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Energy and Process Data Processing and Visualisation for Wastewater Treatment Plant Optimisation

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Abstract:
Effective data communication is an important step to enable WWTP operators to assess their plant. However, examples show that this step lacks attention in practice. In this article we describe a method offering fast, relevant and intuitive information as a decision support tool for operators. Embedded in a larger process optimisation software, we develop a key performance indicator visualisation tool for energy and process data. In order to ensure that the visualisation tool is used and covers the need of the plant staff, we develop this part of the software in collaboration with the WWTP Hard in Winterthur, Switzerland.

Keywords: optimisation, data visualisation, wastewater

1. Introduction

Energy and resources are important cost factors for wastewater treatment (Hernandez-Sancho & Sala-Garrido, 2008). On a daily basis, operation optimisation requires a sharpened awareness about process characteristics and energy consumption of any WWTP. Moreover, several studies claim that energy savings can be achieved, just by providing frequent or real-time energy data to decision makers (Siero et al., 1996; Fischer, 2008). However, limited thought has been given to effective communication. For a broad and complex indicator set, as ours, visualisation and arrangement of several graphical elements is crucial in order to catch the operator’s attention.
In the existing literature visualisation in wastewater treatment is often connected with methods to process data. Popular approaches are based on unsupervised learning models such as principal component analysis (e.g. Aguado & Rosen, 2008; Maere et al., 2012) or self-organising maps (e.g. Dürrenmatt & Gujer, 2012; Garća & González, 2004) and have been studied intensively in the scientific area.
In our case, visualisation also includes the communication of the processed data in an intuitive and relevant matter. However, research about this aspect of visualization is rather limited. In this work, ideas on intuitive visualisation of WWTP data are tested.

2. Software Design Philosophy

2.1 Modularity
The visualisation tool fits into a larger project in which software is developed for optimisation of WWTP operation. The demand for the developed tools, including visualization tools, is expected to vary considerably, because of scale, location or further specific conditions of different WWTPs. For this reason, a modular development strategy is taken. Efforts to use the software on a plant should be limited to accommodations for data acquisition, plant configuration and data availability.

2.2 Data Quality
An important aspect of data visualisation in wastewater treatment practices is that the displayed data must be of guaranteed quality so to prevent errors in the decision-making process. Therefore, the software is built so that only data with guaranteed quality provided to the visualization tool. The data quality module consists of techniques using hardware redundancy (e.g. sensor multiplicity), process redundancy (e.g., mass balancing) or empirical relationships (e.g., pattern recognition).

2.3 Data Granularity
During development of a data visualisation tool, several aspects of full-scale data have to be addressed. One is that not all data are measured at the same frequency. The update interval for visualisation should be higher than the update interval for the data which are visualised. More importantly, a too frequent computation may render an erroneous picture to the operator, further leading to aggressive actions or

mistrust in the software. This is to be bargained against a slower response of the operator if the chosen granularity is so low (not enough detail) so that important events are missed or detect faster by the operator instead of the software.

3. Case Study

The WWTP Hard in Winterthur, Switzerland was selected as the first test bed for the visualization tool. This is a conventional activated sludge treatment plant equipped with a pre-denitrification stage, iron based phosphorus precipitation and effluent sand filters. The average load is approximately 130`000 population equivalent (p.e.). The WWTP staff is directly involved in the design process and test-phase of all software modules, which is especially critical for feedback on the visualisation module.

The data chosen for visualisation can be separated in two groups, energy indicators and process indicators. For the energy indicators we consider existing guidelines from the Swiss Water Association (VSA, 2008) and from the German Association for Water, Wastewater and Waste (DWA, draft). The selected indicators (Table 1) help operators with ideal and guideline values to benchmark their plants. The VSA only defines these values for five plant size classes. The guideline values of the DWA are calculated using basic plant data (e.g., reactor dimensions, water temperature). In both guidelines population equivalent indicators are based on a daily Chemical Oxygen Demand (COD) load of 120g COD/p.e./d. For each indicator, a fixed temporal scale is selected (see column "Colour bar value" in Table 1). Usually, the maximal peak consumption is also subject to fees. Therefore, we added another energy related indicator to the selection from the VSA and DWA. In addition, elimination performance and resource efficiencies are also computed and displayed. For visualization of these, ideal and guideline values are replaced by legal limits and/or internal quality objectives.

