Extending the Benchmark Simulation Model No. 2 (BSM2) with detailed models for dynamic pumping energy consumption

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Abstract: Despite the increasing level of detail in wastewater treatment process models, too oversimplified energy consumption models (i.e. constant “average” power consumption) are often still being used for plant performance evaluation in optimization exercises. A new dynamic model for a more accurate prediction of pumping costs in wastewater treatment has recently been developed to overcome this unbalance in the coupled submodels. This new model has now been evaluated for its impact in the frame of the Benchmark Simulation Model No. 2 (BSM2).

Keywords: wastewater treatment; control; performance evaluation

INTRODUCTION

The use of a benchmark for assessment of process performance, control strategy evaluation, etc. is well established within chemical engineering and research. The success of the COST/IWA Benchmark Simulation Model No 1, BSM1 (Copp et al., 2002) for control strategy development and evaluation clearly indicates the usefulness of such a tool. Under pressure of the need of a plant wide evaluation of control strategies, a new benchmark, the IWA Benchmark Simulation Model No. 2 (BSM2) has first been proposed by Jeppsson et al. (2007), and a final version was presented in Nopens et al. (2010). The BSM2 includes a detailed protocol for implementing, analysing and evaluating the impact and performance of both existing and novel control strategies applied to WWTPs (Nopens et al., 2010). Unlike in BSM1, in BSM2, the pumping energy cost has been diversified according to the different flows and their assumed specificities. However, a fixed averaged energy consumption/cost regardless of the delivered pumping flow rate is adopted for each flow as illustrated in Table 1.1.

Table 1.1 Fixed pumping energy consumption factors as used in BSM1 (Copp et al., 2002) and BSM2 (Gernaey et al., 2006).

Benchmark	Pumped flows	Pumping energy (kWh/m^3)
BSM1	All	0.040
BSM2	Mixed liquor recycle	0.004
BSM2	Secondary sludge recycle	0.008
BSM2	Secondary sludge to thickener	0.050
BSM2	Primary sludge to digester	0.075
BSM2	Thickened secondary sludge to digester	0.060
BSM2	Dewatering liquid to primary clarifier	0.004

A new detailed dynamic model for the calculation of pumping energy consumption was recently developed within the frame of the FP7 SME EU Project ADD CONTROL (Amerlinck et al., 2012). This new model has now been evaluated for its impact on the evaluation criteria and the final decisions for the BSM2 platform.

MATERIALS AND METHODS

The BSM2 model implementation in the WEST® modelling and simulation software (mikebydhi.com; Vanhooren et al., 2003) is used. The virtual plant is designed for an average influent dry weather flow rate of 20,648 m³/day and an average biodegradable COD in the influent of 592 mg/l, serving a population of 80,000 Population Equivalents (PE). The BSM2 plant (Figure 1.1) contains a primary clarifier (900 m³), an activated sludge unit (12,000 m³), a secondary clarifier (6,000 m³), a sludge thickener (900 m³), an anaerobic digester (3,400 m³), a storage tank, and a dewatering unit. The activated sludge unit is a modified Ludzack–Ettinger configuration consisting of five tanks in series (Jeppsson et al., 2007). For this study, the BSM2 model was extended with a control of the sludge recycle based on the influent flow rate measurement. A ratio for the sludge recycle flow rate to influent flow rate of 100% was applied.

