WWTP upgrading at any price? A new dynamic simulation concept evaluates the effects of separate reject water treatment

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ABSTRACT

Wastewater treatment facilities are dynamic. The combined effects of changes in influent flow, waste composition, treatment unit processes, and operational modifications result in complex dynamic behavior that can be difficult to understand and, therefore, difficult to control and optimize. Current trends toward more advanced treatment processes, such as separate process water treatment, biofilm processes, etc., where biological nutrient removal is aimed, are increasing plant complexity and prompting a growing number of engineers to rely on dynamic models and computer-based decision support tools when deciding how best to improve plant design or operation.

The paper describes the results of systematic investigations through dynamic simulation concerning process water treatment. More operation techniques are tested to:

1) avoid load peaks by storing the process water in intermediate tanks, before it is mixed with the main stream (24 hours operation),

2) use conventional wwtp operation, a situation which is common for the majority of the wwtp; process water is recycled to the main plant between 8°00 - 16°00 hour

3) treat the process water by side stream technology

4) mix the process water directly with the main stream of the wwtp by using enhanced operational control
INTRODUCTION

If a dynamic model is accurate in its representation, users can test various hypotheses by simulating existing or possible conditions. A model can be used, for example, to determine why a system behaves the way it does, identify important system elements or critical issues that must be addressed, design new systems, and forecast future behavior. Conversely, optimization techniques can be used to determine the inputs needed to achieve a desired output.

Dynamic models that simulate wastewater treatment plant operation have been available for many years. Until recently, however, they were difficult to build and use because they required powerful computer systems and significant amounts of time for model structuring, calibration and verification. Today low cost computing equipment and innovative software tools are bringing modeling and simulation technology to the wwtp, where it is being used to improve stability, performance, and cost efficiency.

In the following figure 1 the simulated effluent results, with and without process water treatment, are presented. The thin line represents the normal situation. Bold lines show the results of a simulation with process water treatment. 15% of the N-load at the inflow could be reduced.

Figure 1: Simulation results of the N-effluent quality in aeration tank by using or not side stream process water treatment
Wastewater treatment plant operations are complex. A typical plant has several unit processes to be monitored and maintained. Plants must be stable and meet performance and safety criteria in a cost-effective way. Effective design requires balance between these objectives. A new model strategy gives the opportunity to select between process water treatment and main stream conventional upgrading by evaluating the effluent quality, process stability and the arising investments in terms of additional space needed for nitrification and denitrification.

MODEL DEVELOPMENT

Proper model development involves three steps:

- preliminary analysis of plant layout and raw data
- model construction by using dynamic streamlines and input-output data
- model calibration and verification

Plant data and layout provides information that serves as a basis for the model construction. Once the model is complete, calibration studies use raw-input data to calculate the output-effluent quality in terms of nitrogen and total carbon concentrations in a certain period of several days. The calculated data should be corresponding to the measured one by correlation. Once the model is verified, selected simulation scenarios can be tested to examine plant's dynamic behavior.

A plant simulation method and especially the last step of model verification is very costly and requires high experience potential. Figures 2 and 3 are shown such a verification step, where ammonium and nitrate simulated data are correlated to the actual plant concentration measurements. Although, the deviation of the nitrate calculated to actual data can be explained in terms of measurement errors, inadequate model parameters and/or simplification model assumptions, the model is very reliable.
Figure 2: Comparison of simulated 7 days \(\text{NH}_4^+\)-N concentrations with corresponding measured values in wwtp

Figure 3: Comparison of simulated 7 days \(\text{NO}_3^-\)-N concentrations with corresponding measured values in wwtp
SIMULATION RESULTS INVOLVING REJECT WATER TREATMENT

In order to implement four different cases of simulation strategies by including reject water treatment, a standard wwtp model has been selected. The plant is designed including predenitrification and nitrification without biological phosphorus removal, according to the principle of IAWQ activated sludge model Nr. 1.

The simulation temperature is defined to be 12°C, which is in accordance to the European design guidelines, and the process water is recycled to the wwtp between 8:00 and 16:00 hour. It is also assumed that the internal process stream, called reject water -produced from the sludge dewatering or further sludge treatment- , contains 15 % of the total nitrogen load on the aeration tank, which contributes only a minor 2 % of the total influent flow.

