The main wastewater treatment plant of Vienna: favourable operation conditions as a consequence of well designed tender procedures

T. Partaj, M. Papp and J. Weiss

ABSTRACT

In the planning phase of the extension of the Main Treatment Plant of Vienna, special effort and emphasis were put on the conception of the tender procedure. The project tender was divided into several tender units in order to achieve optimum quality standards by specialised workmanship. Important parameters for operation conditions, especially energy consumption and maintenance costs, were considered and evaluated according to the tender guidelines. Suppliers were required to prove the guaranteed quality standards of the tender documents by means of preliminary installation units and extensive performance check procedures. Only after fulfilment of all requirements were suppliers allowed to apply the design of the preliminary installation works to the entire installation. If necessary, extensive optimization works were carried out. Thus favourable operation conditions were achieved and, in particular, a highly efficient aeration system was implemented.

Process parameters were optimized by means of a follow-up project during the regular operation phase, taking into consideration the results of the performance check procedures. Further optimization of energy consumption was thereby achieved.

Key words | aeration system, optimization of energy consumption, quality standards, tender procedure, wastewater treatment

INTRODUCTION

The extension of the Main Wastewater Treatment Plant of Vienna (MTPV) was carried out during the years 1999–2005 in order to meet strict Austrian legal requirements, especially those concerning nitrogen removal and full nitrification. A two-stage process concept was implemented, fully integrating the existing plant as high load 1st stage of the extended plant (Klager 2001; Kroiss et al. 2004). The design criteria for the extended plant are summarized as follows:

- 4 Mio p.e.; max DWF: 9.4 m³/s; max WWF: 18 m³/s;
- BOD₅: 240 t/d; TN: 38 t/d; TP: 5.7 t/d.

At the end of 2005 the test operation was finished and MTPV entered its regular operation phase.

While high attention was paid to quality standards throughout the whole project, the basis for their achievement was established by means of a detailed and strict conception of the project tender documents.

In order to achieve an optimum quality standard in the individual technical specialist areas (building and construction work, machinery equipment, electrical equipment, control and automation, measuring and analytics) the project was divided into “specialized” tender units.

It was the principal strategy of the tender process of MTPV to achieve not only good prices for construction and installation works (low investment costs), but also to assure best conditions for plant operation, especially in relation to energy costs and maintenance costs.

Therefore, particularly in the conception of the tender documents for the machinery equipment, not only were...
investment costs considered, but important parameters for the plant operation were also taken into account.

On the one hand, minimum requirements were defined in the tender documents and were to be guaranteed by the suppliers/competitors. On the other hand, suppliers/competitors were themselves required to set data for important parameters. Based on these data operation costs were calculated for a certain operation period. These operation costs were added to the investment costs and this overall sum was decisive for the selection of the supplier/competitor. Suppliers/competitors had to prove their data given in the tender process by means of strict performance checks on site.

This concept was especially applied to the respective tender units of the compressors for the second stage aeration system, the pumps of the intermediate pumping station and to the measurement/analytics-tender unit, which put special emphasis on measurement accuracy as well as maintenance. Since the aeration system causes the bigger part of energy-costs (as well as an important part of maintenance costs) of wastewater treatment plants (Lindtner 2004), particular interest was placed on the tender unit for the machinery equipment of the second stage aeration tanks. This paper focuses on this tender unit and gives an overview of the consequences for installation works and operation conditions of MTPV.

A follow up-project is also described, which was started after the first months of full operation in order to optimize process parameters and minimize energy costs. During this project experiences of the performance checks of the respective tender units were put into practice.

**METHODS**

The total aeration tank volume of the 2nd stage plant extension amounts to 176,000 m$^3$, which is composed of 15 parallel aeration tank lines of 11,700 m$^3$ each. One aeration tank consists of a denitrification zone (cascade 1) with two agitators (vertical axis) and two aerated cascades in series (cascade 2 and cascade 3) with circulation flow. Each aerated cascade is provided with four agitators (horizontal axis) and the equipment for the aeration system, i.e. air tube, shut-off valves, control valve and air volume measurement, diaphragm valves for aerator branches and aerators (fine bubble membrane disc diffusers). In cascade 3 a recirculation pump is installed for the internal recirculation flow from cascade 3 into cascade 1. Besides the equipment for agitation and aeration system, each aeration tank is provided with a system for the removal of floating sludge and a coarse bubble diffuser system in the degasification zone after cascade 3. The machinery equipment listed above was covered by the tender unit, “machinery equipment of aeration tanks”.

