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A method to calculate and express energy consumption of industrial wastewater treatment for the purpose of water reuse —

Part 1:
Biological processes

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 4, *Industrial water reuse*.

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

Biological wastewater treatment is a major process step in many cases of industrial wastewater treatment for reuse.

In the field of biological wastewater treatment, the energy consumption of the process is commonly normalized in order to account for difference in flow and concentration when comparing different treatment options. For example, energy consumption is reported per unit volume of wastewater treated (e.g. kWh/m^3) or per unit of pollutant removed BOD_5 (e.g. kWh/kg BOD_5), TN (e.g. kWh/kg TN).

The disadvantages and limitations of these indicators include:

— Neither of the existing indicators are agreed to and accepted as a standard in the industry;

— They do not provide means to compare nitrifying processes to non-nitrifying processes;

— There is no differentiation between design values and measured values, and there are no standard methods to obtain the indicator for each case.

Another approach is to report on the results from standard tests in water as oxygen transfer capacity per unit energy consumed (e.g. kg O_2/kWh).

The disadvantages and limitations of this type of indicator include:

— It is less convenient for the market to apply to its cases, (for example because not all removal is by oxidation, some is by metabolic consumption);

— It only considers oxygen transfer equipment or processes able to dissolve oxygen in water, which does not apply to all biological treatment processes (such as rotating biological contactor (RBC) and trickling filter (TF)).

These issues are discussed in the literature, which compares results expressed in different ways and correspondingly provides contradicting indications (see References [4], [5] and [10]).

Therefore this document aims to create a quantitative measure for universal characterization of the energy consumption for aerobic biological wastewater treatment systems. Such standardization will benefit engineers in specification of systems and comparison of systems. The need arises especially in consideration of life cycle cost of a wastewater treatment system.

NOTE 1 Normalized energy consumption of wastewater treatment systems typically decreases with increasing size of the system, mainly due to higher efficiency of larger electromechanical equipment such as pumps and blowers. Thus, large wastewater treatment plants will have lower normalized energy consumption than small wastewater treatment systems. In order to neutralize the influence of plant size in comparison of energy consumption, a correlation such as published by Silva, C., et al. (see Reference [11]) can be used, regardless of this document.

NOTE 2 Higher effluent quality requirements are generally associated with higher normalized energy consumption. Typically, normalized energy consumption will be compared for similarly performing systems. However, it is possible, for example, to present the normalized energy consumption for different treatment qualities as such.

NOTE 3 This document quantifies the energy consumption, regardless of treatment efficiency that can vary for different types of wastewater. Treatment efficiency might typically be characterized by retention time and/or volumetric loading rate and/or volumetric removal rate or other indicators which are not part of this document.

A method to calculate and express energy consumption of industrial wastewater treatment for the purpose of water reuse —

Part 1: Biological processes

1 Scope

This document sets out the general principles for, and provides guidance on, the quantitative characterization of the energy consumed by industrial biological wastewater treatment systems. It does not aim to characterize the treatment pollutants removal performance or process reliability or any other consideration in the selection of a wastewater treatment system.

This document includes the following sub-systems of biological treatment system:

— Biological reactors, which might be suspended growth or fixed film processes or a combination thereof, and can include anaerobic, anoxic and/or aerobic tanks and/or zones.

— Solid-liquid separation processes such as sedimentation, flotation, or membrane filtration, used for clarification of the water before discharge to downstream processes, which can also involve the return of a the separated solids as sludge back to the biological reactor.

— Any pumps, blowers and mixers for water circulation, mixing and air supply in and between the sub-systems listed herein.

— Heating or cooling of the water for treatment.

This document does not include the following subsystems of the biological treatment system:

— Wastewater feed pumps.

— Pre-treatment systems, which for the purposes of this document also include preliminary and primary treatment processes, such as but not limited to, screening, sedimentation, dissolved air flotation, chemical oxidation, oil separation.

— Post-treatment processes, such as but not limited to, disinfection, desalination, ion exchange, sludge treatment and handling systems.

— Site lighting or any energy consumption involved in office operation.

— Energy recovery from processes such as anaerobic reactors producing biogas.

Filtration processes, which are sometimes part of the biological treatment process and at other times part of the post treatment, are referred to separately within this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

ISO 20670, *Water reuse — Vocabulary*

3 Terms and definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20670 and the following 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/

3.2 Symbols and abbreviated terms

A^2O	anaerobic-anoxic-oxic wastewater treatment process
Bardenpho	a process for biological nutrient removal developed by James Barnard of South Africa in the 1970’s
BOD_5	bio-chemical oxygen demand (5 days) concentration or load, mg/l or kg/d, respectively
COD	chemical oxygen demand concentration or load, mg/l or kg/d, respectively
DAF	dissolved air flotation
DO	dissolved oxygen
DGF	dissolved gas flotation
MBR	membrane bio-reactor
MLE	modified Ludzack Ettinger process of wastewater treatment
NEC	normalized energy consumption, kWh/kg
NO_3-N	net oxidizable mass removed
TN	total nitrogen concentration or load, mg/l or kg/d, respectively
UCT	University of Cape Town process of wastewater treatment
VIP	Virginia Initiative Plant process of wastewater treatment
VFD	variable frequency drive
RBC	rotating biological contactor
TF	trickling filter
TKN	total Kjeldahl nitrogen concentration or load, mg/l or kg/d, respectively
VSS	volatile suspended solids

4 Expression and normalization of energy consumption

4.1 Energy consumption indicator

Following are details and explanations of values needed for later calculations in 4.2.

