspect concerns the introduction of organisms in the environment during transport, treatment, and storage but mainly during utilisation.

NOTE 3 This may be closely related to health aspects if pathogens are introduced into the biocenosis, and then carried by birds or rodents. This could include the introduction of resistance genes into the biocenosis, a potential risk that applies to treated wastewater as well. Antibiotic resistant bacteria may be present in sludge, and therefore could contribute to the presence of so called “community acquired multiresistant bacteria” in human populations. However, it is likely that other ways of transmissions are of primary importance [10].

Epidemiological risks arise because pathogens may survive for a considerable period of time in excreta, manure, sludge and the environment [2]. A compilation of general epidemiological risks due to handling and the utilisation of organic wastes as fertilisers in agriculture is given in Table A1.

## 4.5 Definition of the hygienic objective of treatment

The hygienic objective of treatment is to be defined for the treatment. The definition of this objective is on the authority of each country regulation. The principle is to determine the microorganisms you want to inactivate and the microorganisms you accept there are remaining.

An example for inactivation of remaining type of organisms is given in Table 1. Suggestions for test organisms for validation of treatment processes are given in Table 2.

**Table 1 — Hygienic objectives**

NOTE Pathogenic prions are not covered by this approach, if present in the sludge other treatment options as given below must be considered.

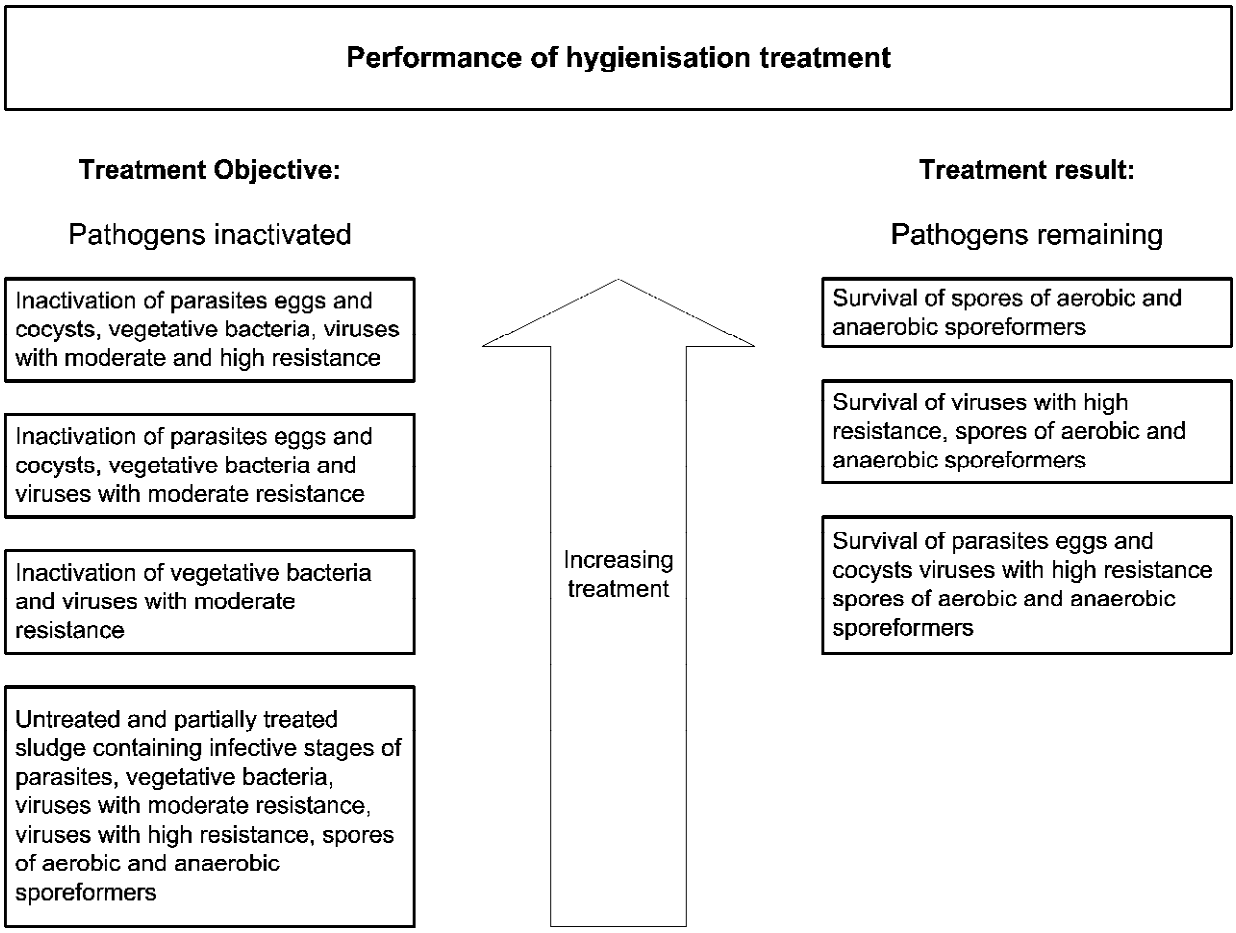

**Table 2 — Possible test organisms for validation of treatment processes in relation to the intended hygienic level (informative)**

