Technical-economical evaluation of the operation of oxidation ditches

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Abstract The optimisation of the economic performance is a central aspect in the management of wastewater treatment plants. A model-based procedure was developed that could provide a clearly enunciated and concise way of reporting to the stakeholders on how well the assets are performing and can perform, separating the firm inefficiency from the effect of the treatment. The applied modelling method is conventional considering current modelling research practice, but very good from practical point of view in that it is applicable utilising existing plant data, i.e. without the use of additional measuring campaigns. This paper illustrates the validity of the developed procedures through the evaluation of the performance of oxidation ditches.

Keywords Costs; benchmarking; economics; activated sludge; oxidation ditches

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Introduction

In Flanders now that most of the wastewater treatment plants (WWTPs) are built, and operate in compliance with the EU Urban Wastewater Treatment Directive for sensitive areas, attention is increasingly directed towards the optimisation of their economic performance. A study was carried out to answer basic questions such as: How "good" or "bad" are the Flemish WWTPs really performing? At what level should they set their performance targets? How to achieve those targets?

The available data had to be integrated by predictive modelling to reach meaningful and clear interpretation of the results. Modelling allowed a proper stratification of the results, a critical aspect to separate the firm inefficiency from the effect of the treatment (i.e. to separate the firm inefficiency from the local unique circumstances). The alternative to obtain the unavailable but required stratification of the results would have been universal measurement of field operations, implying prohibitive costs and possible disruptions of the operation.

The aim of this paper is to illustrate the general applicability of the developed modelling procedure. The evaluation of the operation of oxidation ditches is taken as an example. In Flanders oxidation ditches with intermittent or anoxic zones and simultaneous chemical precipitation are the standard process technology for municipal sewage treatment of conglomerations between 2,000 and 30,000 PE (Ockier *et al.*, 2001).

Model approach

The hydraulic behaviour of the oxidation ditch was modelled based on the completely stirred tank reactor (CSTR) theory. A literature review show that there is not yet consensus on the modelling of the hydraulic behaviour of oxidation ditches. Some authors propose relatively sophisticated models (Alex *et al.*, 1999; Dudley, 1995; Hunze, 1996; Stamou, 1997; Von Sperling, 1990). Others argue that the significantly higher computation time of a one-dimensional approach is only justifiable by design purposes and that either a tank-in-series (Abusam and Kessman, 1999; De Clerq *et al.*, 1999) or a CSTR approach (Derco *et al.*, 1994) produce satisfactory results.

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The biological characterisation of the system was modelled with a modified version of the Activated Sludge Model No. 3 (Gujer *et al.*, 1999). The chemical phosphorus precipitation was added to the process equations. The settling behaviour of the secondary clarifiers was modelled with the Takács model (Takács *et al.*, 1991).

A pragmatic model calibration/validation approach, consisting of exploiting only the information collected by the operators in the day-to-day follow-up of the WWTP (Table 1), was adopted.

Despite the fact that the input for the calibration can be considered quite limited when compared to the data requirements of the procedures illustrated in the literature (e.g. Petersen, 2000), acceptable calibration results could be obtained. The validation results of the calibrated model of WWTP Eksel are illustrated in Figure 1 as an example. In Figure 1 the lines represent the results of the simulation and the dots the observations.

Assessment of the operability space

Operability charts were developed to graphically visualize the operability space of the controllable variables and evaluate the robustness of a control strategy. The operability of a process refers to its ability to perform satisfactorily under conditions different from the nominal design conditions. The operability space is of particular significance in the comparison of the WWTP performance as, for instance, building with a smaller footprint (i.e. a lower capital investment) may result in a higher probability of incidents, or increased need of supervision (in the form of capital or labour).

In the first instance we developed a steady-state procedure to calculate the operability space of the most important controllable process variables. The controllable variables refer to the nitrification/denitrification, the settling and the chemical phosphorus precipitation processes. Table 2 shows the controllable variables that we have considered for each of the areas of interest.

Another aspect that was taken into account is the influence of the temperature on the biologic processes and the variability of the influent characteristics, both in loads and flow, throughout the year. Three different scenarios representing summer, winter and spring/autumn conditions were developed. In each of them the influent is characterised by the seasonal average flow and loads and the process temperature is assumed constant. Graphs for dry weather flow, wet weather flow and first flush events were also developed.

