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Sludge recovery, recycling, treatment and disposal — Guidance on thermal treatment of sludge

Valorisation, recyclage, traitement et élimination des boues — Lignes directrices pour le traitement thermique des boues

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Foreword

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This document was prepared by Technical Committee ISO/TC 275, *Sludge recovery, recycling, treatment and disposal*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

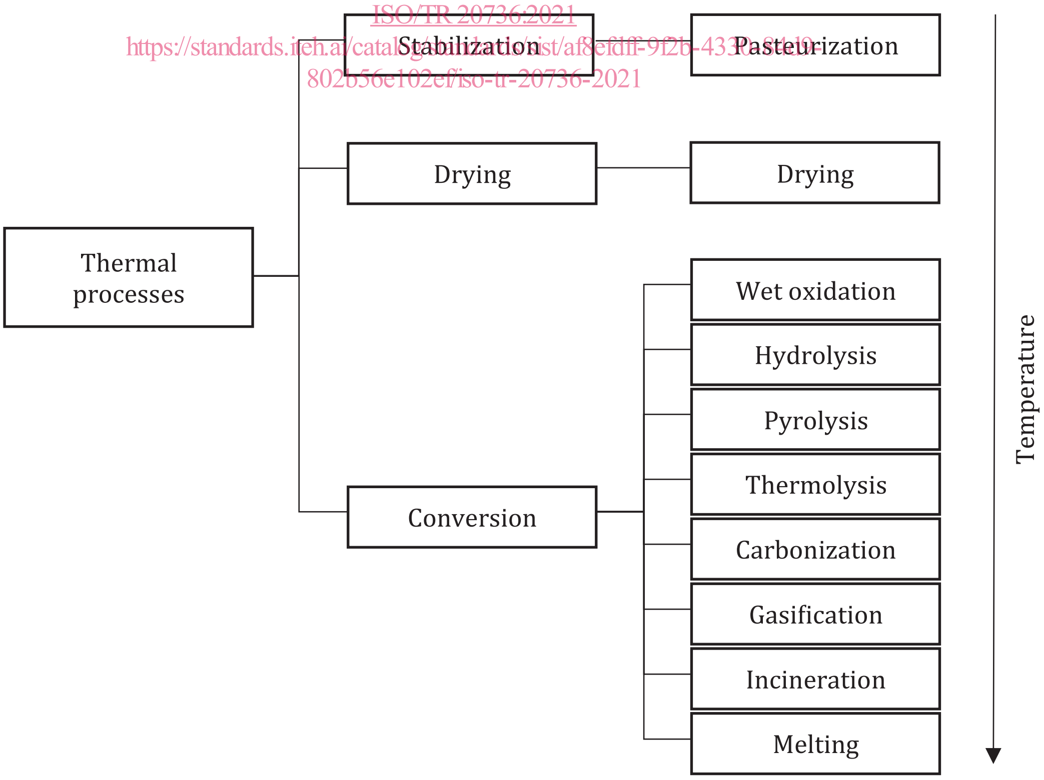
Sledge treatment and management is globally a growing challenge for most countries:

- sludge is a by-product of water treatment process produced in large quantities as new wastewater treatment facilities are built and the existing ones are upgraded to keep up with the population growth;
- sludge treatment and disposal constitutes one of the most significant costs associated with water and wastewater treatment;
- stricter regulations on conventional outlets such as beneficial agricultural land, composting, landfilling require more treatment due to concerns about the long-term impacts on public health and environment;
- sludge is now being considered as a source of renewable energy, and also a source of valuable components such as carbon and nutrients.

The growing trend to recover energy and resources from waste sludge and stricter regulations on outlets have created interest in a number of thermal treatments and may meet, under certain conditions, the circular economy principles.

The objective of this document is to pragmatically present the methods for thermal treatment of sludge by covering the different process fundamentals, the associated technologies and operational aspects, the management of energy, valuables and residues, the aspects related to impacts and integration of installations referring to them.

Figure 1 highlights the thermal processes covered according to their main function and operating temperature.



NOTE The processes listed in the right column and connected to conversion and drying as main functions also achieve the sludge stabilization.

Figure 1 — Thermal processes covered by this document

Sludge recovery, recycling, treatment and disposal — Guidance on thermal treatment of sludge

1 Scope

This document describes good practices for the incineration and other organic matter treatment by thermal processes of sludges.

Thermal conditioning is excluded.

This document applies to sludges specifically derived from:

- storm water handling;
- night soil;
- urban wastewater collecting systems;
- urban wastewater treatment plants;
- treating industrial wastewater similar to urban wastewater.

