

Sludge, treated biowaste and soil — Determination of pH

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Foreword

This document TC BT TF 151 WI CSS 99017 has been prepared by Technical Committee CEN/TC BT TF 151 "Horizontal standards in the fields of sludge, bio-waste and soil", the secretariat of which is held by DS.

This document is currently submitted to the CEN Enquiry.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

This standard is applicable and validated for several types of matrices. The table below indicates which ones.

Material	Validated for (type of sample, e.g. municipal sludge, compost)	Document
Sludge	Municipal sludge	<p>Andersson, S., Nilsson, S.I. & Jennische, P. (2003). Desk study to assess the feasibility of a draft horizontal standard for pH.</p> <p>Nilsson S.I., Johnsson L. & Jennische, P. (2005). A horizontal standard for pH measurements – The influence on pH measurements of sample pretreatment, ionic composition / ionic strength of the extractant and centrifugation / filtration</p>
Soil	Arable soil and forest soil	<p>Andersson, S., Nilsson, S.I. & Jennische, P. (2003). Desk study to assess the feasibility of a draft horizontal standard for pH.</p> <p>Nilsson S.I., Johnsson L. & Jennische, P. (2005). A horizontal standard for pH measurements – The influence on pH measurements of sample pretreatment, ionic composition / ionic strength of the extractant and centrifugation / filtration</p>
Soil improvers		

Sediment		
Treated biowaste	Compost	<p>Andersson, S., Nilsson, S.I. & Jennische, P. (2003). Desk study to assess the feasibility of a draft horizontal standard for pH.</p> <p>Nilsson S.I., Johnsson L. & Jennische, P. (2005). A horizontal standard for pH measurements – The influence on pH measurements of sample pretreatment, ionic composition / ionic strength of the extractant and centrifugation / filtration</p>

Introduction

This document is developed in the project 'Horizontal'. It is the result of a desk study entitled "Desk study to assess the feasibility of a draft horizontal standard for pH (Andersson, Nilsson & Jennische, 2003) and a ruggedness study entitled "A horizontal standard for pH measurements – The influence on pH measurements of sample pretreatment, ionic composition/ionic strength of the extractant and centrifugation/filtration" (Nilsson, Johnsson & Jennische 2005) and aims at an evaluation of the latest developments in assessing pH in sludge, treated biowaste and soil. Please note that soil improvers and growing media are not included.

After an evaluation study, in which e.g. the ruggedness of the method was studied, a European wide validation of the draft standard has taken place. The results of the desk studies as well as the evaluation and validation studies have been subject to discussions with all parties concerned in CEN. The standard is part of a modular horizontal approach in which the standard belongs to the analytical step.

Until now test methods determining properties of materials were often prepared in Technical Committees (TCs) working on specific products or specific sectors. In those test methods often steps as sampling, extraction, release or other processing, analyses, etc were included. In this approach it was necessary to develop, edit and validate similar procedural steps over and over again for every material or product. Consequently this has resulted in duplication of work. To avoid such duplication of work for parts of a testing procedure references to parts of test methods from other TCs were introduced. However the following problems are often encountered while using references in this way: 1) The referenced parts are often not edited in a way that they could easily be referred to, 2) the referenced parts are often not validated for the other type of material and 3) the updates of such test standards on products might lead to inadequate references.

In the growing amount of product and sector oriented test methods it was recognised that many steps in test procedures are or could be used in test procedures for many products, materials and sectors. It was supposed that, by careful determination of these steps and selection of specific questions within these steps, elements of the test procedure could be described in a way that can be used for all materials and products or for all materials and products with certain specifications.

Based on this hypothesis a horizontal modular approach is being investigated and developed in the project 'Horizontal'. 'Horizontal' means that the methods can be used for a wide range of materials and products with certain properties. 'Modular' means that a test standard developed in this approach concerns a specific step in assessing a property and not the whole "chain of measurement" (from sampling to analyses). [A beneficial feature of this approach is that "modules" can be replaced by better ones without jeopardizing the standard "chain".](#)

The use of modular horizontal standards implies the drawing of test schemes as well. Before executing a test on a certain material or product to determine certain characteristics it is necessary to draw up a protocol in which the adequate modules are selected and together form the basis for the test procedure.