Figure 2 illustrates the results of the application of the procedure to a real case study. The three charts represent three seasonal scenarios at WWTP Ertvelde. The lines identify the boundaries of the operability space. The lower line determines the denitrification fraction that leads, for a fixed MLSS concentration, to an oxidised nitrogen concentration of 10 mg N/l in the effluent. The upper line identifies the boundary corresponding to an ammonia concentration in the effluent equal to 5 mg N/l.

Table 1 Available data and their frequency during the measuring campaigns of the water authority

Design data	
Process schema, dimensions of treatment units, aeration capacity, capacity of the pumps, …	
Operational data	*Frequency*
Installation settings during campaign	
return flow rate, excess sludge flowrate	daily
aeration settings (denitrification time, dissolved oxygen setpoint, cycle time)	daily
daily average dissolved oxygen in the aeration tank	daily
MLSS in the aeration and in the return	twice a week
settling conditions in the clarifiers (thickness of the sludge blanket, SVI)	twice a week
Influent–effluent characteristics	
flow, BOD5, COD, suspended solids, NH_4-N, KjN, NO_2-N, NO_3-N, TN, TP	daily

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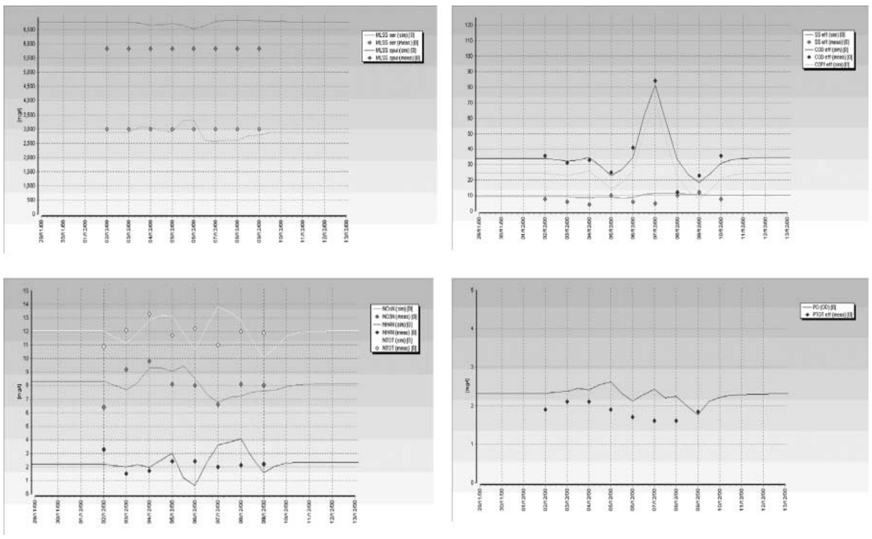

Figure 1 Results of validation for WWTP Eksel: (a) MLSS concentration in the aeration and in the return, (b) COD, COD filtered and suspended solids in the WWTP effluent, (c) NH_4-N, NO_3-N and total nitrogen in the WWTP effluent, (d) total phosphorus in the WWTP effluent (lines: simulations; points: observations)

Figure 2 shows that in 2002 the plant was operated within the operability space during summer and spring/autumn, while in winter the majority of the measurements lay above the upper boundary. The observations confirmed that WWTP Ertvelde experienced a relatively high ammonia concentration. An inappropriate control management could easily be detected and the high concentrations of ammonia predicted.

A similar analysis was conducted for the settling process in the secondary settler. A modified version of the Takàcs model (Devisscher and Boonen, 2003) was used. The controlled variables are the MLSS concentration in the aeration tank and return flow rate (Qras). It is worth remarking that the settleability of the sludge is taken into consideration through the sludge volume index. The boundaries represent in this case the conditions leading to a sludge blanket under 0.5 m from the surface of the clarifier. The model shows that this condition results from the application of an either too low or too high return flow rate. In most cases, however, it was the capacity of the return pumps that determined the upper boundary of the operability space. Figure 3 shows the results of the application of the procedure to a real case study.

Figure 3 shows that in 2002 WWTP Achel operated within the boundary conditions, as the observations confirmed.

