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Sludge recovery, recycling, treatment and disposal — Requirements and recommendations for the operation of anaerobic digestion facilities

Valorisation, recyclage, traitement et élimination des boues — Lignes directrices pour l'exploitation des installations de digestion anaérobie

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

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Introduction

Anaerobic digestion of sewage treatment plant sludge is an increasing market at world scale. It presents advantages for sludge treatment in terms of sludge volume decrease, organic matter recycling and energy recovery.

Standardization of conditions of operation is therefore a main issue to ensure an efficient development of anaerobic digestion treatment. Anaerobic digestion process is subject to appropriate safety measures because it can represent many risks. Safety parameters are included in risks analyses (e.g. HAZOP).

Therefore, the objectives of this document are:

— to reduce volatile solids, mitigate odours production and generate biogas;

— to obtain good process stability and performance;

— to maximize qualities of by-products: digestate quality, biogas quality for different uses (injection of upgraded biogas into the gas grid, liquefied storage, fuel reuse, electricity and heat production);

— to perform safe and reliable operation: industrial safety for piping and automatism network and biogas equipment is in particular an important issue;

— to reduce emission of greenhouse gasses, especially of methane.

Absolute anaerobic stabilization does not mean sludge sanitization: pathogens reduction is limited to 1 log to 3 logs. Higher reduction can only be obtained with specific conditions of temperature and residence time which are not discussed in this document.

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Sludge recovery, recycling, treatment and disposal — Requirements and recommendations for the operation of anaerobic digestion facilities

1 Scope

This document establishes requirements and recommendations for the operation of the anaerobic digestion of sludge in order to support safe and sufficient operation of anaerobic digestion facilities to produce to produce sufficient biogas and control by-products qualities.

In particular, conditions to optimize mixing within the reactor and appropriate control systems management for safe and reliable operation are described in this document. Performance of the processes in terms of biogas and digestate production are presented depending on type of technologies available on the market. Blending sludge with waste (co-substrate) and mixing the sludge with organic wastes to increase digester loading are also considered.

This document is applicable to decision-makers and operators in charge of an anaerobic digestion system.

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2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
acetoclastic methanogenic microorganism
anaerobic microorganism which use acetate as a main substrate

3.1.2
anaerobic digestion
anaerobic process which achieves two equally important functions, the anaerobic stabilization of substrate and the production of energy through conversion of substrate into biogas

3.1.3
biochemical methane potential
BMP
volume of methane generated during the sample degradation referred to the mass of the sample of biosolid and expressed in normal conditions of temperature (0 °C) and pressure (1 013 hPa)

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3.1.4
digestate
digested sludge
remaining effluent from the anaerobic digestion process including solid fraction and liquid fraction

[SOURCE: ISO 20675:2018, 3.19]

3.1.5
digester gas
biogas
gas mixture generated during anaerobic digestion consisting mainly of methane and carbon dioxide

3.1.6
feeding
process of adding substrate into an anaerobic digester

3.1.7
hydrolysis
biological, chemical, thermal or physical transformation of solid chemical oxygen demand into dissolved chemical oxygen demand by reaction with water

3.1.8
phase
distinct metabolic pathways

EXAMPLE Two-phase digestion: hydrolysis/acidogenesis followed by acetogenic/methogenic.

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3.1.9
readily degradable substance
substance which is easily and completely degradable by microorganisms

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3.1.10
sludge age
solids retention time in a reactor

Note 1 to entry: The common unit is d.

3.1.11
stabilization
process in which organic substances are converted to materials that are not biodegradable or are slowly biodegradable

3.1.12
stage
consecutive part of a process

EXAMPLE Two-stage digester, i.e. a primary digester followed by secondary digester for completing processes.

3.1.13
substrate
feedstock containing degradable organic components

3.1.14
volumetric organic load
mass of substrate, measured as total solids, volatile solids, biochemical oxygen demand or chemical oxygen demand, fed per digester volume and day

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3.2 Abbreviated terms

ATU	allyltiourea assay
BMP	biochemical methane potential
BOD	biochemical oxygen demand
CAPEX	capital expenditure
CHP	combined heat and power
COD	chemical oxygen demand
ECP	extracellular polymer
FOG	fats, oils and greases
HRT	hydraulic retention time
ITHP	intermediate thermal hydrolysis process
OUR	oxygen uptake rate
OPEX	operational expenditure
SOUR	specific oxygen uptake rate
SRT	solids retention time
TS	total solids
VFA	volatile fatty acids
VS	volatile solids

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4 Fundamentals

4.1 Boundaries

Figure 1 describes the system configuration of the anaerobic digestion. In this document, the focus is oriented on anaerobic digester operation and pre-treatments.