| Pathogens inactivated | Possible test organisms | Minimal reduction to be reached in the validation |
|---|---|---|
| Vegetative bacteria<br><br>Virus with moderate resistance | For biotechnological and chemical treatment: *Salmonella senftenberg* W 775, $H_2S$ negative<br><br>For thermal or other physical treatment: *Enterococcus faecalis* ATCC 2912 [a] | At least 5 log for all test organisms |
| Vegetative bacteria<br><br>Virus with moderate resistance<br><br>Infectious parasitic stages | For chemical treatment: *Salmonella senftenberg* W 775, $H_2S$ negative and eggs of *Ascaris suum*<br><br>For biotechnological and thermal or other physical treatment: *Enterococcus faecalis* ATCC 2912 [a] | At least 5 log for *Salmonella senftenberg* and *Enterococcus faecalis*<br><br>At least 99,9 % inactivation of the eggs |
| Vegetative bacteria<br><br>Virus with moderate and high resistance<br><br>Infectious parasitic stages | For biotechnological and chemical treatment: Bovine parvovirus strain Haden<br><br>For thermal or other physical treatment: Bovine parvovirus strain Haden or Coliphage T1 [a] | At least 3 log for Bovine parvovirus<br><br>At least 5 log for Coliphage T1 |

[a] If validation is done by input-otput analysis for determining a reduction rate in the indigenous bacteria and/or viruses the parameters "E. coli", "Enterococci" or "Coliphages" may be used instead.

Generally, treatments used to stabilise sludge have the effect of enhancing the natural decay in the indigenous as well as in the pathogenic micro-organisms present and generally to restrict regrowth within certain limits. The effect depends on their biological properties. The factors leading to the inactivation can be chemical, physical or biological in nature. Every treatment may have some effect on the beneficial soil conditioning properties of the sludge (e.g. loss of nutrients, loss of organic matter, loss of beneficial organisms).

Wastewater treatment results in sludge. Untreated sludge may contain pathogenic vegetative bacteria, as well as bacterial spores, viruses with different chemo- and thermoresistance, as well as infectious stages of different parasites (see Tables A2 to A4 in Annex A). This is the material related to the highest epidemiological risk in this context.

# 5 General methodologies and tools to define the hygienic effect of treatment, and to manage the hygienic safety

## 5.1 General

An appropriate approach for good health practices should:

a) identify the relevant pathogens and the thresholds that ensure sanitary protection of the exposed population. This can be done with a health risk assessment;

b) include HACCP with process validation;

c) monitor contamination levels in sludge before use in general.

## 5.2 Health risk assessment

The health risk assessment comprises four steps:

a) hazard identification;

b) dose-response assessment;

c) exposure assessment;

d) risk characterisation

Health risk assessment is a scientific tool designed to help regulators, decision makers, risks managers and industries to identify and quantify the potential hazards linked to a specific human activity. Health risk assessment is used to determine if a list of selected pollutants (chemical or biological agents) pose a significant risk to human health and under what circumstances.

### 5.2.1 Hazard identification

Hazard identification is the first step in health risk assessment. It is the process of determining whether exposure to an agent could (at any dose) cause an increase in the incidence of adverse health effects in humans. This hazard identification is carried out for each pollutant selected in the risk assessment protocol.

Hazard identification shall result in the identification of one or more key pathogens known to be present in the sludge in high numbers and which could be transmitted by the way the sludge is used.

### 5.2.2 Dose-response assessment

Dose-response assessment defines the relationship between the dose of an agent and the probability of a specific adverse effect in the exposed organisms.

Dose-response assessment is not as well-defined for pathogens as it is for chemicals.

In the case of pathogens, it is sometimes possible to identify a minimum infectious dose which corresponds to the level of pathogen likely to cause a pathology (this dose can vary according to the physiological state of the pathogen and of the host).

There are very few dose-response relationships for pathogens in general.

In addition, the assessment is complicated due to the capability of the pathogens to propagate in the environment or in vectors.

### 5.2.3 Exposure assessment

Exposure assessment quantifies the uptake of pollutant (here pathogens) from the environment by any combination of routes of exposure.

Exposure assessment can take into account the worst-case estimate of exposure (maximum contamination value calculated or measured x maximum time of exposure x most sensitive population) in order to quantify the maximum level of risk so as to ensure the safety of the whole exposed population.

### 5.2.4 Risk characterisation

Risk characterization summarizes and interprets the information collected from previous steps of the method and identifies the limitations and the uncertainties in risk.

To evaluate the health risk from an exposure to pathogens, it is either possible to compare the dose of exposure to the minimal infectious dose, when it exists, or to use the mathematical dose-response relationship defined to assess a probability of infection.

### 5.3 Quality Assurance and Hazard Analysis and Critical Control Point (HACCP) for use in sludge

Quality Assurance (QA) revolutionised manufacturing industry and the reliability of its products by formalising procedures in order to ensure that operations were performed correctly every time.

QA was first applied to sludge recycling operations in 1989 by the largest sludge recycler in the UK. The result was 100% auditable compliance with legislation and codes of good practice. Subsequently many others have adopted QA. For example:

— in Germany there is a co-operative QA scheme involving 35,000 farmers and the use of 250,000 t sludge;

— operators in France launched SYPREA in 2002 as a national QA scheme, which includes sludge treatment;

— there are independent QA systems in Sweden;

— in Norway QA for sludge treatment is a legal requirement; and

— the National Biosolids Partnership offers EMS with third-party audit in the United States.