The following four different case studies were selected to be simulated. The simulation is focused on N-elimination:

- Conventional plant operation; the reject water is mixed with the main influent to the aeration unit, during 8:00 and 16:00 hour
- The reject water is introduced continuously (24 hours) to the main stream by using an intermediate tank to maintain constant flow conditions
- The reject water is treated in a side stream separately
- Enhanced control operation; Ammonium on-line measurements at the effluent of the aeration unit control the reject water load on the main stream. By NH₄-concentrations over 1 mg/l reject water is been stored in intermediate tanks.

Figure 4 illustrates the results of the simulation for all scenarios described above. The NH₄-concentration at the effluent of the aeration unit is a typical example of the simulation results for a time period of 10 days. It can be seen that during the conventional wwtp operation, when reject water is been loaded on the main stream between 8:00 and 16:00
hour, the NH$_4^+$-concentration at the effluent reaches high peaks. The simulated NH$_4^+$-concentrations, when the other three operational methods are used, varies in acceptable peaks less than 3 mg/l. Daily plant operation experience proves that the total N-load reaches its highest concentration, mostly between 10$^{th}$ and 14$^{th}$ hour.

![Ammonium effluent concentration](image)

*Figure 4: Effects of different reject water treatment scenarios on the NH$_4^+$-N effluent quality of the wwtp*

According to figure 4, seems to be reasonable avoiding recycle of reject water to the main stream, during the time period between 8$^{th}$ and 16$^{th}$ hour. An intermediate tank facility would be needed to store process water as long as it may needed. During the night hours can then be loaded on the plant.

Figure 5 compares simulated results of the applied strategies for nitrate, NO$_3^-$-N removal. The differences between separate reject water treatment and recycle to the main stream are clearly presented. Higher plant efficiency, can only be achieved by treating reject water separately. To evaluate these treatment options/effects in a total nitrogen removal basis, figure 6 is plotted. It can be demonstrated that
the chosen wwtp is rather overloaded in terms of available total volume for an efficient nitrogen removal.

![Graph](image)

**Figure 5: Effects of different reject water treatment scenarios on the NO₃-N effluent quality of the wwtp**

In almost all three strategies, involving recycle of reject water to main plant, the total nitrogen elimination is not efficient enough to fulfill the new European Regulations concerning demands on nutrient removal. However, a separate treatment of reject water could significantly improve the N_total-effluent quality and in several cases the alternative -upgrading the main plant- could be avoided.

The simulation results of the presented scenarios, involving reject water treatment in relation to the main plant treatment, could be adopted for plants with similar boundary conditions. In wwtp, where other conditions are obtained, a conventional upgrade of the main plant might be a better solution. In almost all cases dynamic simulation models could be successful tools for investigation of the possible design or operation concepts.
Because they can model changes in treatment plant character over time, dynamic simulation models are ideal for studying the effectiveness of various treatment strategies.

CONCLUSIONS AND RECOMMENDATIONS

A promising alternative for conventional wwtp with sludge treatment is the use of separate reject water treatment; pretreatment of reject water, however, is necessary to remove suspended solids. A recent trend in wastewater treatment is the modeling of sludge treatment processes. Until now, there has been only limited knowledge about that kind of modeling. IAWQ model 1 and 2 describes only the modeling of activated sludge treatment processes.

![Graph](attachment:graph.png)

**Figure 6: Effects of different reject water treatment scenarios on the N\textsubscript{total} effluent quality of the wwtp**

For example, it is very important in a wwtp, depending on the existing sludge treatment system, one to be able to decide whether or not to treat reject water separately (side stream) in order to avoid high
nitrogen concentrations at the main stream and therefore to get into process control trouble.

With the development of hardware and software in the last few years it has become possible to tackle computational problems which are more complex than few years ago. Simulation of the micromorphology of the floc including shape image analysis and observation of the directional growth of activated sludge may provide an insight into processes happening on the microscale, as well as potential for an "early warning system" to detect process inefficiency in sludge treatment. Simulation of the activated sludge structure on this scale may lead to better understanding of the relationship between influent conditions and proper plant operation and the interaction between main and side stream processes to the effluent quality.

Dynamic simulation as a research tool will help identify the processes and parameters of crucial importance and may also shorten the time of pilot plant studies, if needed, because the influence of process changes into the plant total efficiency can be easily evaluated, saving at the same time large amount of investigation and/or operation costs and valuable time as well.

By way of recommendation, this paper shows the benefit of a dynamic simulation approach to evaluate the effects of reject water recycle upon the plant efficiency in terms of nutrient removal. Used together pilot testing and modeling-simulation methods provides the ability to define a process well and is recommended for use in design concepts. Though many of these efforts are in the conceptual stage, the promise for the future is significant.

REFERENCES


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