Continuous Measurement Quality Control of WRRF operational data

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Introduction and problem statement

Water Resource Recovery Facility (WRRF, aka WWTP) operators and possibly even more consulting engineers are often painfully aware of the uncertainty they face when interpreting operational data from wastewater treatment. According to benchmarking results from Austria (Lindtner et al. 2008) an average of 5% to 10% of operational costs is spent on monitoring. This is obviously too much for the production of junk data.

Mass balancing is widely accepted as a reliable and practically applicable way to detect faults in measurement data (e.g. Rieger et al., 2010). It can be applied to conservative components of wastewater and sludge. Those are usually COD, TN and TP, but NVSS, Fe and other measurement values can also be balanced. COD, TN and TP are the main variables describing the plant loading and operational state while operation itself depends more on online sensor data such as O2, NH_4^+, NO_x^-, pH and others. Mass balancing is based on the laws of mass conservation and has until now mostly been applied to mean values of data collected over a time period of at least 2 sludge retention times (SRT). However, this approach has some drawbacks. Data quality can only be evaluated a considerable time after the measurements have been taken. This makes it difficult to link possible faults in data to their causes. Moreover, an "acceptable" balancing error over a long time period might very well be composed of several time periods with considerable, but opposed (and thus mutually compensating) balancing errors. In this case the data might be interpreted as free of errors while in fact the errors in the data only compensate each other. Moreover, it remains unclear what size of mass balancing error is acceptable depending on the type of measurement and the length of the time period under evaluation.

Methods and Results

Continuous mass balancing (Spindler and Vanrolleghem, 2012; Spindler and Krampe, 2015) can deal with these shortcomings by evaluating the temporal redundancy in data in addition to its structural redundancy. It has been successfully applied to data from two large Austrian WRRFs. An example is given in Figure 1.

Continuous mass balancing can be applied not only to historic, but also to current (balanceable) data. While in historic data it allows determining time periods of well-balanced measured loads (and therefore good data quality) it can be used even more productively to monitor the data quality as they are collected. This enables WRRF operators to react quickly when systematic measurement errors occur. It provides for good quality operational data ready for exploitation at any time.

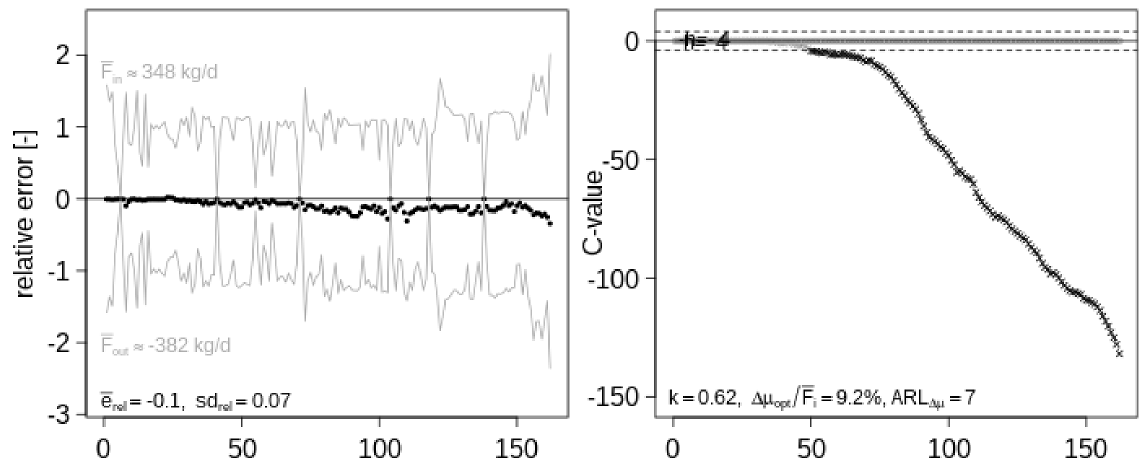

Figure 1 Continuous nitrogen balance of an anaerobic digester. **Left:** Balancing error vector and normalized influent and effluent load. The mean balancing value is at -10% of the influent load. **Right:** The CUSUM chart signals a problem at day 50, from around day 70 the deviation is very clear. The mean balancing error is only -4% before day 70 and rises to -12% thereafter.