One of the criticisms of QA is that it makes sure that you do the same thing every time but that if the process has not been designed properly the outcome will be wrong every time. This is not really an entirely fair criticism of QA but a process design paradigm from the food industry provides an ideal complement to QA because it is a structured approach to analysing the hazards that could affect the product. It is called **Hazard Analysis and Critical Control Point (HACCP)** [Codex Alimentarius 1997 [10]]

HACCP systems are used internationally in the food industry to ensure product quality standards (see EN ISO 22000) and with some modifications it is part of EU legislation on animal by-products (Regulation 1774/2002 [11] not intended for human consumption). HACCP principles are applicable to sludge treatment (e.g. in U.K. and in Norway) and utilisation.

In this guide, the aim is to use the applicable principles of HACCP in order to identify all measures to be taken with respect to safe transport, treatment, storage and utilisation of sludge under the aspects of hygienic safety.

First the risks related to the amount and type of pathogens as well as micro-organisms with undesired properties present in the receiving wastewater must be identified as well as the intended utilisation for the treated sludge, because safe utilisation can avoid certain hygienic risks. This determines the final product (assured product) standards.

The initial stage of establishing a HACCP system in the treatment plant itself is to undertake a hazard analysis, which identifies points in the treatment process, which are critical to delivering the stated final product standards. These are the critical control points. At these points, the relevant process parameters related to the inactivation of pathogens should be continuously measured such as temperature, time, concentration, pH-value, etc. For these Critical Control Points (CCPs) control data for the management of the safe inactivation of the relevant pathogens can only be fixed by a validation procedure testing the degree of inactivation of such pathogens using representative test organisms in an experimental approach (process validation). With certain well documented treatment systems, these could be taken from the literature. Once validated, the HACCP system operating limits are set, and by operating the system within those limits the end product quality is assured. This means that end product testing which is always critical due to the difficulty of defining a representative sample can be reduced to a level which limits microbiological end-product control to the monitoring of a reasonable amount of samples (e.g. the presence and absence of *Salmonella*).

For each process a contingency programme is required which details the plan of action if any CCP goes outside its limits and ensures failed product cannot contaminate assured product or enter the utilisation process.

There are many systems available for sludge treatment and each one can be run under a HACCP concept. The principles of a HACCP concept may also be applied for the utilisation of the product in agriculture and related fields.

The HACCP - system has two major benefits for sludge treatment:

a) it does not restrict the processes that can be used to treat sludge as long as CCPs can be identified which deliver the required product quality;

b) it is a system well understood by the food industry that needs assurance that the use of treated sludge on crops does not compromise food safety.

An example of a decision tree for identification of critical control points is shown in Figure 1.