The modules that relates to this standard are specified in section XX Normative references.

An overview of modules and the manner, in which modules are selected will be worked out later, at which time proper reference in this standard will be provided

1 Scope

This European Standard describes an instrumental method for the routine determination of pH using a glass electrode in a 1:5 (V/V) suspension of sludge, treated biowaste or soil in either water (pH-H₂O), or a 0,01 M calcium chloride solution (pH-CaCl₂). The standard is applicable to both fresh and air-dry soil samples (ISO 10390 as a basis), sludge (EN 12176 as a basis) or treated biowaste (EN 13037 as a basis). Soil improvers and growing media are not included.

2 Comments to the method

For practical reasons, for instance if there is a need to make strict comparisons with previous measurements, soils should generally be air-dried, even if fresh samples would represent the field conditions in a better way (Andersson, Nilsson & Jennische 2003). Air-drying can be used for all soils, except for those containing sulphidic minerals or volatile acids. In both cases fresh soil should be used to avoid either sulphide oxidation resulting in the formation of sulphuric acid, or volatilisation of low-molecular organic acids. Regarding sludge and treated biowaste, fresh samples are recommended. In these materials air-drying may introduce artefacts due to a stimulation of oxidation processes and should therefore be avoided.

Water or 0,01 M CaCl₂ are recommended as extractants. The use of a 0,01 M CaCl₂ solution will in general yield a lower pH value than will water. The use of the two extractants is largely based on previous empirical experience, and there is no unequivocal scientific support for choosing one or the other. The choice may be made according to the tradition in the specific setting where the determination is carried out. If pH of different materials (sludge¹, treated biowaste or soil) should be compared, it is obvious that the same extractant has to be used for all the materials tested. It is equally obvious that both H₂O and 0,01 M CaCl₂ have to be used on one and the same sample for comparisons between extractants. Whenever 0,01 M CaCl₂ is used for extraction of cations or anions other than Ca²⁺ and Cl⁻, it is recommended that this extractant is also used for pH measurement.

Extraction with 1 M KCl is sometimes used for pH measurement. This extractant has not been included in the current standard. Although it is normally used for quantitative determination of exchangeable soil acidity by titration there is no obvious advantage of using it for routine measurements of pH. The KCl solution has a high ionic strength (1,0 M) which is unrealistic for pH measurements in soil. The CaCl₂ solution on the other hand, has an ionic strength of 0,03 M which is closer to the expected value in soil solutions. Therefore, 0.01 mol/l CaCl₂ is a more reasonable choice of a neutral salt extractant.

For sludge and treated biowaste, fresh samples should be preferred. Air-drying may introduce artefacts due to stimulation of oxidation processes and should therefore be avoided. Water should primarily be used as an extractant.

The issue of fresh samples versus air-dried samples is specified according to the following table:

1) Concerning liquid sludge, see Clause 5 and Clause 9.

Table 1 — XXX

Sample category	Fresh	Dry
Sludge	X	
Treated biowaste	X	
Soils containing sulphide minerals	X	
Soils containing volatile acids	X	
Other soils	X*	X*
*Optional depending on whether comparisons are to be made with previous measurements on fresh or air-dry samples.		

3 Normative references

This European Standard incorporates by dated or undated references, provisions from other publications. These normative references are cited at appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN ISO 3696, *Water for analytical laboratory use – Specification and test methods*

ISO 11464, *Soil quality – Pretreatment of samples for physico-chemical analyses*

ISO 10390, *Soil quality – Determination of pH*

EN 12176, *Characterization of sludge – Determination of pH-value*

EN 13037, *Soil improvers and growing media – Determination of pH*

CSS99031 *Sludge, treated biowaste, and soils in the landscape – Sampling – Framework for the preparation and application of a sampling plan*

CSS99058 *Sludge, treated biowaste, and soils in the landscape – Sampling – Part 1: Guidance on selection and application of criteria for sampling under various conditions*

CSS99057 *Sludge, treated biowaste, and soils in the landscape – Sampling – Part 2: Guidance on sampling techniques*

CSS99032 *Sludge, treated biowaste, and soils in the landscape – Sampling - Part 3: Guidance on sub-sampling in the field*