Table 1. VSA, DWA and custom energy indicators (VSA, 2008; DWA, draft)

VSA Indicator	Unit	Colour bar value
Total electricity consumption per population equivalent	kWh/p.e./a	Daily average of last daily composite COD sample.
Electricity consumption of the biological treatment step (aeration, recirculation, stirrers) per population equivalent	kWh/p.e./a	Daily average of last daily composite COD sample.
Litre of sewage gas produced per kilogram of oTSS loaded into the digester	l/kg oTSS	Average production rate of all organic Total Suspended Solids (oTSS) samples within one solid retention time of the digester.
Degree of sewage gas usage for energy purposes	%	Average of the last 24 hours
Degree of sewage gas usage for electricity or direct motive force purposes	%	Average of the last 24 hours
Self-sufficiency electrical energy	%	Average of the last 24 hours
Self-sufficiency thermal energy	%	Average of the last 24 hours
DWA Indicator	**Unit**	**Colour bar value**
Total electricity consumption per population equivalent	kWh/p.e./a	Daily average of last daily composite COD sample.
Electricity consumption of the aeration per population equivalent	kWh/p.e./a	Daily average of last daily composite COD sample.
Litre of sewage gas produced per kilogram of organic TSS loaded into the digester **or**	l/kg oTSS	Average production rate of all organic Total Suspended Solids (oTSS) samples within one solid retention time of the digester.
Litre of sewage gas produced per population equivalent	l/p.e./a	
Degree of sewage gas usage for electricity production	%	Average of the last 24 hours
Self-sufficiency electrical energy	%	Average of the last 24 hours
External heating energy per population equivalent	kWh/p.e./a	Average of the last 24 hours
Custom energy indicator	**Unit**	**Colour bar value**
15 minutes electricity peak load	kW	Daily maximum 15-min average value
Indicator	**Unit**	**Colour bar value**
Elimination performance COD, N & P, whole plant	%	Values of last daily composite samples
Elimination performance COD, N & P, biological step	%	Values of last daily composite samples
Elimination performance COD, N & P, sand filter	%	Values of last daily composite samples
Effluent concentration (TSS/COD/Nitrogen compound/…)	mg/l	Values of last daily composite samples
Fraction of current COD/N/P plant capacity in use	%	Values of last daily composite samples
Absolut and relative denitrification performance	kg/d and %	Values of last daily composite samples
Precipitant usage per kg of P precipitated	mol/mol P	Values of last daily composite samples/Daily average (online P-sensor)

4. Results

Two graphical elements help to visualise the key performance indicator; the “colour bar” and the “calendar view” (Wicklin & Allison, 2009). The colour bar (c.f. Figure 1, b) includes two scales. One is the numeric scale of the indicator with the online measured (M) or calculated value and corresponding guideline (G) and ideal (I) values, if available. The second scale is the (permanent) gradient colour fill of the bar from red to yellow to green. This additional colour scale is intended to enable a faster and more intuitive understanding of the plant’s status matches the European Union energy label for household appliances (European Union, 2013), which is also an accepted and well-known label in Switzerland (c.f. Figure 1, a). Each colour bar includes background information including a description of the calculation, used data sources and the time of the last calculation value. If the data do not allow a new calculation it will be indicated next to the colour bar.

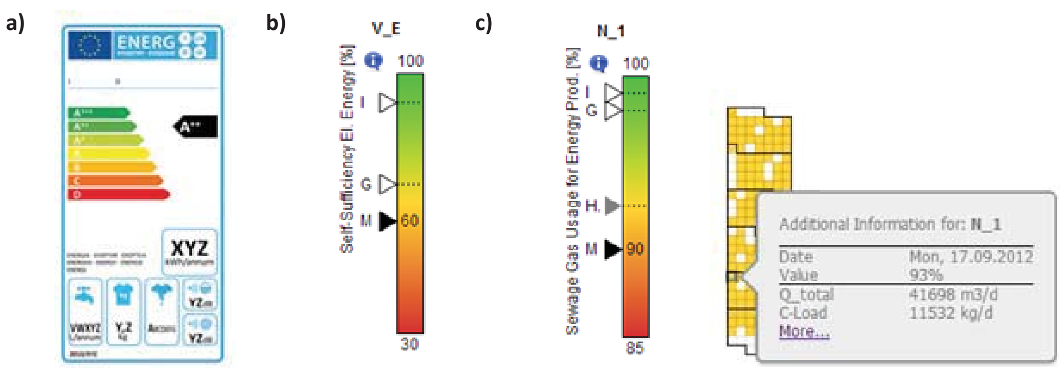

Figure 1
a) European energy label for household appliances (European Union, 2013)
b) Colour bar component. I: Ideal value, G: Guideline value M: Measured value
c) Calendar view with the interactive mouse hover information frame.
I: Ideal value, G: Guideline value M: Measured value, H: Historical value

The “calendar view” consists of a calendar where weekdays are arranged in columns and where each row represents a week (c.f. Figure 1, c) with each box a day. The colour of each box corresponds to the one in the colour bar. If an indicator is not calculated the day remains uncoloured. Such a calendar view supports the operator to find weekly or even monthly patterns within one or among several indicators. Moreover, interactive options (e.g. mouse hover effects) assist in understanding the indicated value in perspective of the nutrient and hydraulic load at the chosen day (H).
The prototype of the module visualising energy and process data on WWTPs is shown in Figure 2. Horizontally arranged gauges indicating key performance indicators and guideline values facilitate getting an overview on the plant’s state. For each gauge, a calendar view allows analysis of temporal variations by emphasizing weekly and seasonal patterns. This visualization lead to a closer inspection of the Winterthur WWTP data during a number of days with red colouring for the phosphorous efficiency indicators (marked with a red circle in Figure 2). The corresponding reduced performance happened simultaneously with ongoing maintenance work on the plant.