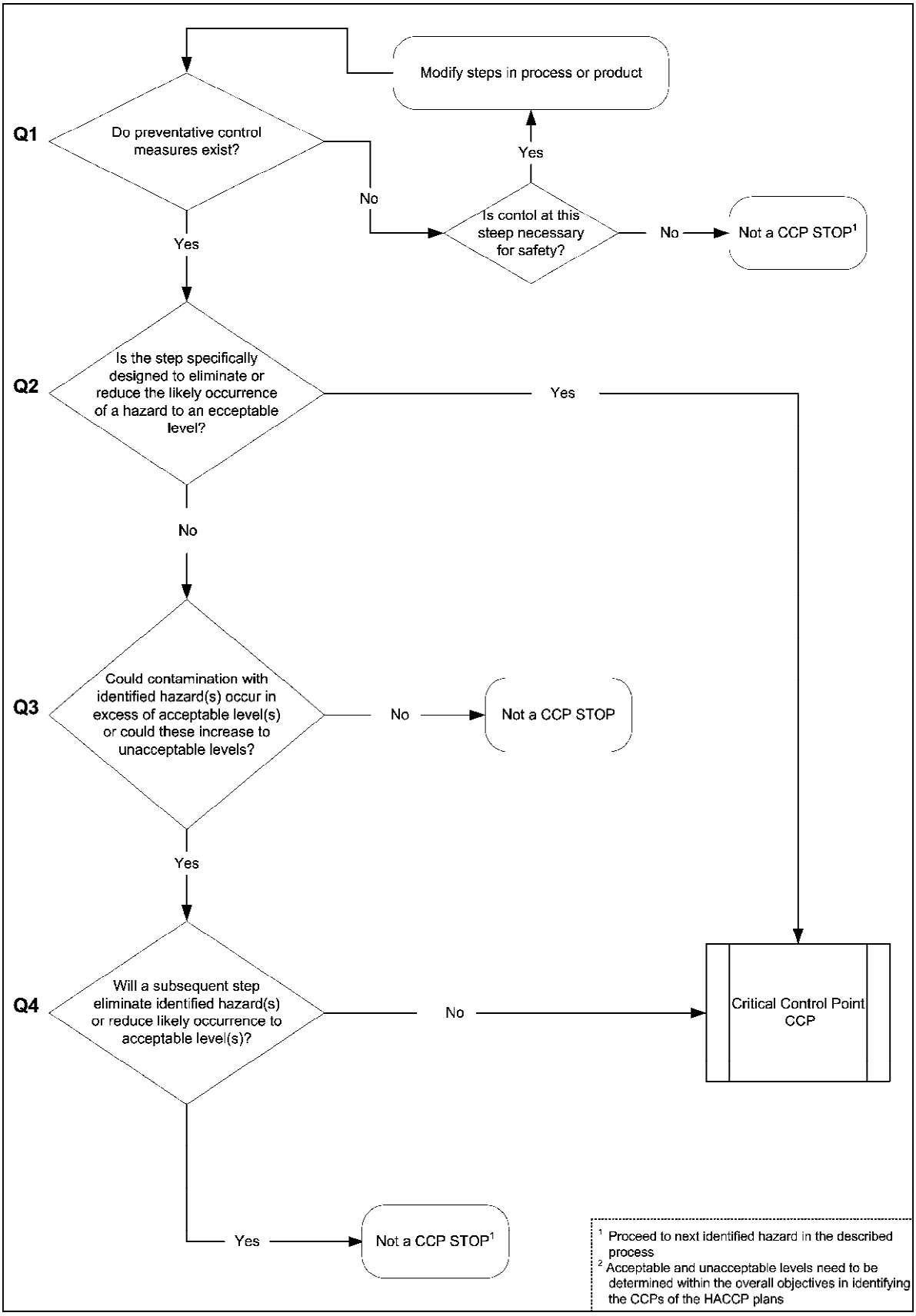


**Figure 1 — HACCP decision tree to identify whether a step is a CCP [Codex Alimentarius, 1997]**

# 6 Treatments available: efficiency and drawbacks

## 6.1 General

There are several different types of sludge treatment process. The treatment factors that cause inactivation of pathogenic organisms (i.e. pathogen reduction) include temperature, pH, chemical (principally ammonia and/or, in the case of anaerobes, oxygen), desiccation, lack of nutrients (starvation) competition and predation.

The risk of growth of bacterial pathogens after recontamination is higher in sludge resulting from some treatments than from others.

Much attention has been given to heating as a means of sanitising sludge. It can be achieved easily and it is the means by which much of our food is sanitised. Feachem et al. (1983) [12] summarised the published information about time to temperature relationship of inactivation of a selection of the pathogens of interest in the landmark diagram reproduced in Figure 2. The lines represent conservative upper boundaries for pathogen death, i.e. estimates of the time-temperature combinations required for pathogen inactivation. A treatment process with time-temperature effects falling within the "safety zone" should be lethal to all excreted pathogens.