CSS99059 *Sludge, treated biowaste, and soils in the landscape – Sampling – Part 4: Guidance on procedures for sample packaging, storage, preservation, transport and delivery*

CSS99060 *Sludge, treated biowaste, and soils in the landscape – Sampling – Part 5: Guidance on the process of defining the sampling plan*

CSS99034 *Soil, sludge and treated biowaste – Guidance for sample pre-treatment*

4 Terms and definitions

For the purpose of this European Standard, the following definition applies:

4.1 pH

hydrogen ion activity $\{H^+\}$ at equilibrium in a water or salt solution suspension, expressed as $-^{10}\log \{H^+\}$.

5 Principle

A suspension of sludge (fresh), treated biowaste (fresh) or soil (fresh or air-dry) is made up in five times its volume of one of the following:

- water
- a 0,01 M solution of $CaCl_2$

The pH of the suspension is measured using a pH-meter.

NOTE To make the procedure generally applicable to all types of sludge, treated biowaste and soil samples, one V/V shaking ratio is chosen because then all types of samples can be treated in the same way. For the purpose of this standard, taking the required volume of test portion with a measuring spoon is sufficiently accurate. Measurements in liquid sludge should only be made directly in the water suspension. No extra water should be added.

6 Interferences and sources of errors

In samples with a high content of charged particles (organic matter, clay) the suspension effect can modify the potential difference between the electrodes, and thereby have an influence on the recorded pH value. This problem is minimized by a gentle stirring of the suspension. For calcareous material, it is possible that carbon dioxide is absorbed by the suspension. Under the circumstances mentioned, it is difficult to reach an equilibrium value. Other sources of error are associated with materials containing sulphidic minerals or volatile acids (see Clause 1).

7 Reagents

- a) Use only reagents of recognised analytical grade.
- b) Water must have a specific electric conductivity not greater than 0,2 mS/m at 25 °C, and a pH not greater than 5,6 (grade 2 water in accordance with EN ISO 3696).
- c) Calcium chloride solution with the molarity of 0,01 M.

Dissolve 1,47 g of calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$) in water (7.1) in a 1000 ml volumetric flask and make up to volume with water.

This solution may be stored for several months in a refrigerator in a closed volumetric flask or other type of closed glass vessel.

8 Apparatus

- a) Equipment for sample preparation according to EN 12176 (sludge), EN 13037 (treated biowaste) and ISO 11464 (soil samples).
- b) pH-meter, with slope adjustment and temperature control

- c) A glass electrode and a reference electrode

9 Sampling and sample pre-treatment

Sampling shall be carried out in accordance with sampling standards CSS99031-32 and 99057-60.

Samples should be pretreated according to EN 12176, EN 13040 and ISO 11464. The particle size of soils should be ≤ 2 mm, while that of treated biowaste should be 20 mm to 40 mm.

NOTE 1 Sample preparation for liquid sludge is unnecessary. pH should be determined directly according to EN 12176. Pastelike sludge may need a breakdown of solid particles before the preparation of a suspension (9).

NOTE 2 ISO 11464 refers to air-dry soil. Except for the drying procedure, it is applicable to fresh soil samples as well.

10 Procedure

10.1 Preparation of a suspension

10.1.1 Take a representative test portion of at least 5 ml from the laboratory sample (solid sludge, soil) using a spoon of known capacity (at least 5,0 ml). Place the test portion in a polyethylene or glass bottle (capacity at least 50 ml) with a tightly fitting cap or stopper. Add water (see 6.a) or calcium chloride solution (see 6.b)) at an amount which is 5 times the volume of the test portion. For treated biowaste the procedure and volume ratio (1:5) is the same, except that a 60 ml sample is added to 300 ml of water or calcium chloride solution according to EN 13037.

10.1.2 Shake or mix the suspension for $60 \text{ min} \pm 10 \text{ min}$ using a mechanical shaker. Wait for at least 1 h, but not longer than 3 h. Ingress of air during standing after shaking should be avoided.