The third operability space is the operability space of the chemical phosphorus precipitation process. The main controllable variables are the flow-rate of the excess sludge production and the dosing rate of the chemical precipitants. The lower and upper boundaries of the operability space for medium size installations were set at a concentration of

Table 2 Overview of the controllable variables whose operability space is assessed in the operability charts

Process	Variables			
		Unit		Unit
Nitrification/denitrification	denitrification fraction	% of cycle time	MLSS	g/l
Setting	return flow rate	m^3/d	MLSS	g/l
Phosphorus removal	sludge production	kg/d	precipitants dosed	l/d

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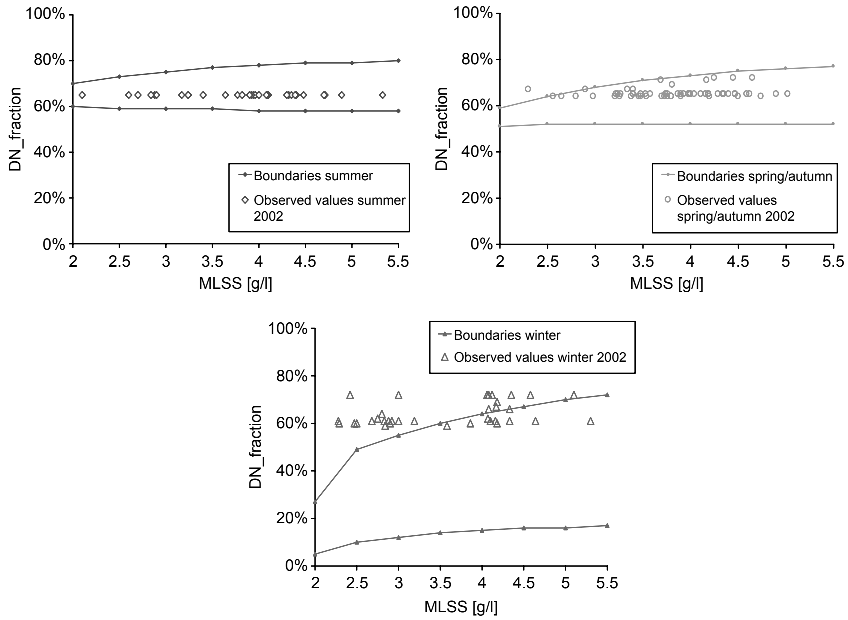

Figure 2 Operability space of the nitrification/denitrification process: boundary conditions for MLSS and the DN fraction and values observed in 2002 at WWTP Ertvelde

respectively 1.7 mg P/l and 1 mg P/l total phosphorus in the effluent. For that plant size the effluent consent is 2 mg P/L on an average annual basis. The upper boundary is set to 1 mg/L since it was considered not economically justifiable to have a further reduction of the effluent phosphorus concentration.

Figure 4 shows the results of the application of the analysis to WWTP Heist-op-den-Berg. The code of practice of this installation prescribes dosing a constant volume of iron salts throughout the year. The analysis shows, however, that the code overestimates the quantity of salts required, in particular during the winter period, when higher influent flows are characterised by a diluted phosphorus concentration.

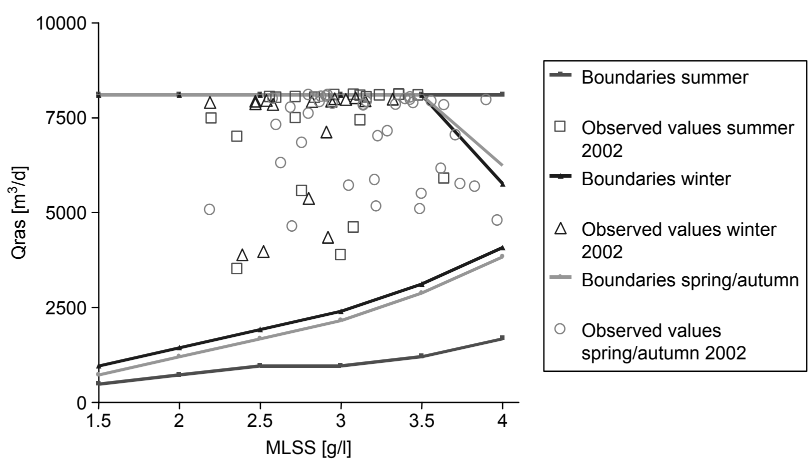

Figure 3 Operability space of the sedimentation process: boundary conditions for MLSS and Qras and values observed in 2002 at WWTP Achel