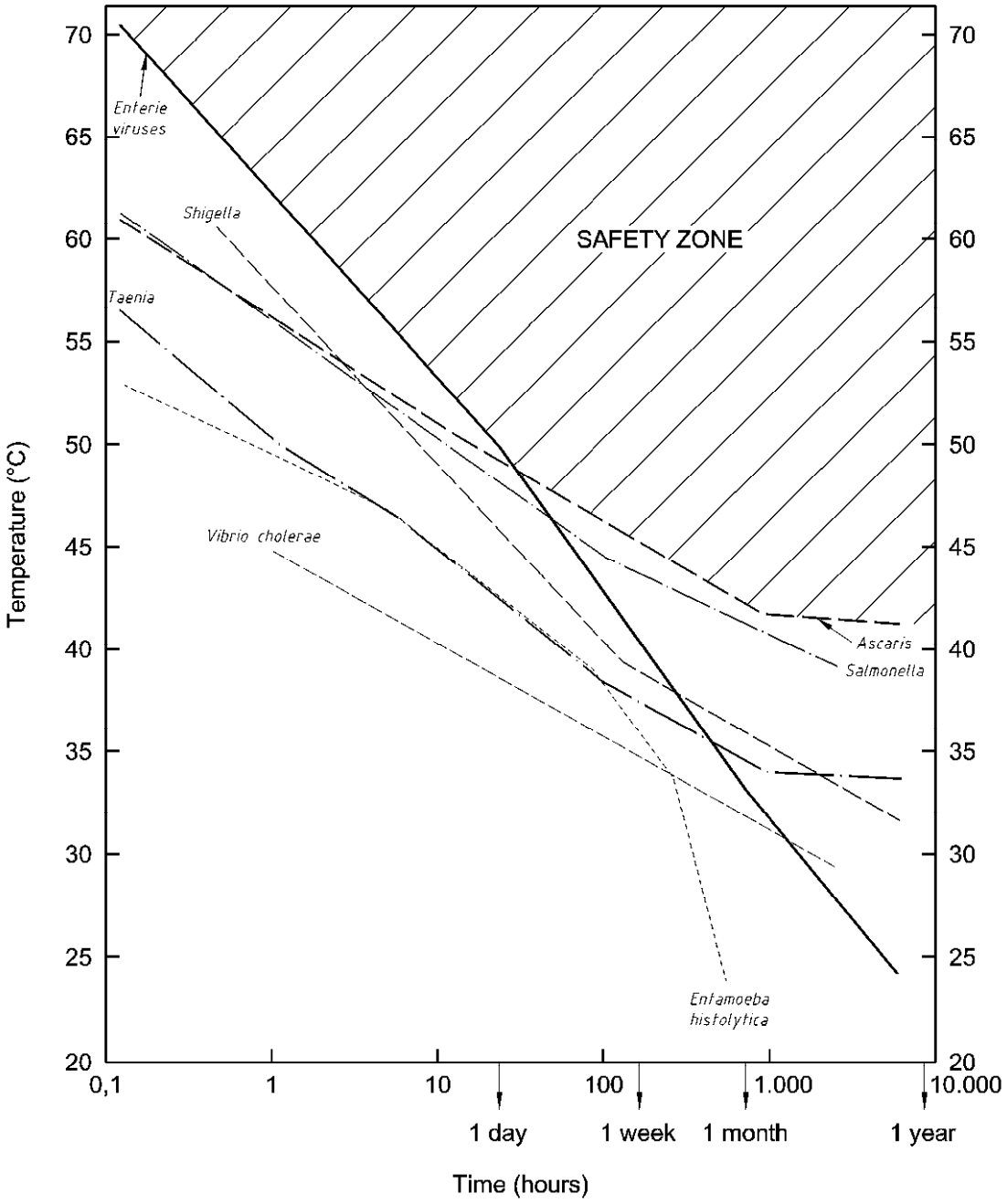


**Figure 2 — Influence of time and temperature on the elimination of selected pathogens in sludge [12]**

Indicator organisms or test organisms are used for validation and verification of treatment methods (for test organisms see Table 2).There are many organisms of concern that might possibly be present in sludges. It would be very costly and time-consuming to monitor for all of these individually. For some, such as Cryptosporidium, there is no alternative to counting them using a microscope and at the same time differentiating viable from non-viable on the basis of the cells' appearances. This is also the situation for helminth ova.

UKWIR (2002) [13] showed that the degree of inactivation of indigenous E. coli (i.e. the strains of E. coli that are in all animal faecal material) is a reliable indicator for inactivation of bacterial pathogens by sludge treatment. Some countries use faecal coliforms or faecal enterococci as indicator organisms.

## 6.2 Biological treatment

Aerobic and anaerobic treatment can be done with biological technologies in the mesophilic or in the thermophilic range. In such processes a more or less rapid inactivation of pathogens occurs due to different factors like antibiosis, pH-shift, redox-potential, antagonism, nutrient deficiencies and exothermic metabolism. Biological treatment is very effective because of the combination of all these factors.

### 6.2.1 Anaerobic digestion

Anaerobic digestion (AD) with combined heat and power generation (CHP) became popular in the 1930s and today accounts for the largest proportion of sludge treatment in Europe. There has been renewed interest to maximise its efficiency because of its capacity to make renewable energy whilst at the same time conserving all of the plant nutrients and reducing the quantity of sludge produced. It stabilises the sludge, reduces pathogen numbers and produces biogas. It is also used for treating manures and biodegradable wastes. The hygienic safety of the treated material depends on the physical and chemical properties of the substrate, the temperature and the shortest real exposure time of the feed substrate in the reactor.

Mesophilic anaerobic digestion as done in the course of sewage treatment according to the state of the art is not capable of completely inactivating pathogens in the exposure time given by the standard procedure of operation. Additional physical or chemical treatment can increase the pathogen inactivation (Table 1).

Anaerobic digestion is a continuous process; typically digesters are fed with sludge every 1 to 6 hours. They are designed to achieve a *mean* hydraulic retention time (HRT), which is typically 15 days. Thus, if the HRT is 15 days and digesters are fed hourly, 0,11% of the volume is fed (and removed) each hour. Digesters are continuously mixed so between each feed the newly added sludge is mixed with the material already in the digester, thus a small proportion of the sludge has a very short residence time, which is why single stage MAD is unlikely to exceed 2-$\log_{10}$ reduction of *E. coli*. This can be increased to 4-$\log_{10}$ by secondary digestion, i.e. batch storage for and appropriate length of time (e.g. 1 week). The small proportion of sludge that has a very short residence time can be regarded as partial by-pass. Odour reduction is related to the amount of organic matter [VS for volatile solids] destruction and to by-pass.

Thermophilic anaerobic treatment at temperatures between 53 °C and 55 °C can be effective in inactivation of vegetative bacteria, viruses with moderate resistance and infectious stages of parasites. Most bacteria and viruses with moderate resistance have a time necessary for one log reduction at 55 °C ($D_{55}$-value) of 1,4 to 2,0 h depending on the properties of the substrate. Heat resistant viruses have $D_{55}$-values of 2,8 to 7,8 h under the anaerobic conditions in the reactor.

For the inactivation of eggs of *Ascaris* spp. At 55 °C a minimum exposure time of 2 h ($D_{55}$ about 40 min). and at 50 °C of 8 h ($D_{50}$ about 160 min) can be recommended for a 99,9 % reduction of viable eggs [14].