10.2 Calibration of the pH meter

Adjust the pH-meter as indicated in the manufacturer's manual. Calibrate the pH-meter as specified in the manufacturer's manual, using buffer solutions at $20^\circ\text{C} \pm 2^\circ\text{C}$: Potassium hydrogen phthalate ($\text{C}_8\text{H}_5\text{O}_4\text{K}$) at pH 4,00, and potassium dihydrogen phosphate (KH_2PO_4) + disodium hydrogen phosphate (Na_2HPO_4) at pH 6,88. For strongly alkaline materials disodium tetraborate decahydrate ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) at pH 9,22 may also be required. The use of commercially available standards within the same pH range can also be used.

10.3 Measurement of the pH

Measure the pH in the suspension at $20^\circ\text{C} \pm 2^\circ\text{C}$ immediately after or whilst being stirred. The stirring should be at such a rate to achieve a reasonably homogenous suspension of the soil particles, but entrainment of air should be avoided. Note the recorded values to 2 decimal places.

10.4 Blank determination

The water (or CaCl_2 solution) should be checked before the suspensions are prepared (see 6.a) and 6.b)). Blank determination in the strict sense is not relevant for pH measurements.

10.5 Quality Assurance of the overall procedure

If duplicate measurements are made (optional), the average value should be reported. A reference sample should be included in each batch of samples. The reference could be either "home made" or consist of a certified reference material.

11 Expression of results

The results of the determinations should be reported to the nearest 0,1 pH-unit.

12 Precision data

The performance characteristics of the method (Annex A) data have been evaluated. Table 2 gives the resulting typical values for repeatability and reproducibility limits as their observed ranges. The typical value is derived from the data in Table A.2 in Annex A by taking the median value and rounding the numbers.

Table 2 — Typical values and observed ranges of the repeatability and reproducibility limits

The reproducibility limit provides a determination of the differences (positive and negative) that can be found (with a 95 % statistical confidence) between a single test result obtained by a laboratory using its own facilities and another test result obtained by another laboratory using its own facilities, both test results being obtained under the following conditions : The tests are performed in accordance with all the requirements of the present standard and the two laboratory samples are obtained from the same primary field sample and prepared under identical procedures. Conversely, the repeatability limit refers to measurements obtained from the same laboratory, all other conditions being identical. The reproducibility limit and the repeatability limit do not cover sampling but cover all activities carried out on the laboratory sample including its preparation from the primary field sample.		
Results of the validation of the Determination of pH in soil, sludge and treated biowaste	Typical value %	Observed range %
Repeatability limit, r	0.84	0.7 – 1.7
Reproducibility limit, R	5.6	2.7 – 8.4

NOTE 1. The above results refer to the difference that may be found between two test results performed on two laboratory samples obtained under the same conditions. In the case when reference is made to the dispersion of the values that could reasonably be attributed to the parameter being measured, the above typical reproducibility values and observed reproducibility ranges should be divided by $\sqrt{2}$ to obtain the corresponding typical dispersion limit and its observed range. In the example of pH CaCl₂ in Sludge 2 the result and its dispersion limit is 7.09 ± 0.45 ($2 * sR = 6.33$ % of 7.09). This means that with a 95 % statistical confidence, the values reasonably attributable to the measured parameter are larger than 6.64 and lower than 7.54.

NOTE 2. The repeatability limit (r) and the reproducibility limit (R) as given in Table A.2 (Annex A) and in this table are indicative values of the attainable precision if the determination of pH is performed in accordance with this standard [CSS99017].

NOTE 3 A limited number of materials and parameters were tested. Consequently, for other materials and parameters, performance characteristics may fall outside the limits as derived from the validation of the the determination of pH in soil, sludge and treated biowaste.

NOTE 4 In particular for relatively heterogeneous materials, the repeatability and the reproducibility limits may be larger than the values given in Table A.2 (Annex A) and this table.

13 Test report

The test report shall contain the following information:

- a) A reference to this European Standard including its date of publication;
- b) Precise identification of the sample;
- c) Type of sample preparation: fresh, air-dry or (concerning liquid sludge) no preparation;
- d) The aqueous medium used to make the suspension: pH-H₂O, pH-CaCl₂ or no aqueous medium added (liquid sludge);
- e) Expression of results, according to the nearest 0,1 pH-unit;
- f) Any deviation from this standard, and any facts which may have influenced the result, stating the reason for deviation.