Special emphasis was placed on assuring best conditions for plant operation when working out the tender documents for this tender unit, particularly concerning energy consumption and maintenance costs.

The following values and parameters were to be guaranteed by the suppliers/competitors in accordance with the tender guidelines (minimum requirements):

1. Oxygen transfer in clean water: 700 kg O$_2$/h per aeration tank cascade at a maximum air flow of 7500 m$^3$ N/h per aerated cascade (total number of aerated cascades: 30).
2. Agitation in denitrification zone (cascade 1): maximum variance from median of suspended solids concentration (max 10%).
3. Agitation in aerated cascades (2 and 3): minimum flow velocity (0.3 m/s without aeration, 0.2 m/s with aeration, 0.15 m/s 0.5 m above bottom of aeration tank).
4. Agitation in aerated cascades (cascades 2 and 3): maximum variance from median of suspended solids concentration (max 10%).

In addition to the investment costs, the following issues were considered and valued by means of the tender-guidelines (see Table 1).

In relation to the valued parameters, suppliers/competitors were required to enter data of their own choice and consideration into the tender documents. But of course these data directly influenced the valued costs, and in that strongly influenced the overall valued sum, criteria for the identification of the best offer. Therefore suppliers/competitors had to commit themselves to proving their values by means of strict performance checks.

Table 1 also shows the proportion of investment costs and valued operation costs (referring to the offer of the supplier contracted after the tender procedure). It can be seen that the valued costs surpassed the investment costs.
and amounted to more than half of the overall valuated sum. The biggest share of the valuated costs is due to oxygen transfer efficiency. But agitator power consumption and aerator change are also important. Suppliers’ warranty prolongation of 10 years for the aerators (from 3 years up to 13 years) and of 2 years for control valves and agitators resulted in an important reduction of the valuated costs.

In the aeration tanks machinery equipment tender unit especially, an extensive performance check procedure was required in order to ensure compliance with data entered into the tender documents by the supplier. This procedure included the following steps:

1. Full installation of the machinery equipment for one aeration tank line, “experimental aeration tank”.
2. 1st performance check: if the supplier missed the guaranteed value of oxygen transfer by more than 15%, the principal would have the right to oblige the supplier to install other equipment than originally appointed in the contract at the supplier’s cost.
3. Optimization phase.
4. Performance check after optimization.
5. Full installation of the machinery equipment (optimized layout!) of all 15 aeration tank lines.
6. Final performance checks.

7. Supplier bonus or/and supplier fine are fixed according to the results of the performance checks.

If the results of the final performance checks did not meet the data given in the tender process (even after optimization), the supplier would have to pay a fine amounting to the difference between the operation costs calculated according to the results of the performance checks and the operation costs calculated according to the tender data.

On the contrary, a bonus would be awarded to the supplier if better results were obtained in the performance check than data given in the tender process (in the case of particularly important parameters—e.g. oxygen transfer efficiency). Thus the supplier was encouraged to make use of the optimization phase scheduled after the first performance check.

### RESULTS AND DISCUSSION

After full installation of the machinery equipment for the first aeration tank (“experimental aeration tank”), the first performance check was carried out in May 2003.

The results of the oxygen transfer in clean water and the results of the flow velocity did not accomplish the required

### Table 1 | Valuated parameters for tender unit machinery equipment of aeration tanks

<table>
<thead>
<tr>
<th>Valuated parameter</th>
<th>Remarks/Valuated costs in % of investment costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen transfer efficiency in clean water at 2,500 m³ N/h (per cascade)</td>
<td>10-year aeration operation costs based on this value are valuated 65.6</td>
</tr>
<tr>
<td>Power consumption of agitators in denitrification zone</td>
<td>15-year operation costs based on this value are valuated 4.1</td>
</tr>
<tr>
<td>Power consumption of agitators in aerated cascades</td>
<td>15-year operation costs based on this value are valuated 15.1</td>
</tr>
<tr>
<td>Aerator membrane change (2 sets)</td>
<td>Investment- and labour costs are valuated 4.5</td>
</tr>
<tr>
<td>Aerator change (1 set)</td>
<td>Investment- and labour costs are valuated 17.3</td>
</tr>
<tr>
<td>Number of sets needed in 25-year operation period</td>
<td>Overall costs of this number of aerator membrane sets is valuated 6.8</td>
</tr>
<tr>
<td>Maximum fault of air volume measurement</td>
<td>Fault [%] multiplied by the expected energy costs of 2nd stage aeration system during 10-year operation period is valuated 1.4</td>
</tr>
<tr>
<td>Warranty prolongation</td>
<td>Valuated as reduction on the investment costs of the respective component or product −11.2</td>
</tr>
<tr>
<td>Costs of spare- and worn parts</td>
<td>6.0</td>
</tr>
<tr>
<td>Costs for extern. maintenance works</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Investment costs</strong></td>
<td>100.0</td>
</tr>
<tr>
<td><strong>Overall valuated sum</strong></td>
<td>210.1</td>
</tr>
</tbody>
</table>
values. Considering the results of the oxygen transfer in clean water, even the minimum-allowed value to pass on to the optimization phase was only barely surpassed, taking into account the tolerance range of the first performance check (15%) and the range of measurement inaccuracy.