It includes all sludge that may have similar environmental and/or health impacts but excludes hazardous sludge from industry and dredged sludge.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
melting
thermal treatment which makes sludge or ash temperature raising over melting point of sludge inorganic substances

3.2
drying
thermal treatment for evaporating water from dewatered sludge to control water content by heating

3.3
carbonization
part of *pyrolysis* (3.4), focusing on production of a solid secondary resource so-called bio-charcoal

3.4
pyrolysis
thermal treatment without supply of oxygen

[SOURCE: CEN/TR 16788, 3.4]

3.5
gasification
thermal treatment with less than the stoichiometric supply of oxygen or air (partial combustion)

3.6
char
combination of non-combustible materials and carbon produced from devolatization, *gasification* (3.5), *pyrolysis* (3.4) or *carbonization* (3.3) process

3.7
bio-charcoal
biochar
solid secondary resource, generated from carbonization (or pyrolysis) process

3.8
thermal treatment
treatment in which heat is applied to remove moisture, microbial content and organic compounds

3.9
thermal process
technique for the application of *thermal treatment* (3.8)

3.10
combined treatment
treatment of sludge and other waste in the same device

3.11
furnace
enclosed chamber where combustion of organic matter takes place

3.12
boiler
specific part of the thermal treatment plant where heat exchange takes place in view of recovering heat and energy

3.13
flue gas treatment
any physical or chemical process aimed at cleaning the gas emission resulting from the *thermal treatment* (3.8) with regard to their discharge into the atmosphere

3.14
bottom ash
combustion residue collected at the bottom of a combustion furnace

3.15
fly ash
solid material that is entrained in a flue gas stream

3.16
energy recovery
use of combustible waste as a means to generate energy through thermal treatment with recovery of heat

3.17
recycling
activity in a production process to process waste materials for the original purpose or for other purposes, excluding *energy recovery* (3.16)

3.18
slag
partially glassy by-product obtained by cooling a mineral liquid phase

3.19
energy efficiency
amount of energy and/or heat recovery in relation to the energy content of input material

3.20
wet oxidation
wet air oxidation
aqueous-phase oxidation of organics under pressure, using either air or oxygen as the oxidant

3.21
syngas
mixture of gases (including carbon monoxide, hydrogen, methane, etc.) produced from *gasification* (3.5) or *pyrolysis* (3.4) process

3.22
combustion
chemical and exothermic reaction with full oxidation of combustible materials

3.23
autothermal conditions
conditions that keep combustion without auxiliary fuel and/or other external energy

3.24
paste-like sludge
sludge capable of continuous flow under the effect of pressure above a certain threshold and having a shear resistance below a certain threshold

[SOURCE: CEN/TR 15463, 1.2.b]

3.25
solid sludge
sludge having a shear resistance above a certain threshold

[SOURCE: CEN/TR 15463, 1.2.c]

4 Abbreviated terms

BAT	Best available technology
CFBF	Circulating fluidized bed furnace
DM	Dry matter
FBF	Fluidized bed furnace
GCV	Greater (or gross) calorific value
LCV	Lower (or net) calorific value
LOI	Loss on ignition

MHF	Multiple hearth furnace
MSW	Municipal solid waste
PFBF	Pressurized fluidized-bed furnace
SCR	Selective catalytic reduction
SNCR	Selective not catalytic reduction
3T	Temperature, turbulence and (residence) time

5 Sludge properties

5.1 General

Sludge characterization for the assessment of thermal processes involves the evaluation of both technical and economic parameters. The main technical characteristics to evaluate the suitability of thermal process are DM or moisture content, calorific value, ash content. The main economic parameters are cost of processing, collection and transport, and the characteristics of the recovered materials and by-products.

5.2 Physico-chemical characteristics

5.2.1 General

The main physico-chemical characteristics to be taken into account are:

- DM (or moisture content);
- loss on ignition;
- calorific value;
- amount of grease, scum and screenings.

Physical consistency, together with rheological properties, also play an important role, especially as far as the design of feeding system is concerned.

5.2.2 Dry matter

The DM, or moisture content, is of primary importance for thermal processes because it strongly affects the LCV of organic material which decreases when the moisture content increases.

In thermal processing of sewage sludge DM is a parameter affecting both fuel requirement and exhaust gas production. Generally, any increase in DM is believed to be beneficial in the combustion for the reduction in fuel requirement. When the condition for autothermal combustion, at a given temperature, is reached the increase in DM corresponds also to a decrease in combustion gases production. Any further increase of DM beyond the limit of autothermal combustion involves a more abundant gas production, due to dilution air or water needed for the control of the combustion chamber temperature depending on design of incineration plant. However, the use of water, reduces the quantity of recoverable heat in the boiler.