Annex A (informative)

Repeatability and reproducibility data

A.1 Performance characteristics

A.1.1 Objective of the interlaboratory comparison

In a European wide interlaboratory comparison study according to ISO 5725-2, the performance characteristics of the standard "Determination of pH in soil, sludge and treated biowaste" were established.

A.1.2 Materials used in the interlaboratory comparison study

The interlaboratory comparison of determination of pH in soil, sludge and treated biowaste was carried out with 14 -16 European laboratories on 6 materials. The materials selected for the interlaboratory comparison were chosen to represent soil, sludge and biowaste as broad as possible, because the standard will find general application across different types of soil and soil related materials. (detailed information can be found in the final report on the Interlaboratory comparison study mentioned in the Bibliography).

In the interlaboratory comparison study the following starting points were used:

The laboratory samples were all taken from one large batch of the different materials according to the normal practice. The normal size reduction and the normal repeated mixing were carried out as needed to obtain representative laboratory samples from the large batch sample (ref JRC).

The experimental plan was designed by project HORIZONTAL on the basis of each laboratory being given two laboratory samples of each material to be tested. This is in accordance with ISO 5725-2.

The materials examined cover all the grain size classes to which the the determination of pH in soil, sludge and treated biowaste applies: very fine grained materials (like sludge: 0 μm to about 125 μm) and fine-grained materials (soil and compost: 0 mm to 4 mm).

Table A.1 provides a list of the types of materials chosen for testing and the selected components.

Table A.2 — Material types tested and components analysed in the interlaboratory comparison of the method for the determination of pH in soil, sludge and treated biowaste.

Grain size class	Sample code	Material type tested	Parameters/congeners
Sludge (<0.5 mm)	Sludge 1	Mix 1 of municipal WWTP sludges from North Rhine Westphalia, Germany	pH aq, pH CaCl ₂
	Sludge 2	Mix 2 of municipal WWTP sludges from North Rhine Westphalia, Germany	pH aq, pH CaCl ₂
Fine grained (< 2 mm)	Compost 1	Fresh compost from Vienna, Austria	pH aq, pH CaCl ₂
	Compost 2	Compost from Germany	pH aq, pH CaCl ₂
	Soil 4	A sludge amended soil from Hohenheim, Germany	pH aq, pH CaCl ₂
	Soil 5	An agricultural soil from Reading, UK	pH aq, pH CaCl ₂

A.1.3 Interlaboratory comparison results

The statistical evaluation was conducted according to ISO 5725-2. The average values, the repeatability standard deviation (s_r) and the reproducibility standard deviation (s_R) were obtained (Table A.2).

The repeatability is determined as an interval around a measurement result (i.e. "repeatability limit"). This interval corresponds to the maximum difference that can be expected (with a 95% statistical confidence) between one test result and another, both test results being obtained under the following conditions: The tests are performed in accordance with all the requirements of the present standard by the same laboratory using its own facilities and testing laboratory samples obtained from the same primary field sample and prepared under identical procedures.

The repeatability limit was calculated using the relationship : $r_{\text{test}} = f \cdot \sqrt{2} \cdot s_{r,\text{test}}$ with the critical range factor $f = 2$. For instance, the repeatability limit around a measurement result of pH CaCl₂ of 7.0 is ± 0.06 (i.e $\pm 0.9\%$ of 7.0)

NOTE The above relationship refers to the difference that may be found between two measurement results performed each on two laboratory samples obtained under the same conditions. The value $f = 2$ used in the factor $f \cdot \sqrt{2}$ corresponds to the theoretical factor of 1,96 for a pure normal distribution at 95 % statistical confidence. Also, this value $f = 2$ corresponds to the usual value $k = 2$ of the coverage factor recommended in the Guide to the expression of Uncertainty in Measurement (GUM). However it may be necessary to use a larger value for f in situation as described in clause 12.

The reproducibility, like repeatability is also determined as an interval around a measurement result (i.e. "reproducibility limit"). This interval corresponds to the maximum difference that can be expected (with a 95% statistical confidence) between one test result and another test result obtained by another laboratory, both test results being obtained under the following conditions : The tests are performed in accordance with all the requirements of the present standard by two different laboratories using their own facilities and testing laboratory samples obtained from the same primary field sample and prepared under identical procedures.