In many practical cases, (continuous) mass balancing of operational data is still not possible because some measurements were not taken, so that the available measurement data is not structurally redundant (Spindler, 2014). WRRF operators should therefore be encouraged and supported in organizing their daily monitoring routines in a way that supports the maximum number of measurement variables being reflected in mass balancing equations. This includes the suggestion to occasionally measure component concentrations in the various sludges. For these measurements a frequency of once per month was found to be sufficient (Spindler and Krampe, 2015).

Continuous mass balancing is based on the application of CUSUM charts, a statistical process control approach frequently applied in process engineering (Page, 1954). The continuous calculation of short term mass balances on a daily basis yields an error vector which resembles a stationary process with a known expected value of zero. This process can be analysed by applying the CUSUM chart method.

While the implementation of the method is straightforward for flow data, some special considerations have to be made for mass flows. First, sludges in WRRFs have a considerable retention time. Loads entering a subsystem on one day can be (partly) retained and will be contained in the following days' effluent(s) approximately according to the laws of 1st order kinetics and thus depending on the subsystem's volume. Second, the typical elemental compositions of sludges are never measured on a daily basis, if at all. They must be determined from more frequent TSS and/or VSS measurements, requiring careful interpretation. Both issues have been investigated and were solved satisfyingly (Spindler and Krampe, 2015).

The approach of continuous mass balancing can be augmented with expert knowledge such as checking the typical specific VSS yield in digested sludge or the typical ratio between excess sludge yield and COD removal. Just like continuous mass balancing, this is an intuitively comprehensible method. This characteristic of the proposed method will support WWTP operators in the interpretation of their data quality. The inclusion of expert knowledge also allows finding additional, simple balancing equations for some of the measurement variables.

When expert knowledge in the form of known ratios between measured values is checked, the compensation of the hydraulic retention is expected to reduce noise as well. In the example (Figure 2), the *specific organic load* in the digested sludge (DS) was calculated for a large Austrian WRRF. Nowak et al. (1999) found that well digested (stabilized) sludge contains around 18 g VSS/p.e./d. Obviously, a rise in the organic influent load of a WRRF will be reflected in the (organic) digested sludge load only after a considerable time, depending on SRT in the water and sludge treatment stages. It follows that for a continuous evaluation the *specific organic sludge load* should be calculated from the *current organic sludge load* and its *corresponding influent load*. Because the *current organic sludge load* is also influenced by daily operational decisions (e.g. no sludge is withdrawn when the dewatering equipment is under maintenance) and its higher frequency fluctuations do not necessarily reflect variations in the influent load, this time series was smoothed by means of a Kalman filter. *The corresponding influent load* results from the varying influent in the past, hydraulically retained through SRT in aerobic and anaerobic stages (an unusual 100 days for the example). It is obvious, that the target value of 18 g VSS/p.e./d was not reached after day 100. There is some evidence that it was met from day 1 to day 80. This corresponds well with the continuous nitrogen balance of the digester (Figure 1).