5.2.3 Loss on ignition

The loss on ignition represents the portion mass escaping as gas as a result of the ignition of the dry mass of sludge.

The loss of ignition is generally used as a measure of the volatile matter content but it should be noted that inorganic substances or decomposition products (e.g. H_2O, CO_2, SO_2, O_2) are released or absorbed and some inorganic substances are volatile under the reaction conditions.

It is measured by heating sludge in a furnace at 550 °C ± 25 °C (see Reference [4]) or 600 °C ± 25 °C (see Reference [18]) and expressed as percent of the dry mass. The loss on ignition can be used as an assessment of the organic part of the sludge, and is therefore related to its heat value.

The presence in the sludge of iron with oxidation during ignition from iron (II) to iron (III), and of calcium hydroxide or calcium oxide, when sludge is conditioned with lime, can involve decreasing of the loss on ignition value (see EN 15935).

5.2.4 Calorific value

Calorific value of sludge is a very important parameter for the evaluation of thermal processes, as it represents the heat quantity developed in the combustion process by the unit mass of material in standard conditions.

The calorific value can be expressed as (see EN 15170):

- GCV at constant volume which is absolute value of the specific energy of combustion, in Joules, for unit mass of a solid sludge burned in oxygen in a calorimetric bomb under the conditions specified. The products of combustion are assumed to consist of gaseous oxygen, nitrogen, carbon dioxide and sulfur dioxide, of liquid water (in equilibrium with its vapour) saturated with carbon dioxide under the conditions of the bomb reaction, and of solid ash, all at the reference temperature;
- LCV obtained by calculation from the gross calorific value provided that either the hydrogen content of the sludge or the amount of water found in the combustion test can be determined.

Sludge usually contains much water, combustible and incombustible solids. Therefore, their calorific value, especially on the "as received" basis is quite low.

The calculation of calorific value of sludge can be expressed per LOI (loss on ignition) or DM.

Typical calorific values of municipal wastewater sludge range from 22,1 MJ/kg LOI to 24,4 MJ/kg LOI (anaerobically digested primary) to 23,3 MJ/kg LOI to 27,9 MJ/kg LOI (raw primary). Secondary sludge displays values between 20,7 MJ/kg LOI and 24,4 MJ/kg LOI.

Given typical values of organic matter content (LOI), the calorific value of sludge would generally be in the range of 12 MJ/kg to 17 MJ/kg DM for non-digested sludge, 10 MJ/kg to 12 MJ/kg DM for digested sludge.

GCV and LCV values can be calculated according to the standard method EN 15170, while the procedures for the theoretical calculation of GCV and LCV are reported in Annex A.

5.2.5 Grease, scum and screening

Grease, scum and screenings can be thermally treated together with sludge but generally they pose several problems.

Screenings clog feed mechanisms for certain types of furnace and therefore grinding or shredding is advisable before feeding. Screenings also contain bulky and incombustible materials, which create problems in the ash disposal system.

Skimmed material generally contains more than 95 % moisture and therefore should be dewatered to at least 25 % solids before treatment. Skimming is difficult to handle in the dewatered state due to its viscosity and a heating process to 70 °C to 80 °C is generally requested to get skimming pumpable. After dewatering, scum solids should be ground to a size not exceeding 6 mm. GCV of skimming and screenings are in the range 37 000 to 44 000 kJ/kg DM and 23 000 to 25 600 kJ/kg DM, respectively.

Quantities of screenings are strictly dependent on the screen openings. They can vary in the range of 3×10^{-6} m^3/m^3 to 40×10^{-6} m^3/m^{3}of sewage for openings of 12 mm to 25 mm (the upper limits apply to the reduced openings). As dewatered sludge production can be approximately evaluated in 1 l/m^3 of sewage, the screenings production can be accounted in approximately 0,2 % to 4 % in mass of sludge production, considering that the density of wet screenings is 640 kg/m^3 to 1 000 kg/m^3.

Quantities of scum are very much dependent on the quality of the sewage and on the collecting system in the wastewater treatment plant. The highest values can be as high as 17 g of DM/m^3 of sewage which means up to 1,7 % of sludge production. At a concentration of 25 % this value increases to 6,8 %.

The quantity of any added material, especially grease, scum and screening, is limited by the capacity and the efficiency of the gas treatment.

5.2.6 Physical consistency and others

The physical consistency of the sludge influences the selection and design of thermal processes.

Therefore, the evaluation of specific parameters giving information on this aspect (e.g. flowability, solidity, piling behaviour) appears useful in this designing step (see Reference [2]).

Other characteristics influencing thermal processes are particle size, bulk density and morphology.

