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Translating removal efficiencies into operational performance indices of wastewater treatment plants

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ABSTRACT

Removal efficiencies are often used to assess the performance of a single or a group of unit operations/processes (UOPs) of a wastewater treatment plant (WWTP). However, depending on the influent concentration (C_{in}), the same efficiency of removal (Er) may be insufficient or excessive to achieve the UOP or WWTP effluent quality requirements, expressed by concentration limit values (LVs). This paper proposes performance indices (PXs), Er-based, as new metrics for benchmarking, i.e. for assessing and improving the performance of each UOP or treatment step and ultimately of the WWTP as a multi-barrier system, and comprehensively describes the stepwise method of translating Ers into PXs. PXs are dimensionless and vary between 0 and 300 to define three performance levels: unsatisfactory (0–100), acceptable (100–200) and good (200–300) performance. The method developed takes into consideration C_{in} and LV, and the reference values for judging the performance are given from Er-C_{in} typical ranges and Er vs. C_{in} model curves, LV based and field data based. The general equations of the Er model curves are derived. A set of six curves is calibrated for TSS (Total Suspended Solids) and COD (Chemical Oxygen Demand) removal by primary sedimentation and activated sludge systems (carbon or combined carbon and nutrients removal), using 5-year (2006–2010) field data from five Portuguese WWTPs. A statistical analysis of the PX results is additionally proposed to assess treatment reliability. The new method is applied in two WWTPs and the PX results are compared with those of conventional measures – Er and performance indicators (PIs). The results demonstrate that, whereas a simplistic Er-driven or PI-driven management of the WWTPs shows limitations, the developed PXs are adequate measures for benchmarking removal efficiencies towards WWTP reliability and sustainability.

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1. Introduction

The percentage of population connected to sanitation systems, the number of urban wastewater treatment plants (WWTPs) and the treatment level required have been growing in Europe and worldwide to ensure the communities' development and the compliance with increasingly restrictive water legislation.

In addition to an adequate project design, good management practices of WWTPs are a key-factor to prevent the watershed pollution and preserve the public health while supporting the economic sustainability of these facilities. The recommended management practices for benchmarking wastewater services are based on a "plan-do-check-act" approach where performance assessment plays a key-role (ISO, 2007a,b; Cabrera et al., 2011). The management tools should address the WWTP's main goals, i.e. the compliance with the water and biosolids quality requirements using energy, water and chemical resources in a cost-effective and sustainable way. In addition to assessing the performance of the plant as a whole (overall performance), this calls for the WWTP assessment as a multi-barrier system, i.e. of each unit operation/process (UOP) or treatment step.

The efficiency of removal (Er) has been commonly used to assess the WWTP overall performance in terms of individual water quality parameters (e.g. Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), nutrients) on a (multi) annual (El-Gohary et al., 1998; Mines et al., 2007; Gallego et al., 2008, Al-Turki, 2010; Kumar et al., 2010; Zorpas et al., 2010; Rodriguez-Garcia et al., 2011; Özkan et al., 2012) or seasonal (Ying-Hua et al., 2012) basis.

Some authors used a so-called general efficiency indicator (Colmenarejo et al., 2006) or an integrated efficiency (Jamwal et al., 2009), determined as an average Er of target parameters, to compare the overall performances of different WWTPs, while others proposed Er-based methodologies for assessing the plant overall cost-efficiency (Sala-Garrido et al., 2011). Muga and Mihelcic (2008) and Balmér and Hellström (2012) developed performance indicator (PI) systems for WWTPs which include annual Ers of key-parameters (e.g. TSS, COD, nutrients, pathogens). Removal efficiencies have been also used in combination with mass balance evaluation to assess WWTP performance under different operating conditions (Puig et al., 2010), as well as in risk-based approaches to improve WWTP monitoring and assessment (Barjoveanu et al., 2010; Sweeney et al., 2012).

However, Er designation and units (dimensionless or in percentage) may drive a simplistic direct reading of the results, e.g. the higher the better (as in Al-Turki, 2010), which often misleads the performance assessment. In fact, the same Er value may be insufficient or be excessive, depending on the influent concentration of pollutants and the treated water quality requirements. The Er comparison with Er typical ranges (Özkan et al., 2012; Sweeney et al., 2012), obtained from the literature (e.g. Qasim, 1999; Metcalf and Eddy, 1991, 2003; WEF, 2008) and widely used for design purposes, or with constant Er targets (Al-Turki, 2010; Kumar et al., 2010) also lacks robustness as discussed by Strecker et al. (2001), Barrett (2008) and McNett et al. (2011). Typical Er values are applicable only to UOPs operated at typical ranges of influent concentration and operating conditions, assumptions often not verified in real situations. In both cases (direct Er reading or comparison with typical ranges), an Er-driven management of the WWTPs may lead to non-sustainable (environmentally and/or economically) wastewater treatment services related with non-compliances, waste of resources and lack of benchmarks for the continuous improvement of the service.

We have been developing a performance assessment system (PAS) for WWTPs (and an analogous one for drinking water treatment plants) which comprises: i) a PI system for the overall assessment of the plant, on an annual-basis, in terms of treated water quality, plant efficiency and reliability, use of natural resources and raw materials, by-products management, safety, personnel, financial resources, and planning and design (Quadros, 2010; Quadros et al., 2010; Silva et al., 2012), and ii) a system of performance indices (PXs) for assessing the daily performance in terms of treated water quality (Silva et al., 2014), operating conditions and removal efficiencies (Er-based PXs), herein presented for the first time.

Regarding removal efficiencies, PAS integrates Er-based PIs for the overall assessment of the plant, and new Er-based PXs for assessing and improving the operational performance of each treatment step in a multi-barrier context. This paper describes the innovative and comprehensive method developed to translate Ers into PXs, the Er model curves involved and their calibration with field data from five Portuguese WWTPs. The PAS potential for benchmarking WWTP removal efficiencies is illustrated for two WWTPs in Lisbon metropolitan area, with conventional primary sedimentation and secondary treatment by activated-sludge processes.

2. A novel method for translating removal efficiencies into performance indices

2.1. *Performance indicators, indices and functions*

According to earlier studies, the developed PIs refer to a reference period (usually, one year) and require reference values to judge the performance (Alegre et al., 2006; ISO, 2007a,b; Quadros et al., 2010; Cabrera et al., 2011; Silva et al., 2012), whereas the performance index (PX) corresponds to a dimensionless performance measure containing a pre-established judgment which allows a direct reading of the performance (Alegre, 2008).

The abovementioned PAS for WWTPs includes four Er-based PIs (and the reference values, Table 1) for assessing, on an annual basis, the plant performance as a whole, and Er-based PXs for assessing and improving the daily operational performance of each UOP or treatment step.

The developed PXs vary between 0 and 300, where PX 100 corresponds to the minimum acceptable performance and PX 300 to the excellent performance. This scale defines three performance levels with high resolution (100 wide each) and intuitive and easy-to-read "traffic light" graphing of the performance (Fig. 1) (Silva et al., 2014): unsatisfactory performance in the [0, 100[range, acceptable in the [100, 200[range and good performance in the [200, 300] range (Fig. 1).