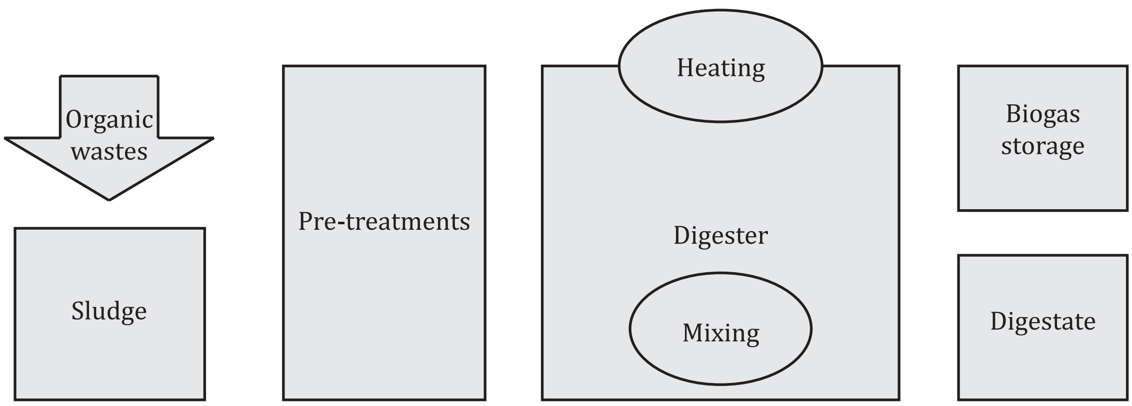

Figure 1 — Typical system configuration of anaerobic digestion

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4.2 Principle

Anaerobic digestion is a cornerstone process of wastewater treatment operations, wherein solid waste streams can be effectively treated and resources recovered. Anaerobic digestion usually requires primary sludge. Most of the digester gas is generated from primary sludge. Secondary or tertiary sludge can also be stabilized, but they should be (usually mechanically) thickened prior to anaerobic digestion. The pervasive rollout of activated sludge-based wastewater treatment processes in particular throughout the 20th century, necessitated digestion processes to effectively stabilize the large volumes of generated waste activated sludge. The key purpose of anaerobic digestion during wastewater treatment is to achieve disintegration and destruction of the degradable sludge solids fraction in order to reduce this fraction and to reduce the mass and volume of the sludge material after dewatering or drying.

This treatment recovers useful resources such as combustible digester gas (methane) and nutrients in the digester sludge. Anaerobic digestion involves microbial decomposition of the organic constituents present in wastewater sludge (i.e. proteins, carbohydrates and lipids) in the absence of dissolved oxygen. Microorganisms involved in anaerobic digestion comprise a complex consortium of microbes, with different metabolic properties and physicochemical requirements. The key products of anaerobic digestion, apart from digested and stabilized solids rich in phosphorus include water containing high levels of ammonia and alkalinity, and a biogas which comprises principally methane (typically 60 % v/v to 70 % v/v) and carbon dioxide (typically a volume fraction of 30 % to 40 %), with other minor constituents including hydrogen, nitrogen, hydrogen sulfide and siloxanes. Digester gas composition depends on substrate quality. It can be different for industrial sludge or where co-substrates are added.

Anaerobic digestion transfers energy from solids to digester gas (methane). Only a very small amount of energy is used for the production of biomass. Theoretical calculation gives 0,35 m^3 methane with an energy content of 3,5 kWh per kg of COD removed.

Anaerobic digestion is performed through four distinct biological steps, namely hydrolysis, acidogenesis, acetogenesis and methanogenesis; an additional pre-treatment stage may be added prior to hydrolysis for feedstocks containing solid particles in order to breakdown solids to smaller particles which are more amenable to hydrolysis.[50]

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— Hydrolysis: Hydrolysis generates soluble organic components (e.g. sugar) from volatile solids which microorganisms can absorb through their cell membranes. Hydrolysis is usually the rate-limiting step during the digesting process.

— Acidogenesis: Hydrolyzed compounds formed during the hydrolysis step are further converted to a mixture of short-chain volatile fatty acids (e.g. acetic acid, propionic, butyric and valeric acids), alcohols, esters, sugars and other simple organic compounds (e.g. carbonic acid) by a diverse array of microorganisms called acidogens. The relative proportion of the different metabolic co-products (H_2 and CO_2) depends on the substrate quality as well as the operating conditions.

— Acetogenesis: Products of acidogenesis are further transformed to acetic acid, CO_2 and H_2 by acetogenic microorganisms. Acetogenic microorganisms are relatively slow growing compared to the acidogens, such that careful process control and stable digester operation is required to avoid excessive acid accumulation and concomitant pH drop which can lead to digester upsets or process failure. Nevertheless, the slowest growing microorganisms are the methanogens.

  Some minor route such as syntrophic acetate oxidation performed by methane microorganisms (oxidation of acetate into H_2 and CO_2) can occur and be prevalent when stressful conditions are encountered (e.g. high concentration of ammonia resulting from high ammonium concentration, high pH and high temperature).