4.1.1 Normalized energy consumption shall be expressed in terms of energy per net oxidizable mass removed.

4.1.2 The net oxidizable mass removed (NOR) shall comprise of

— COD removed,

— TKN removed,

— Nitrate created (or subtraction of nitrate removed).

4.1.3 Constituents included in the indicator shall be factored for their oxygen demand value. Specifically the following factoring principles shall be applied, based on the references indicated in Annex A and in References [1], [2] and [5].

— COD removed shall be multiplied by +1,0.

— In design, COD concentration in the sludge shall be calculated on the basis of VSS concentration multiplied by 1,42 (References [8], [12], Annex A); the VSS concentration in the sludge, taken for calculations in this document, shall be the same as the value for VSS concentration in the sludge taken in process design. Process design values for sludge composition can be calculated according to conventional design procedures (Reference [8], Annex A).

— TKN removed shall be multiplied by +1,71 (corresponding to oxidation to nitrogen gas regardless of the chemical pathway).

NOTE The fraction of TKN which was not reduced to zero-valence nitrogen is accounted for as nitrate and nitrite, with the multipliers as specified below.

— In design, TKN concentration in the sludge shall be calculated as 12 % of the VSS, on the basis described above for COD calculation.

— Nitrate nitrogen removed or produced shall be multiplied by −2,86 or +2,86, respectively.

— Nitrite nitrogen removed or produced shall be multiplied by −1,71 or +1,71, respectively.

4.1.4 Removed mass for each constituent in the NOR shall be calculated as: constituent load in the inlet subtracted by constituent load in the outlet of the system as shown in Formula (1), wherein load is defined as the concentration multiplied by the flow rate.

4.1.5 Concentration and flow used for load calculation shall be representative samples, and flow shall be average daily flow. Attention should be paid to use results which do not significantly deviate from typical values, see for example existing wastewater sampling standard ISO 5667-10.

4.1.6 The indicator shall be expressed in metric units as follows: kWh/kg NOR.

4.1.7 All calculations and factors shall refer to metric units, and specifically concentrations in g/m^3 and flow in m^3/d.

4.1.8 Actual average daily power consumption in kW shall be used for the calculation of the normalized energy consumption. The power consumption should be measured by electricity power meters as required, installed on the mains of all the components included in the biological treatment system as defined in 5.2.

4.1.9 It shall be noted if all values are measured in an actual operating plant or calculated theoretically according to design.

4.1.10 It should be noted in addition, what type of wastewater the result is associated with, referring to ISO 22447.

4.1.11 The energy consumption in terms of NEC may be calculated for any of average/typical or peak conditions. It shall be noted alongside the result when energy consumption is calculated for peak conditions.

4.2 Calculation

The basic formulae for calculating energy consumption of a biological wastewater treatment system process shall be as follows:

$$\mathrm{LR}_i = \left(Q_{\mathrm{influent}} \cdot C_{i,\mathrm{influent}} - Q_{\mathrm{effluent}} \cdot C_{i,\mathrm{effluent}} - Q_{\mathrm{sludge}} \cdot C_{i,\mathrm{sludge}}\right) / 1\,000 \quad (1)$$

where

Q	is the average daily flow through the biological treatment, m^3/d;
Q_{influent}	is the influent average daily flow through the biological treatment, m^3/d;
Q_{effluent}	is the effluent average daily flow through the biological treatment, m^3/d;
Q_{sludge}	is the sludge average daily flow through the biological treatment, m^3/d;
C_i	is the concentration of constituent *i*, and specifically: COD or TKN or NO_3-N or NO_2-N or DO, all in mg/l;
LR_i	is the daily load of constituent *i*, removed, kg/d.

NOTE Regarding average daily flow through the biological treatment — flow and all concentrations are without (excluding) any circulations but with (including) return streams such as filter backwash and reject water from sludge handling operations. In other words: the flow and concentrations taken for calculation of LRi need to include return streams from backwash of filters and sludge handling.

$$NOR = LR_{\mathrm{COD}} \cdot 1{,}0 + LR_{\mathrm{TKN}} \cdot 1{,}71 - LR_{\mathrm{NO_3\text{-}N}} \cdot 2{,}86 - LR_{\mathrm{NO_2\text{-}N}} \cdot 1{,}71 - LR_{\mathrm{DO}} \cdot 1{,}0 \quad (2)$$

where NOR is the net oxidizable mass removed, kg/d.

$$NEC = \frac{W \cdot 24}{NOR} \quad (3)$$

Example calculations of Formulae (1), (2) and (3) are shown in Table B.1, Table B.2 and Table B.3.

5 Components contribution to the energy consumption

5.1 General

It is common in engineering design calculations to take different safety factors according to experience or recommendations from the literature. In all design calculations of NEC as part of this document, a safety factor of 1.0 shall be taken (i.e. no safety factor).

5.1.1 Steady state conditions

Measurements shall be performed at conditions where there is no positive or negative accumulation in the system. In order to avoid erroneous reporting of transition phase results as representative, the general conditions of the system should not be monotonously changing over the period of measurement,