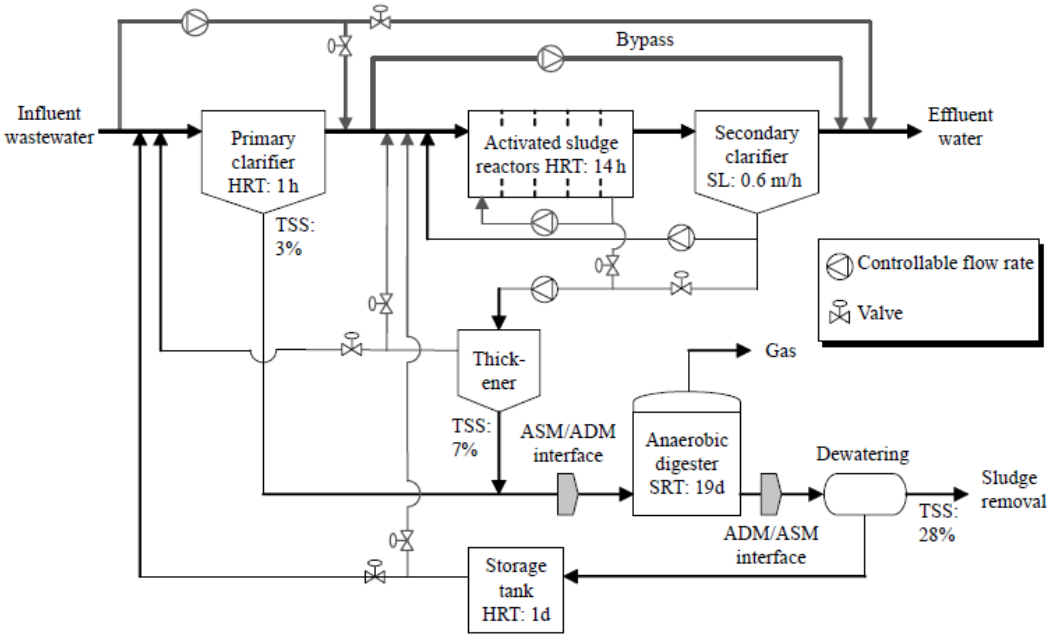

Figure 1.1 The BSM2 plant layout (Nopens et al., 2010).

Dimensions for the BSM2 plant have been set up to be able to deal with the calculation of the system curve. Two secondary clarifiers have been foreseen, each of them with a surface area of 750 m² (Gernaey et al., 2006), resulting in an expected surface loading rate of about 0.6 m/h. The return sludge flow rate (Qr) needs to be pumped from the bottom of the secondary clarifier to the mixing box. In the mixing box, the pre-settled wastewater (effluent primary clarifier) is mixed with the return sludge. It is assumed that the liquid surface level in the mixing box is one meter higher than in the secondary clarifier, i.e. static head is equal to one meter. The return sludge flow is pumped from about five meters below the liquid surface level of the secondary clarifier (five meters corresponds to the depth of the secondary clarifier, including the sludge hopper). In the design, it is assumed that the return sludge from each secondary clarifier is pumped to the mixing box in a separate pipe, with an assumed thickness of 0.4 m. The reason for not including a pipe junction in the return sludge line is that this configuration with two separate pipes provides the highest flexibility (while performing maintenance or reparations on one pipe, the other half of the activated sludge plant can operate normally). The minor losses factor contains a contribution from the 45 and 90 degree elbows (0.18 m), and a contribution from the outflow structure (0.5 m) (Gernaey et al., 2006). Each clarifier was equipped with one pump; for which the FLYGT NL 3300 LT was chosen using the web based xylect tool (http://www.xylect.com) made available by FLYGT itself.

The new model for dynamic pumping energy consumption was integrated in the BSM2 to allow for the comparison of the two approaches (fixed versus dynamic energy consumption). The new model takes into account the effect of control strategies (e.g. variable frequency drive (VFD) control or a throttling valve) on either the system curve or the pump curve. In addition the model accounts for the changing efficiency for changing flow rates delivered by the pump. The wire-to-water efficiency is considered to be the product of the motor efficiency, the pump efficiency and, if applicable, the VFD efficiency.

RESULTS

21 days of BSM2 operation have been simulated. The results of the secondary sludge pumped recycle flow are shown in Figure 1. 2. It can be clearly observed that the pumping energy factors newly introduced in the BSM2 result in a significantly lower pumping energy prediction compared to the fixed factor used in BSM1, which is recommended no longer to be used. The total energy consumption predictions using the new dynamic model is similar to that of the constant BSM2 factor over the 21 days period, though significant deviations over time can be observed, which means that instant power consumptions are different and major contributions to the total energy consumption occurs at different moments in time and, hence, different flow rates. This is illustrated in Figure 1. 3 that shows the detail of a shorter time period, in which the pumped flow rate differs substantially from the best efficiency point flow rate for the pump under consideration. The effect over even longer periods needs to be investigated in detail, but will likely result in larger deviations in total energy consumption.