The supplier was therefore required to make use of the optimization phase to achieve the guaranteed values.

A special aerator layout was designed and installed for the optimization phase. It allowed the testing of many different aerator layout options, and the effects of different types of air supply distribution through opening or closing parts of the aerator system.

Figure 1 depicts the aerator layout at the first performance check (before optimization) as well as aerator layout during the optimization phase. Water depth above aerators is approximately 5.2 m.

The following influencing factors were considered and tested in the experimental aeration tank using the special aerator layout for the optimization phase:

- Number of aerators (air admission per aerator at maximum air volume flow).
- Density of aerator allocation (number of aerators per m²): density of aerator allocation could be varied for testing purposes by opening and closing every other aerator branch.
- “Flow lanes” without aerators between lines with aerator allocation.
- Aerator allocation in the “turn around” zones of the circulating flow.
- Position of agitator axis and agitator revolutions per minute.
- Use of guide walls to optimize circulating flow conditions.
- Number of isolated aerated areas (flow loss between aerated and non-aerated zone).

There were almost no limitations set to the experimental options during the optimization phase. The only precondition for the aerator layout was the allocation of aerators in the zone where the oxygen sensors for the aeration control were to be installed according to the measurement and control design (upper left aeration zone in each aerated cascade) (Partaj 2004). Measurement of oxygen concentration was thus ensured where air can be supplied continuously, which is crucial for an efficient aeration system (Svardal et al. 2003).

A selection of the trials carried out during the optimization phase can be seen in Table 2.

During the optimization phase, several findings concerning the influencing factors on oxygen transfer could be obtained by means of the experimental aeration tank.
First of all, additional isolated aeration zones (aeration zone is not bordering another aeration zone) have an unfavourable effect on the oxygen transfer. This is probably due to the flow loss at the threshold between aerated and non-aerated zones.

Aerator allocation in the turn around zones of the circulating flow proved to be favourable. Also, a lower density of aerator allocation (<3.5 units per m²; surface area of one aerator: 0.047 m²) resulted in better oxygen transfer values than a higher density of aerator allocation (>5 units per m²). Neither guide walls (allocated at the beginning of aerated zones near the water surface in order to minimize the flow loss between aerated and non-aerated zones) nor the uplifting of the agitator axis could improve the results of the oxygen transfer.

As result of the optimization phase, the total number of aerators was increased from 1200 units to 1613 units per aeration cascade. Aerator allocation layout was changed substantially – the new layout was based on trial number 6 of the optimization phase (see Table 2). Aerator supply tubes were set to flow direction instead of perpendicular to flow direction. The final aerator allocation layout is depicted in Figure 2.

In the performance check after optimization, positive results were obtained. The oxygen transfer in clean water accomplished the required values, taking into account the range of measurement inaccuracy (5%). The required values of flow velocity, as well as of air volume measurement accuracy, were also met by the results of the second performance check. Since all requirements were fulfilled, the supplier was allowed to install the machinery equipment of all 15 aeration tanks according to the new optimized concept.

The results of the final performance checks – after full installation of machinery equipment and after beginning of operation with wastewater – also met the required values.

Table 3 gives an overview of the results of oxygen transfer and oxygen transfer efficiency of the respective performance checks.

As a result of optimization due to the whole performance check procedure, an increase of oxygen transfer in clean water of approx. 15% was obtained. For operation energy costs the results of the oxygen transfer efficiency in clean water were even more important: oxygen transfer efficiency in clean water was increased by approximately 9% throughout optimization. Thus the final value of oxygen transfer efficiency in clean water surpassed the guaranteed value by approx. 15%. Based on these results, a bonus of 1.6% of the entire investment costs was awarded to the supplier in accordance with the tender guidelines.