5.3 Chemical and microbiological characteristics

5.3.1 General

The main characteristics to be taken into account are:

- sulfur;
- phosphorus;
- nitrogen;
- chlorine and other halogens;
- organic micro pollutants;
- trace elements (especially mercury);
- pathogens.

The presence of the above-mentioned chemicals should be known in order to prevent or minimize toxic emissions (gaseous, liquid, solid) from thermal processes.

Typical elemental composition depends also on the type of sludge, primary, activated or digested primary sludge (see Reference [13] for more details).

5.3.2 Sulfur

The sulfur content of sewage sludge ranges generally from 0,5 % to 2,1 % of DM.

In anaerobic digestion, sulfate is converted to sulphide by sulfate reducing bacteria. Some of it precipitates with iron and other metals as insoluble sulphides, while some other is stripped as hydrogen sulphide and is transferred to the biogas stream from which it can be removed by scrubbers. The amount of residual sulphides in anaerobically digested sludge is proportional to the metal content in the raw sludge. If sludge is not treated anaerobically, most of the sulfate remains in solution as such. If sulfate containing compounds are used as inorganic conditioners in thickening and dewatering, sulfur content increases. Sometimes, this can affect the cost of acid gas removal (e.g. in flue gas desulfurization). Because a fraction of the sulfur is present in the oxidized sulfate form, not all of this sulfur is converted to sulfur dioxide during combustion. Sulfur dioxide then combines with moisture, either in the waste gas treatment system or in the atmosphere, to form sulphuric and sulphurous acids.

5.3.3 Phosphorus

Phosphorus may be present in sewage sludge in concentration ranging from 1 % to 16 % DM.

However, phosphorus concentration in dry sludge can be widely changed, depending on wastewater treatment system prior to sludge treatment. This concentration mainly depends on the phosphorus load in the wastewater system and on the level of phosphorus removal accomplished in the treatment plant.

During combustion phosphorus and phosphorus compounds are converted to calcium phosphate which can be present in the furnace ash up to 15 % mass fraction of P_2O_5 in certain conditions; therefore, combustion ashes represent a useful source of phosphorus and its recovery should be considered.

5.3.4 Nitrogen

Nitrogen content of sewage sludge ranges from 2 % to 12 % of DM; typical values are around 5 % to 7 % of volatile solids in a mixed primary and secondary sludge. Organic nitrogen can be converted during combustion to molecular nitrogen or to NO_x, depending on the temperature and atmosphere inside the furnace. NO_x formation from fuel bound nitrogen can be controlled by restricting the air flow to the minimum excess above the stoichiometric requirement and by staging the air flow to the furnace (see 8.4). Nitrous oxide, N_2O, is generated as a result of reaction in thermal oxidation processes, which has approximately 300 times as high as CO_2 in terms of greenhouse gas effect.

5.3.5 Chlorine and other halogens

Organic and inorganic chlorine compounds play an important role in the combustion processes after tendency of the chlorine radicals to bind active radicals, like O*, H*, OH*, RO*, thus determining a decrease in the combustion rate with potential formation of toxic compounds. Chlorine and other halogens are also responsible for the presence in the exhaust gases of undesirable acidic compounds inducing corrosion problems especially at high temperatures. The presence of organic chlorine in sewage sludge is generally negligible (less than 50 mg/kg DM) but the concentration of inorganic chlorine may exceed some units per cent dry mass depending on the chlorine content in the sludge water and on the use of inorganic conditioners. The agroindustry sludge, similar to sewage sludge from food and/or beverage transformation and production, do not contain organic chlorine. As for sewage sludge, inorganic chlorine can be present in such sludge after the use of $FeCl_3$ as conditioning agent.

Bromine can exert similar effects as chlorine but the organic compounds are more easily formed and they can also be more easily destroyed at high temperatures.

5.3.6 Organic micro pollutants

Although the presence of biopersistent organic micro pollutants (such as chlorinated hydrocarbons, phenols and polyphenols, polychlorinated biphenyls, pesticides and polycyclic aromatic hydrocarbons and pharmaceuticals) in sewage sludge may be in some cases noticeable, they generally do not pose relevant problems in thermal processing.

Formation of dioxins can be a serious problem depending on the gas treatment and the temperature of incineration. Dioxins are rarely formed in sewage sludge mono-incineration process as the concentrations of dioxin precursor and unburned carbon are very low. Dioxins can be formed again (*de novo* synthesis) during the gas treatment, especially in the range of temperature 200 °C to 600 °C, for sludge with a high content in organochlorine compounds, this can be avoided by a rapid quench of the exhaust gas. Significant formation of particularly stable compounds has been evidenced in oxygen-deficient environments. However, rapid quenching is not necessary when the concentration of chlorine is low. Different reviews on quality of sewage sludge are available (see Reference [19]).