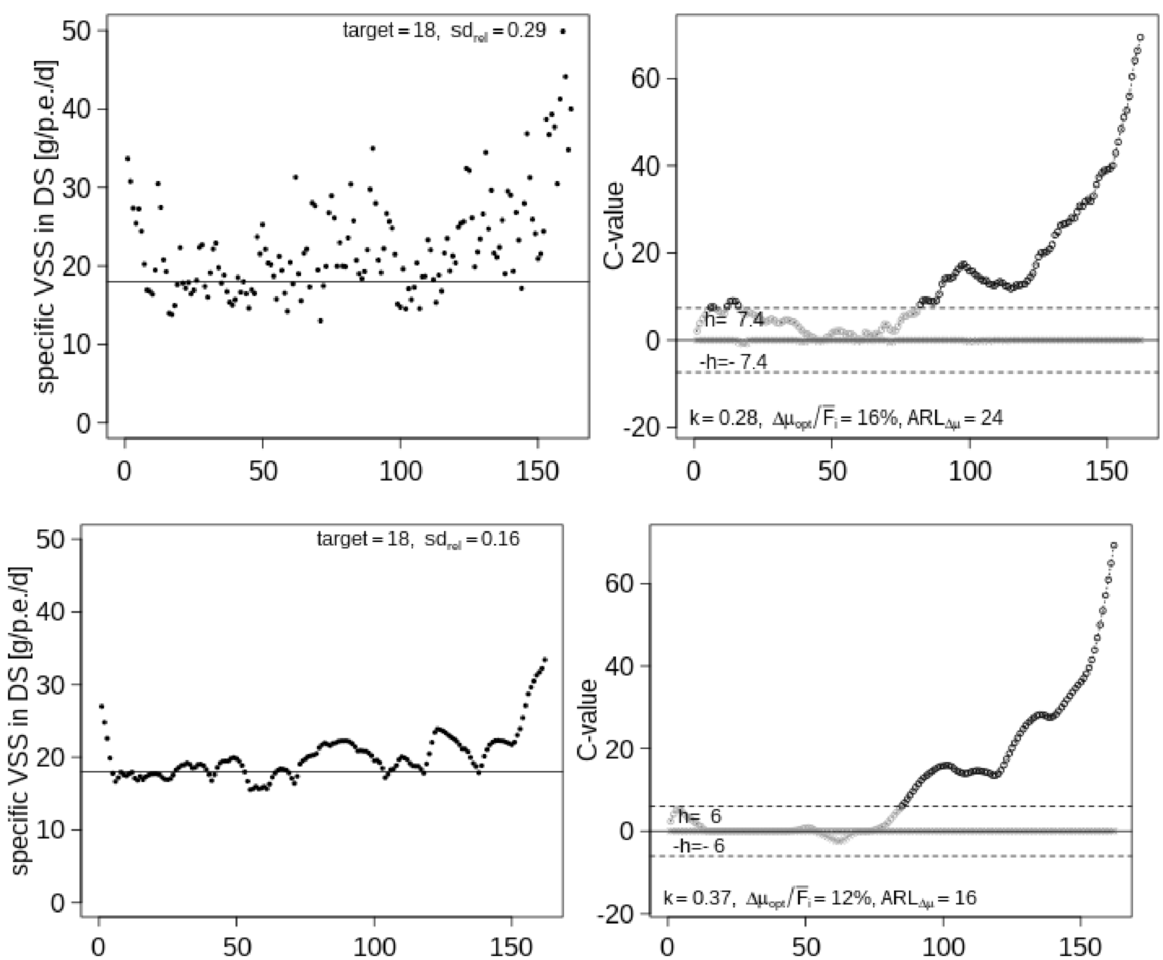

Figure 2 Specific organic sludge load in digested sludge (**left**) and CUSUM chart (**right**).The specific organic sludge load was calculated once without consideration of hydraulic retention (upper part) and once with consideration of hydraulic retention (lower part). In both cases a Kalman filter was applied for data smoothing.

Conclusions

Continuous mass balancing relies on the possibility to set up mass balances on a daily basis, requiring daily measurements of the relevant values. Analyses should be conducted on flow proportional 24h composite samples. Thanks to the processes' long sludge residence times grab samples are usually sufficient for sludge characterization. In contrast to balancing average mass flows over long time periods (thereby "pretending" steady state) continuous mass balancing evaluates the error vector of daily balances. This error vector is a stationary process with an expected value of zero and can be evaluated in a well-comprehensible manner by using CUSUM charts. Hydraulic retention must be compensated for in the analysis when balancing over such short time periods.

The method of continuous balancing has the potential to become an accepted standard of data quality control for WRRF operational data. While it is easily implemented when all necessary measurements are readily available, it usually requires operators to make some adjustments to their monitoring strategy. However, after successful implementation operators will be able to provide reliable data with no additional effort for the internal or external handling of various complex issues at any given time.

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