Two-stage digestion (or two-phase digestion) is an innovation in anaerobic digestion. Several facilities have found that it is easy to separate the acidogens and methanogens by installing a 2-day HRT anaerobic tank before the 15-day HRT biogas digesters. The difference in growth rates is so great that acidogens dominate the 2-day tank and the pH drops to around 5, in addition proteins and carbohydrates are hydrolysed to some extent by extra-cellular enzymes in this first stage. The rate-limiting step in AD of proteins and carbohydrates is hydrolysis. This simple retrofit increases VS destruction from 40 % to 50 %; it also has the benefit that it reduces the percentage ‘by-pass’ and thus increases the *E. coli* $\log_{10}$ reduction from 2 to 4 or 5. By using two or more short retention acid-phase tanks in series, possibly with thermophilic temperatures in some tanks, the VS and *E. coli* destruction have been increased even more.

### 6.2.2 Composting

Composting has been used for centuries and all gardeners know the value of compost for improving the fertility and workability of soil. Composting (like biogas production) is a natural biological process but this time it is aerobic. Dewatered sludge is too dense for air to move through it so straw, woodchips, sawdust, greenwaste or some other material is added to open up the structure. This 'bulking material' also provides extra carbon to feed the composting bacteria and balance the nitrogen content of the sludge. Aerobic bacteria feed on this mixture and give off heat which raises the temperature of the compost.

Composting kills pathogens because they cannot tolerate the high temperatures and other conditions in the composting material.

Composting of dewatered sewage sludge can be done with different techniques in windrows or reactors, in open air conditions or under cover. The C/N ratio has to be around 25:1, and the air pore volume at about 35 %, for optimal composting. The hygienisation in the composting process is achieved mainly by the heat generated in the exothermic aerobic process in relation to the moisture content, exposure time alongside metabolic and antibiotic effects. In order to reach the necessary degree of inactivation of pathogens, other micro-organisms with undesired properties and weed-seeds, the availability of sufficient air for an optimal aerobic heat generating process is necessary. This is generally done by providing forced aeration, mainly in containers or by turning the windrows or piles. The aim of such measures is to ensure the even distribution of the effective temperatures throughout the composting material for the necessary exposure time. Recommended process parameters for hygienisation in composting cannot be given here, because every technique applied has different properties concerning the process parameters to be kept for hygienisation. Therefore every type of composting equipment has to be validated by an adequate technique in order to find out the relevant process data to be achieved in order to achieve hygienic safety.

### 6.2.3 Thermophilic aerobic digestion (TAD) or Aerobic thermophilic stabilisation (ATS)

The principle of the process is to initiate and stabilize an exothermal microbial degradation and metabolic process by containing the sludge in an insulated reaction vessel by a sophisticated technique using air. This results in a rise of temperature and pH-values to about 8. Provided that the vessel is well insulated, that the air supply is correctly calculated and that the sludge has a sufficient concentration of organic matter, temperatures can be reached that result in stabilisation and hygienisation of the sludge. The process should be operated in two-stage reactors (two vessels connected in series) at least, to achieve a sufficient exposure time and avoid hydraulic short-circuiting. It is recommended to run this system in a semi batch type of operation with one hour feeding per day and 23 hours stabilisation (exposure time). Taking into account the temporary decrease of temperature inevitably connected with this type of operation, the following reaction times and temperatures are recommended for achieving an inactivation of vegetative bacteria, viruses of moderate resistance and infectious parasitic stages [2]: 23 h at 50 °C or 10 h at 55 °C or 4 h at 60 °C. It is sometimes used as a pre-hygienisation step before AD.

### 6.2.4 Long term storage

Long term storage of sludge, provided it is properly managed, can be an effective treatment. Depending on treatment and origin even propagation of bacteria like *Salmonella* is possible in sewage sludge during storage under certain conditions. Under middle European climate conditions *Salmonella* are inactivated in stored sewage sludge within 6 months, and the moderately resistant enteroviruses are eliminated after 11 months while a remarkable amount (14 %) of Ascaris eggs remain viable after the same time [15 to become 16].

Since a lot of factors are influencing the survival of pathogens during storage it must be regarded as a method which requires careful validation to determine the level of hygienic safety The storage time depends on the local climate and it is essential that there is a sufficient period of time between the last addition to the store and the time when it is emptied (Recontamination and addition of fresh material have to be avoided during the storage time).

### 6.2.5 Reedbeds

Reedbed treatment of sludge started in the 1980s and has been steadily gaining acceptance. The beds are sealed; they contain drains set in a bed of aggregate on which reeds are planted. Sludge is applied to the beds in sequence in shallow layers. Odour is contained within the reed canopy, even in winter. The reeds excrete oxygen from their roots which maintains the root zone aerobic. Bacteria initially, and later earthworms, mineralise the sludge and sanitise it. The mineralised sludge builds up in the beds (at about 40 %DS). After about 10-15 years the cycle of digging out the beds in rotation is started. This is especially useful for sludge from extended aeration treatment, but it is also suitable for other types of wastewater treatment. Energy and chemical use are very low. Provided there is a sufficient period of time between the last addition to a reedbed and the time when it is dug out, hygienisation can be assured. This time period depends on the local climate;

in Denmark 50 days are sufficient in summer for enhanced treated status [17]. Reedbed treated cake has low odour.

## 6.3 Chemical treatment

Chemical treatment can inactivate vegetative bacteria, viruses with moderate resistance and in certain cases also bacterial spores. Due to several reasons, lime is the most common substance to be added. Besides the hygienic effects, it has the additional advantage of preventing recontamination due to preservation of the treated sludge. Chemical treatment, if not associated with sludge temperature increase, cannot inactivate infectious parasitic stages like Ascaris eggs [2; 17].