5. Discussion

The visualisation tool presented in this paper offers the user a much faster way to extract relevant information from process data, than conventional tools applied in practice today. Two graphical elements facilitate the assessment of the current and historical state of the plant. In combination they enable the operator to interactively analyse the relevant data. On the one hand the tool visualises energy indicators which partly origin from energy analysis guidelines of wastewater associations (VSA, Switzerland & DWA, Germany). On the other hand process data such as effluent concentrations are displayed. Some remaining challenges include the ad hoc selection of temporal resolutions, ill-fitted temporal scales of key indicators for daily evaluation, and a false sense of confidence it might give to a user. In the case of the latter, this tool is expected to provide incentives to gather additional information (e.g. additional sensors or soft-sensing). A further challenge is to ensure general applicability of the software. For this reason, the tool is currently evaluated on multiple Swiss WWTPs of varying size are carried out at the time of writing.

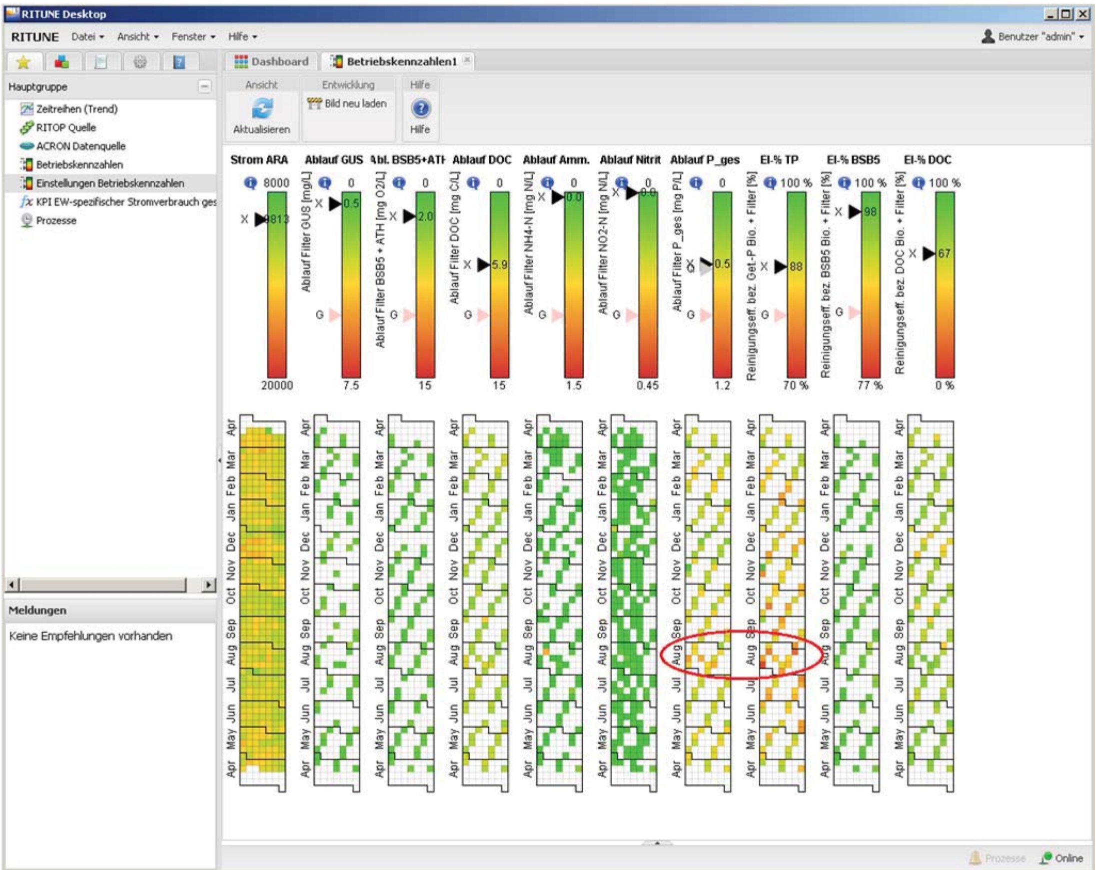

Figure 2 Screenshot of the dashboard prototype indicating the current state of the plant by means of key performance indicators, embedded as plugin module within the optimisation software framework.

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