The reproducibility limit was calculated using the relationship: $R = f \cdot \sqrt{2} \cdot s_R$ with the critical range factor $f = 2$. For instance, the reproducibility limit around a measurement result pH CaCl₂ of 7.0 is ± 0.41 (i.e $\pm 5.8\%$ of 7.0)

NOTE The above relationship refers to the difference that may be found between two measurement results performed each on two laboratory samples obtained under the same conditions. The value $f = 2$ used in the factor $f \cdot \sqrt{2}$ corresponds to the theoretical factor of 1,96 for a pure normal distribution at 95 % statistical confidence. Also, this value $f = 2$ corresponds to the usual value $k = 2$ of the coverage factor recommended in the Guide to the expression of Uncertainty in Measurement (GUM). In the case when reference is made to the dispersion of the values that could reasonably be attributed to the parameter being measured, the dispersion limit is equal to $k \cdot s_R$ with the usual value $k = 2$, resulting in a dispersion limit lower than the reproducibility limit (i.e. a ratio of $\sqrt{2}$). However it may be necessary to use a larger value $f \cdot \sqrt{2}$ (or k) in situation as described in clause 12 .

In case of relatively heterogeneous materials, the repeatability and the reproducibility limits may be larger than the values given in Tables A.2 (this means that the value chosen for the critical range factor f is larger than 2 as well as for the coverage factor k for dispersion). This is because the extreme results may have been obtained in accordance with the present standard and/or be caused by the variability within, or in between, the laboratory samples.

Table A.3 — Results of the interlaboratory comparison studies of the determination of pH in soil, sludge and treated biowaste.

Matrix	Parameter	Mean	sr	sR	r	R	p	Outliers	Total number of data	No of LOD
Sludge 1	pH CaCl ₂	6.54	0.24%	0.96%	0.044	0.176	7	3	34	0
Sludge 2	pH CaCl ₂	7.09	0.39%	3.17%	0.077	0.629	11	0	57	0
Compost 1	pH CaCl ₂	7.68	0.26%	1.90%	0.057	0.409	13	0	64	0
Compost 2	pH CaCl ₂	7.68	0.24%	2.36%	0.051	0.506	9	3	46	0
Soil 4	pH CaCl ₂	6.48	0.60%	2.27%	0.109	0.412	12	0	58	0
Soil 5	pH CaCl ₂	6.59	0.47%	1.20%	0.087	0.221	8	1	43	0
Sludge 1	pH aq	6.71	0.53%	1.11%	0.100	0.208	12	2	58	0
Sludge 2	pH aq	7.51	0.33%	1.43%	0.069	0.301	13	2	61	0
Compost 1	pH aq	8.13	0.50%	0.94%	0.115	0.215	14	2	70	0
Compost 2	pH aq	8.37	0.49%	1.73%	0.115	0.405	13	3	67	0
Soil 4	pH aq	7.05	0.59%	2.58%	0.117	0.509	14	1	66	0
Soil 5	pH aq	7.10	0.32%	2.10%	0.064	0.418	10	3	47	0

Abbreviations: sr Repeatability standard deviation; SR Reproducibility standard deviation; r Repeatability limit (comparing two measurements); R Reproducibility limit (comparing two measurements); p Number of labs.

Bibliography

- [1] ISO 1770, *Solid-stem general purpose thermometers*
- [2] EN 13040, *Soil improvers and growing media – Sample preparation for chemical and physical tests, determination of dry matter content, moisture content and laboratory compacted bulk density*
- [3] Andersson, S., Nilsson, S.I. & Jennische (2003). Desk study to assess the feasibility of a draft horizontal standard for pH. Swedish University of Agricultural Sciences, Uppsala
- [4] Nilsson, S.I., Johnsson, L. & Jennische, P. (2005). A horizontal standard for pH measurements – The influence on pH measurements of sample pretreatment, ionic composition / ionic strength of the extractant and centrifugation / filtration. Swedish University of Agricultural Sciences, Uppsala