### 6.3.1 Treatment with lime

Lime can be applied as slaked lime Ca $(OH)_2$ or quicklime, CaO. The hygienisation effect of lime treatment derives from the following three physico-chemical phenomena which occur during the liming process:

a) increase of the pH in the sludge to an appropriate value, frequently set at 12 or above;

b) increase of the sludge temperature as a result of the hydration of the lime (provided by the addition of CaO to dewatered sludge);

c) release and presence of ammonia resulting from the reaction between the ammonium ions in the sludge and the hydroxyl groups from the lime.

For lime treatment to be effective on sludge, it is necessary to have a homogeneous mixture of sludge and lime. Since this depends on the technical equipment used and on the properties of the sludge, general recommendations on necessary concentration of lime in relation to exposure temperatures cannot be given here.

The increase of the sludge pH to more than 12 inactivates most viruses and bacteria within 48 h. If only vegetative bacteria and viruses with moderate chemoresistance are to be inactivated either slaked lime or quicklime can be used. The recommended dosage is above 0,3 kg CaO/ kg dry matter of sewage sludge or an equivalent in Ca $(OH)_2$ in this case. If also thermoresistant viruses and parasitic stages are to be inactivated, only quicklime should be applied as the use of $Ca(OH)_2$ is not effective against parasitic stages. The temperature elevation of the sludge, resulting from the slaking process with quicklime, effectively reduces the viability of helminth eggs or oocysts of *Cryptosporidium parvum.* The quick lime dose required to inactivate thermoresistant viruses and parasitic stages depends on several factors. Of basic importance are the equipment used, the properties of the sludge (e.g. dry solids content) and the amount of quicklime added. The following time/temperature recommendations for reducing the number of viable Ascaris eggs by 99,9 % can be taken from the literature: at 50 °C 6 hours, at 55 °C 75 min –120 min [18] and at 60 °C 5 min [19]. More details on the relationship between the expected temperature, the required dosage of quicklime and the dry matter content of the sludge can be taken from the literature [20].

However, the release of ammonia to the atmosphere in the case of lime treatment should be considered and avoided by technical measures.

### 6.3.2 Other chemical methods

#### 6.3.2.1 Treatment by acidification and oxydation

Acetic acid and sulphuric acid are used with hydrogen peroxide to treat sludges. This treatment method has found limited practical application.

## 6.4 Physical treatment

In general the application of heat or irradiation is possible. The most common way is heating the sludge in the liquid stage (pasteurisation) or drying dewatered sludge by heat. Irradiation is also effective in principle, but due to a number of reasons not widely applied.

### 6.4.1 Pasteurisation of sludge

Sludge can be heated by direct or indirect heating in a batch process or by microwaves in a continuous mode. If a temperature of at least 70 °C is kept for at least 30 min vegetative bacteria, viruses of moderate heat resistance and all infectious parasitic stages are inactivated if the temperature is evenly distributed in the material. Pasteurisation at 90 °C for 1 hour leads to inactivation of vegetative bacteria, heat resistant viruses including plant pathogenic species and infective parasitic stages in a sufficient level to achieve hygienic safety. Some heat sensitive bacterial spores are also affected. Other combinations of temperature and exposure time may be effective as well if relevant process data had been confirmed in a suitable validation procedure. Generally pasteurisation after anaerobic digestion leads to a material which allows bacterial growth in the case of recontamination during storage, transport and utilisation. Pasteurisation after digestion is not recommended.

### 6.4.2 Thermal drying

There are different methods used for thermal drying (see CEN/TR 15473: Characterisation of sludges – Good practice for sludges drying). All methods could be effective for hygienic objectives, though this must be proven in detail by a process validation. The main factors influencing the inactivation of the relevant pathogens are the temperature, the exposure time and the water activity |$a_w$-value] in the material (Water activity or $a_w$ is the energy state of water in a substance). The latter is of special importance. Low water activity increases the heat resistance of micro organisms, so that vegetative bacteria can even survive temperatures of above 100 °C. Therefore the drying procedure must be designed in a way, that the inactivation of the target organisms is complete before the $a_w$-value of the material drops below 0,9. Since the drying procedure is a complex one, those processes have to be validated on a type related basis in order to fix the relevant effective process data. Recommendations for test organisms for validation of treatment processes is given in Table 2.

NOTE If in such validation, the exposure of relevant test organisms is not feasible due to technical reasons, it may be replaced or completed by an input/output analysis.

In this case, the level of hygienic safety in which vegetative bacteria, viruses with moderate heat resistance and infective parasitic stages are inactivated in a sufficient number, is met, if the bacterial count of Enterococci, E. coli in the dried sludge is at least five log lower than in the input material. If the count of the indigenous Enterococci is too low for such an analysis, the input material has to be enriched up to at least $10^7$ CFU/g [colony forming units] by spiking it with a culture of *Enterococcus faecalis* DSM 2570. If the target of the validation shall also cover the inactivation of thermoresistant viruses, somatic coliphages have to be determined in input and output. In this case, at least 4 log PFU should be inactivated.