**Follow up project: optimization of energy consumption of MTPV**

Nearly one year after the start of operation of the extended MTPV, a follow-up project was started in order to optimize process parameters and minimize energy costs. The project
was finished in January 2007. It was the aim of the project to improve important process control parameters – which had initially been set corresponding strictly to the dimensioning calculations of the planning phase – through experience of the performance check procedures and the test operation phase in 2005.

Optimization of the operation of the aeration system

According to the results of the performance checks, aeration in the turn around zones of the aeration cascades proved to be favourable to the oxygen transfer efficiency.

Oxygen-based and NH4-N-based aeration control strategies have been compared in simulation studies (Alex et al. 2003). On MTPV 2nd stage, both control strategies are available options. Although good operation conditions were also obtained by running the oxygen-based aeration control strategy, the NH4-N-based aeration control strategy was preferably applied because it allows continuous aeration in the turn around zones, whereas the oxygen-based aeration control strategy needs continuous aeration of the zone where the oxygen sensors are installed.

Parameters for the dynamic adaptation of the required pressure in the main air tube were optimized in order to reduce compressor energy demand. Air volume flow thresholds for the adaptation of the aerated volume to the changing load conditions were optimized, taking into account the new optimized aerator allocation layout.

Reduction of recirculation flows

Compared to a one-stage concept, the two-stage treatment concept of MTPV meets the legal requirements with a low specific aeration tank volume of only 70 l/p.e. (Wandl et al. 2006). Thus an important reduction of investment costs was obtained, but additional pumping energy is required due to the internal cycles implemented according to the treatment concept. In particular, the recirculation flow (which brings nitrate containing final clarifier effluent back to the first stage) creates an important additional energy demand. Given the results of the performance checks of the

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Guaranteed</th>
<th>Minimum values</th>
<th>1st perf. Check</th>
<th>After optimiz.</th>
<th>Final perf. check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen transfer [kg O₂/h] at 7500 m³ N/h</td>
<td>700</td>
<td>665</td>
<td>583</td>
<td>667</td>
<td>668</td>
</tr>
<tr>
<td>Oxygen transfer efficiency [kg O₂/kWh] at 2500 m³ N/h</td>
<td>4.0 (4.17⁺)</td>
<td>3.6 (3.84⁺)</td>
<td>4.4</td>
<td>4.8</td>
<td>4.8⁺</td>
</tr>
</tbody>
</table>

*Taking into account measurement inaccuracy; ⁺according to on-site T, p and humidity conditions.
intermediate pumping station at different inflow situations and the nitrate concentration in the plant outflow (i.e. potential of additional denitrification), advantages and disadvantages of additional recirculation flow could be assessed. Recirculation flow could be reduced to a minimum, still meeting all legal requirements.

Optimization of inflow load distribution between 1st and 2nd stage (Bypass)

By maximizing the bypass flow (primary effluent directly transferred to 2nd stage) up to a scale which still guarantees sufficient sludge age in the 2nd stage, two advantages can be achieved:

High bypass flow improves the conditions for denitrification in the second stage, and maximizing the load distribution to the second stage – load is discharged, where the aeration system is much more efficient. Oxygen transfer efficiency of the first stage aeration system operated by surface aerators is approximately 2 kg/kWh. Hence oxygen transfer efficiency of the second stage aeration system is more than twice as high.

By means of the follow-up project the average daily energy consumption was reduced by nearly 7% in comparison with the first months of operation.

Overall, a specific annual energy consumption of 21.9 kWh/p.e. was obtained in 2006 – the first full year of operation of MTPV. This value demonstrates very low specific annual energy consumption in national as well as international comparisons (Svardal et al. 2005).

CONCLUSIONS

Well-designed tender guidelines and strict performance check procedures proved to achieve high quality performance conditions for large wastewater treatment plants. Valuation of important operation parameters, such as maintenance costs and energy consumption during the tender procedures, encourages suppliers to bring in high quality products and specialised know-how. In order to ensure compliance with values guaranteed in the tender documents a concerted selection of performance checks should be implemented in the project schedule, especially the assigning of performance checks for preliminary installation units on site before entire installation. This procedure proved to be very favourable in achieving an efficient aeration system, considering the aeration system to be one of the main keys to efficient operation conditions.

As a “side effect”, high treatment plant “transparency” concerning key operation parameters is achieved from the results of the performance checks of the respective tender units. This information proved to be very useful for further optimization efforts during full operation, as was shown in the case of MTPV.

REFERENCES


Klager, F. 2001 Anpassung der HKA Wien – Ausbautrakt und bauliche Umsetzung. Wiener Mitteilungen 166. Institute for Water Quality and Waste Management - Vienna University of Technology. [in German].