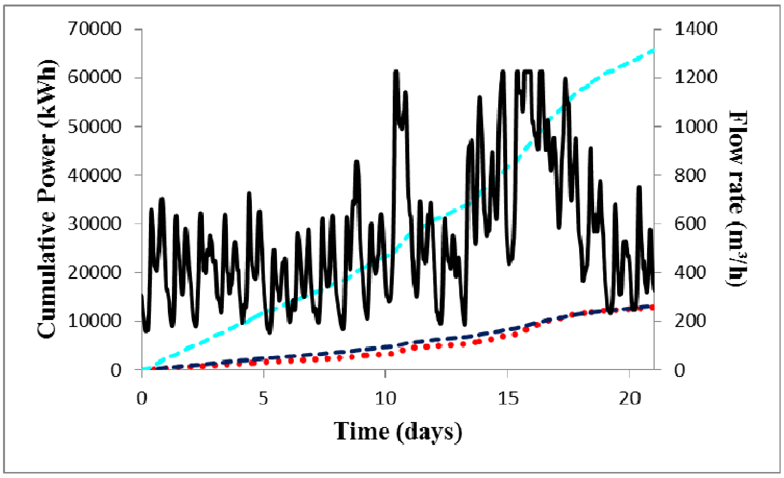

Figure 1. 2 Comparison between the dynamic model and constant factors for the cumulative pumping energy consumption: pumped flow rate (black line - right axis), energy consumption dynamic model (red dots - left axis), energy consumption constant weighing factor BSM2 (dark blue dashed - left axis) and energy consumption constant weighing factor BSM1 (light blue dashed - left axis).

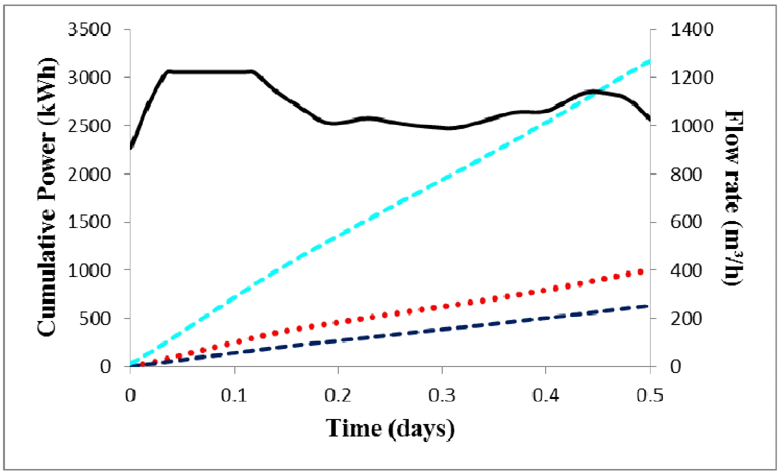

Figure 1. 3 Short period comparison between the dynamic model and constant factors for the cumulative pumping energy consumption in a period with high flow rate: pumped flow rate (black line - right axis), energy consumption dynamic model (red dots - left axis), energy consumption constant weighing factor BSM2 (dark blue dashed - left axis) and energy consumption constant weighing factor BSM1 (light blue dashed - left axis).

CONCLUSIONS

The BSM1 fixed pump factor significantly overestimated the energy consumption and should no longer be used. The fixed energy consumption factor of BSM2 yields similar cumulative total energy consumption compared to the dynamic pumping model for a 21 days simulation. However, the instant contributions differ significantly, especially where the flow rate differs from the best efficiency point flow rate. Hence, prolonged evaluations over larger time frames need to be conducted and likely will result in quite different total energy consumption predictions. Moreover, in the full paper the results will include dynamic models for the other pumps present in BSM2, allowing a more complete energy consumption picture.

REFERENCES

Amerlinck, Y., W. De Keyser, G. Urchegui, and I. Nopens, 2012, Realistic Dynamic Pumping Energy Models for Wastewater Applications. In: Proceedings of WEFTEC 2012, p. 16.

Copp, J. B., H. Spanjers, and P. A. Vanrolleghem, 2002, Respirometry in Control of the Activated Sludge Process: Benchmarking Control Strategies: Scientific and Technical report, v. 11, IWA Publishing.

Gernaey, K., I. Nopens, D. Vrecko, J. Alex, and J. Dudley, 2006, An updated proposal for including further detail in the BSM2 PE calculation, [internal BSM2 taskgroup document].

Jeppsson, U., M. N. Pons, I. Nopens, J. Alex, J. B. Copp, K. V. Gernaey, C. Rosen, J. P. Steyer, and P. A. Vanrolleghem, 2007, Benchmark simulation model no 2: general protocol and exploratory case studies: Water Science and Technology, v. 56, p. 67-78.

mikebydhi.com, Modeling the world of water, DHI.

Nopens, I., L. Benedetti, U. Jeppsson, M. N. Pons, J. Alex, J. B. Copp, K. V. Gernaey, C. Rosen, J. P. Steyer, and P. A. Vanrolleghem, 2010, Benchmark Simulation Model No 2: finalisation of plant layout and default control strategy: Water Science and Technology, v. 62, p. 1967-1974.

Vanhooren, H., J. Meirlaen, Y. Amerlink, F. Claeys, H. Vangheluwe, and P. Vanrolleghem, 2003, WEST: modelling biological wastewater treatment.: *Journal of Hydroinformatics*, v. **5**, p. 23.