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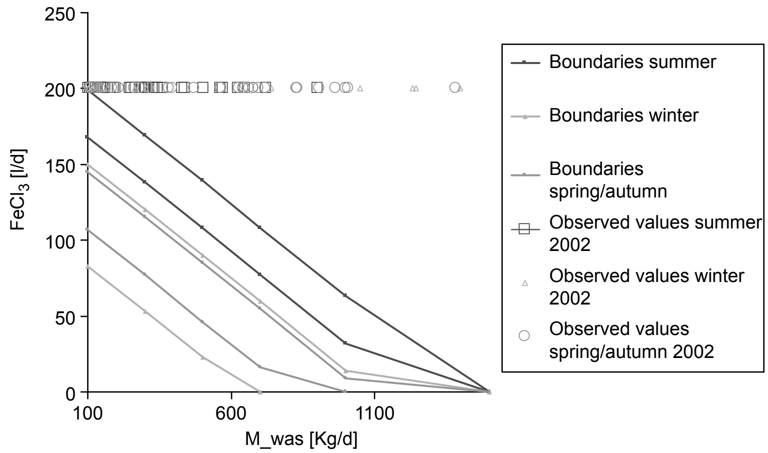

Figure 4 Operability space of chemical phosphorus precipitation: boundary conditions for the sludge production (M_was) and the dosing rate of Fe^{3+} products and values observed in 2002 at WWTP Heist op den Berg

Assessment of the operational costs of current and alternative control strategies

To estimate the settings that minimise the variable operating costs, the analysis was extended to an economical evaluation of the operational costs of the plants (TC) within the operability space. A modified version of the performance indexes defined in the IWA COST benchmark (Copp 2002) was implemented. Aeration (AC), pumping (PC) and sludge disposal (SC) costs were quantitatively evaluated for the current as well as for alternative control strategies.

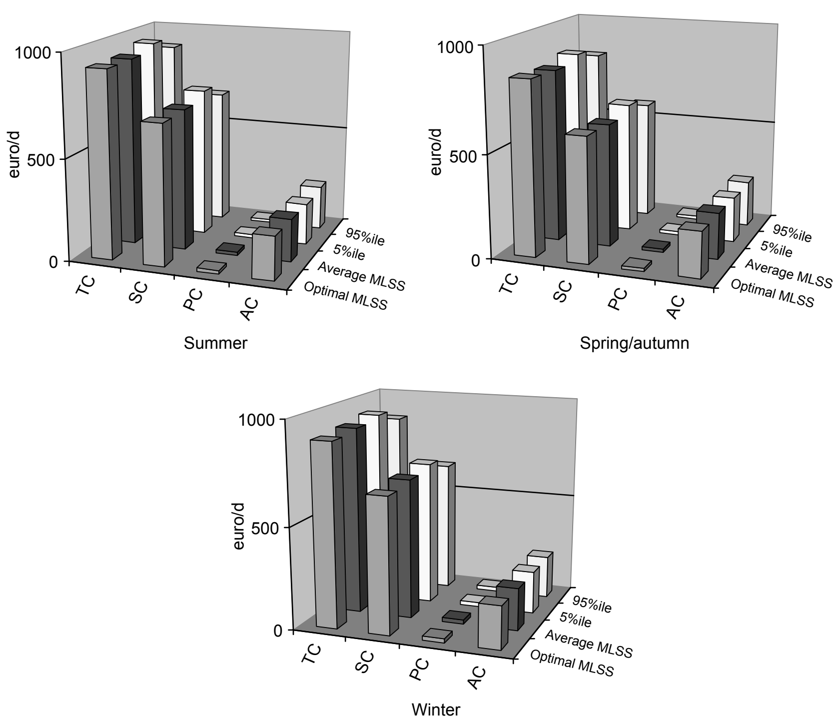

Figure 5 Operating costs of WWTP Boom

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The relevance of the proposed approach for the evaluation of control strategies is best illustrated throughout two examples: one concerning operational benchmarking and one concerning strategic benchmarking.