— Methanogenesis: This final stage generates methane from either acetate or hydrogen by methanogenic microorganisms (Archae). Usually acetate is the main source for the production of methane (approximately 70 %) via so-called acetoclastic methanogens, with the remaining approximately 30 % of generated methane being generated from hydrogen-utilizing methanogens. The balance between methane generation from acetate and from hydrogen is variable depending on operating conditions and substrate characteristics. Methanogens are slower growing than both

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the acidogens and acetogens, and are also susceptible to environmental stresses in the form of pH and temperature imbalance, toxic or inhibitory substances such as free oxygen, or disruptions of nutrient supply.

This succession of steps shows two points of attention in order to optimize anaerobic digestion operation.

a) Methanogenic microorganisms (mainly acetoclastic methanogens) are the slowest to grow because their substrate and their end products have a small energy difference (i.e. they gain little energy). In addition, they are most sensitive to inhibition.

   Methanosarcina have a maximum growth rate of 0,3 d^{-1} and *Methanothrix* have a maximum growth rate of 0,1 d^{-1}.[8] According to the Monod equation, the growth rate depends on the substrate concentration. The Monod equation is given in Formula (1):

$$\mu = \frac{\mu_{max} \times C_s}{K_s + C_s} \times \frac{K_i}{K_i + C_i} \quad (1)$$

where

- μ is the growth rate, in d^{-1};
- μ_{max} is the maximum growth rate at unlimited substrate concentration, in d^{-1};
- K_S is a constant, in g/l, depending on the kind of microorganism and its substrate; if $C_S = K_S$, then $\mu = 1/2 \times \mu_{max}$;
- K_i is a constant, in g/l, depending on the kind of microorganism and its inhibitor; if $C_i = K_i$, then $\mu = 1/2 \times \mu_{max}$;
- C_i is the inhibitor concentration, in g/l;
- C_s is the substrate concentration, in g/l.

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b) Hydrolysis is the velocity-limiting process step during the digesting process. In preferably heated raw sludge storage tanks some biological hydrolysis takes place. Particulate COD is turned into dissolved and easily degradable COD.

   Two stage digestion occurs in a highly loaded first-stage digester followed by a less loaded second-stage digester; the microorganism in both stages can be the same. A two-stage digestion (mesophilic and mesophilic) is more efficient than a single mesophilic reactor because the distribution around the mean retention time is tighter.

4.3 Pre-treatment

4.3.1 General

Substrate thickening is usually the first pre-treatment process. The fed substrate should have a solids concentration (30 g/l to 80 g/l) in accordance with the anaerobic digester operating conditions. This concentration should reach 150 g/l to 250 g/l in case of co-digestion of sludge and other organic waste. Concentration of either sludge or organic waste, or both, shall be performed by gravity or mechanical thickening.

Additional pre-treatments improve anaerobic digestion performance leading to either an increase of organic volumetric organic load or an increase of gas yield, or both. These pre-treatments are preferably designed to enhance sludge hydrolysis which is the velocity limiting step of anaerobic digestion. Fine screening of all fed substrates is generally recommended to remove coarse material, such as hygienic and cosmetic products and plastic matter. Removal of sand and grit reduces abrasion and wear of mechanical equipment and deposit formation in pipelines and channels, and accumulation of grit in anaerobic digesters.

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Advantages and drawbacks for different types of treatment before anaerobic digestion are presented in Table 1.

The full-scale estimations represented in Table 1 are average values which depends on the process characteristics.

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Table 1 — Advantages and drawbacks for different types of treatment before anaerobic digestion

Pre-treatment technique	Type of sludge	Hydrolysis rate (khyd)	Biodegradation	VS removal	Dewaterability of digestate	Return load (NH4-N)	Biogas yied	OPEX	CAPEX	Reference
Physical pre-treatment										
Thermal < 100 °C, time application < 24 h(pasteurization)	Mixed sludge	+	±	±	±	–-	±	++	++	[44]
Thermal > 100 °C	Mixed sludge and excess sludge	++	++	++	+ – polymer demand	– -- COD	++	++	+++	[25];[26];[28];[29];[30];[34];[35];[36];[37];[38];[39];[41]
Mechanical (pressure homogenizer, ultrasonic and mechanical disintegration)	Mixed sludge	+/++	+	+/++	± – polymer demand	-	+	+/++	+/++	[47];[45];[40];[46];[26];[46];[33];[32]
Chemical pre-treatment										
Alkaline hydrolysis	Mixed sludge (industrial and municipal)	++	+	++	- – polymer demand	–	±	++	±	[7]
Oxidation (O_3)	Mixed sludge	++	+	++	+ - polymer demand	- – COD	+	++	++	[45]
Biological pre-treatment										
Enzymes	Mixed sludge	+	±	±	+	-	±	+/++	±	[31];[43];[26]

Key

\+ : improvement (+ low, ++ medium, +++ high)

\- : degradation (- low, – medium, –- high)

±: no significative change

The signs (±) used in this table derive from full-scale anaerobic digestion data with or without pre-treatments.

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