### 6.4.3 Thermal hydrolysis

This process should be use in combination with anaerobic digestion. Thermal hydrolysis pressure cooks feed sludge at 160 °C for 20-30 minutes. Under these conditions the sludge is sterilised, all pathogens are killed and the organic matter is hydrolysed which reduces the viscosity of the feed sludge and increases VS destruction during digestion to 60 %. Biogas yield is increased by 40 %; half of the extra biogas is used to raise steam to heat and drive the process. Because of the reduced viscosity the solids loading to the digesters can be doubled or trebled whilst still enabling them to be fully mixed. The digestate is much easier to dewater (34 % DS is typical from a belt filter press) and the odour is negligible.

## 6.5 Combined treatment and other methods

If two or more of the above described treatments can be combined with each other, additional effects from the point of view of hygienisation and stabilisation can be achieved.

Examples for combinations are:

a) pasteurisation with mesophilic anaerobic treatment;

b) mesophilic anaerobic treatment and composting;

c) aerobic thermophilic pre-treatment and anaerobic digestion;

d) mesophilic anaerobic digestion and aerobic thermophilic stabilisation;

e) long term storage and lime treatment.

# Annex A
(informative)

# Micro organisms which could be found in sewage sludge

**Table A.1 — Epidemiological importance of sewage sludge and some sludge derived products during transport, treatment and utilisation**

| | |
|---|---|
| **A** | **Direct transmission to farm animals** |
| | Contamination of meadows |
| | Introduction of pathogens by storage and processing close to susceptible animals |
| | Aerogenic transmission by spreading the materials onto farm land |
| **B** | **Direct transmission to humans** |
| | Handling of contaminated fertilisers in the household |
| | Occupational exposure to contaminated products |
| | Accidental transmission to immunocompromised persons |
| **C** | **Indirect transmission to farm animals** |
| | Via feed from contaminated sites |
| | Via living vectors |
| **D** | **Indirect transmission to humans** |
| | Via introduction of zoonotic agents into the food-chain |
| | Via food contaminated by living vectors |
| **E** | **Introduction into the environment** |
| | Generation of carriers in the fauna |
| | Introduction of organisms with undesired properties (e.g. antibiotic resistance) to and persistence in soil and water |

**Table A.2 — Examples of bacterial pathogens which can appear in sewage and sewage sludge when it occurs in local human population**

(STRAUCH [2] modified)

| Primary pathogens | Secondary pathogens |
|---|---|
| *Salmonella* spp. | *Escherichia* spp. |
| *Shigella* spp. | *Klebsiella* spp. |
| *Escherichia coli* | *Enterobacter* spp. |
| *Pseudomonas aeruginosa* | *Serratia* spp. |
| *Yersinia enterocolitica* | *Citrobacter* spp. |
| *Clostridium perfringens* | *Proteus* spp. |
| *Clostridium botulinum* | *Providencia* spp. |
| *Bacillus anthracis* | Multiresistant bacteria |
| *Listeria monocytogenes* | |
| *Vibrio cholerae* | |
| *Mycobacterium* spp. | |
| *Leptospira* spp. | |
| *Campylobacter* spp. | |
| *Staphylococcus* spp. | |
| *Streptococcus* spp. | |

**Table A.3 — Selection of viruses excreted by humans which can, with regional differences, appear in sewage and sewage sludge when it occurs in local human population** [2]

| Virus group | Number of types | Diseases or symptoms caused |
|---|---|---|
| Enterovirus | | |
| — Poliovirus | 3 | — Poliomyelitis, meningitis, fever |
| — Coxsackievirus A | 24 | — Herpangina, respiratory disease, meningitis, fever |
| — Coxsackievirus B | 6 | — Myocarditis, congenital heart anomalies, meningitis, respiratory disease, pleurodynia, rash, fever |
| — Echovirus | 34 | — Meningitis, respiratory disease, rash, diarrhoea, fever |
| — New “numbered“ enteroviruses | 4 | — Meningitis, encephalitis, respiratory disease, acute haemorrhagic conjunctivitis, fever |
| Adenovirus | 41 | Respiratory disease, eye infections |
| Reovirus | 3 | Not clearly established |
| Hepatitis A-virus | 1 | Infectious hepatitis |
| Rotavirus | 4 | Vomiting and diarrhoea |
| Astrovirus | 5 | Gastroenteritis |
| Calicivirus (Norwalk agent) | 2 | Vomiting and diarrhoea |
| Coronavirus | 1 | Common cold |
| Adeno-associated virus | 4 | Not clearly established but associated with respiratory disease in children |
| Parvovirus | 2 | One type possibly associated with enteric infection |

**Table A.4 — Selection of parasites which can appear in sewage and sewage sludge when it occurs in local human population**

(STRAUCH [2] modified)

| Protozoa | Cestodes | Nematodes |
|---|---|---|
| *Cryptosporidium parvum* | *Taenia saginata* | *Ascaris lumbricoides* |
| *Entamoeba histolytica* | *Taenia solium* | *Ancylostoma duodenale* |
| *Giardia lamblia* | *Diphyllobothrium latum* | *Toxocara canis* |
| *Toxoplasma gondii* | *Echinococcus granulosus* | *Toxocara cati* |
| *Sarcocystis* spp. | | *Trichuris trichiura* |

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