Example 1: Operational benchmarking

As an example, Figure 5 illustrates the estimates of the operational costs at WWTP Boom when the set-point value for ammonia concentration in the effluent is set as indicated in the code of good practice. Four management alternatives concerning the MLSS concentration in the aeration tank are considered: plant operated at the optimal MLSS value indicated in the code of good practice, at the average MLSS concentration measured during year 2002 and at respectively 5%ile and 95%ile of the values observed in 2002.

The results of the application of this analysis showed that in some cases the practice of the operators has developed into control strategies that differ from what indicated in the code of good practice but imply lower operational costs.

Example 2: Strategic benchmarking

The comparison of two stormflow treatment operational strategies is considered as an example. Standard practice in Flanders is to limit the hydraulic capacity of sewage treatment works to $6Q_{14}$ ($Q_{14} = 1.7$ dry weather flow Q_{DWF}). A maximum of $3Q_{14}$ is treated biologically, while the excess flow undergoes only physical treatment in storm tanks. This practice has been challenged by a new high-flow activated sludge operation concept, consisting of the treatment of the full storm sewage flow in the biological train and of the use of the storm tanks as additional secondary clarifiers (Bixio *et al.*, 2004). Bixio *et al.* (2004) show that this practice provides better ecological results, … but at what additional cost?

Since for this application we needed to reproduce the effects of rain events, a dynamic approach was adopted. In the analysis the sewage volume temporarily stored in the storm tank with the $3Q_{14}$ strategy, which is treated biologically after the rain event is also taken into account. Figure 6 shows the operating costs for a series of 25 days, with a rain event of three days starting at day 15.

Figure 6 shows that the costs of the two operational strategies are comparable during the first two weeks of dry weather flow and the week of dry weather flow following the rain event. During the three days of rain event, however, the costs of the $6Q_{14}$-mode are significantly higher than the costs of the $3Q_{14}$-mode. The results of the application of this analysis allowed estimating that through the $6Q_{14}$ strategy an increment of the operating costs of 4–5% on an annual basis is to be expected.

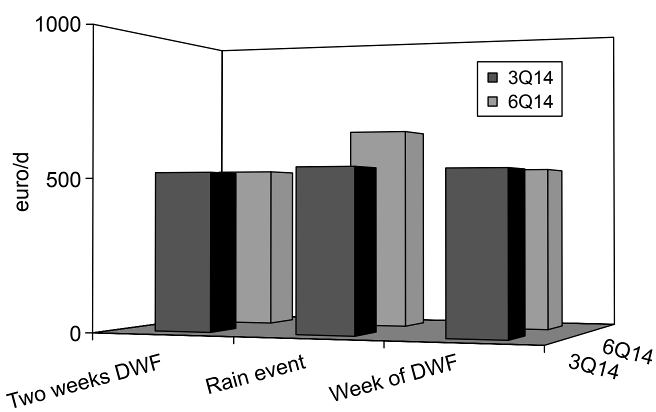

Figure 6 Comparison of the total costs for $3Q_{14}$ and $6Q_{14}$ operational strategies WWTP Boom

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Conclusions

With the developed methodology we could provide a clearly enunciated and concise way of reporting to the stakeholders on how well the assets are performing and can perform, separating the firm inefficiency from the from the effect of the treatment; in other words, to properly consider the local unique circumstances.

With the application of modelling techniques we were able to avoid the prohibitive cost and operational disruption required for universal measurement of field operations to get the unavailable but required stratification of the data.

The procedure could make full use of the information collected by the operators in the day-to-day follow-up of the WWTP. Acceptable calibration results could be obtained without the need of additional measuring campaigns.

The cost-performance of different control strategies could be evaluated and the pay-back period of alternative control strategies could be calculated in a transparent way. For example, we estimated that the incremental operational costs of the innovative stormflow treatment strategy now adopted in a large number of Flemish WWTPs amount to 4–5% more than conventional practice, on an annual basis.

It was illustrated through real examples that developed steady state operability charts can be easily implemented to support the operator in the day-to-day decision-making.

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