Benchmarking of Municipal Waste Water Treatment Plants (an Austrian Project)

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Abstract

An Austrian research project focused on the development of process indicators for treatment plants with different process and operation modes. The whole treatment scheme was subdivided into 4 processes, i.e. mechanical pretreatment (Process 1), mechanical-biological waste water treatment (Process 2), sludge thickening and stabilisation (Process3) and further sludge treatment and disposal (Process 4). In order to get comparable process indicators it was necessary to subdivide the sample of 76 individual treatment plants all over Austria into 5 groups according to their mean organic load (COD) in the influent. The specific total yearly costs, the yearly operating costs and the yearly capital costs of the 4 processes have been related to the yearly average of the measured organic load expressed in COD (110 g COD/pe/d). The specific investment costs for the whole treatment plant and for Process 2 have been related to a calculated standard design capacity of the mechanical-biological part of the treatment plant expressed in COD. The capital costs of processes 1, 3 and 4 have been related to the design capacity of the treatment plant. For each group (related to the size of the plant) a benchmark band has been defined for the total yearly costs, the total yearly operational costs and the total yearly capital costs. For the operational costs of the Processes 1 to 4 one benchmark (€ per pe/year) has been defined for each group. In addition a theoretical cost reduction potential has been calculated. The cost efficiency in regard to water protection and some special sub-processes such as aeration and sludge dewatering has been analysed.

Keywords
Benchmarking, Controlling, Cost efficiency, Waste water treatment, Performance Indicators

INTRODUCTION

Benchmarking can be defined as a systematic search for the best available performance in order to transfer it to the own organisation to improve the cost efficiency of each process. It therefore goes far beyond the traditional comparison of different enterprises. The crucial point in the benchmarking process is to find comparable process indicators in different enterprises in order to find the optimal cost efficiency using best practice and to analyse systematically the cost reduction potential in the own enterprise by using the experience gained in other enterprises.

Benchmarking is a well established instrument for improving the management of private enterprises but can also be applied successfully in public utilities which do not have to compete on the market. Municipal water and waste water management represents a good example for the latter category. The water and waste water infrastructure is owned and operated by authorities, communities or municipalities in most cases.

The basic principles of the benchmarking process as well as their application to the municipal water and waste water management including different definitions of process and process performance indicators are described in literature (Neuhold 1999, Parena 2000, Schulz *et al.* 1998, Wibbe 1999, Wiesmann 1999). The process of unification of the terms and their definitions on an international basis is on the way (IWA 2002, ISO 2003).

The base of this paper is an Austrian-wide benchmarking study for municipal wastewater plants in which 76 WWTPs have participated (Kroiss *et al.*, 2001).

METHODS

Comparison of treatment plants using defined processes

In order to be able to compare costs and performance of waste water treatment plants a methodology has been developed which enables the comparison even for different treatment process schemes and operational modes. For this purpose 4 different processes have been defined, i.e. mechanical pre-treatment (Process 1) mechanical-biological treatment (Process 2), sludge thickening and stabilisation (Process 3) and further sludge treatment and disposal (Process 4).

Development of process indicators

The acquisition of the technical data is based on a questionnaire which was sent to the treatment plant managers. In order to achieve comparable and reliable data special trained experts helped the managers in responding the questionnaire. The goal of the data acquisition was a reliable and accurate technical description of the different processes according to their definition in order to be able to attribute the correct costs to these processes.
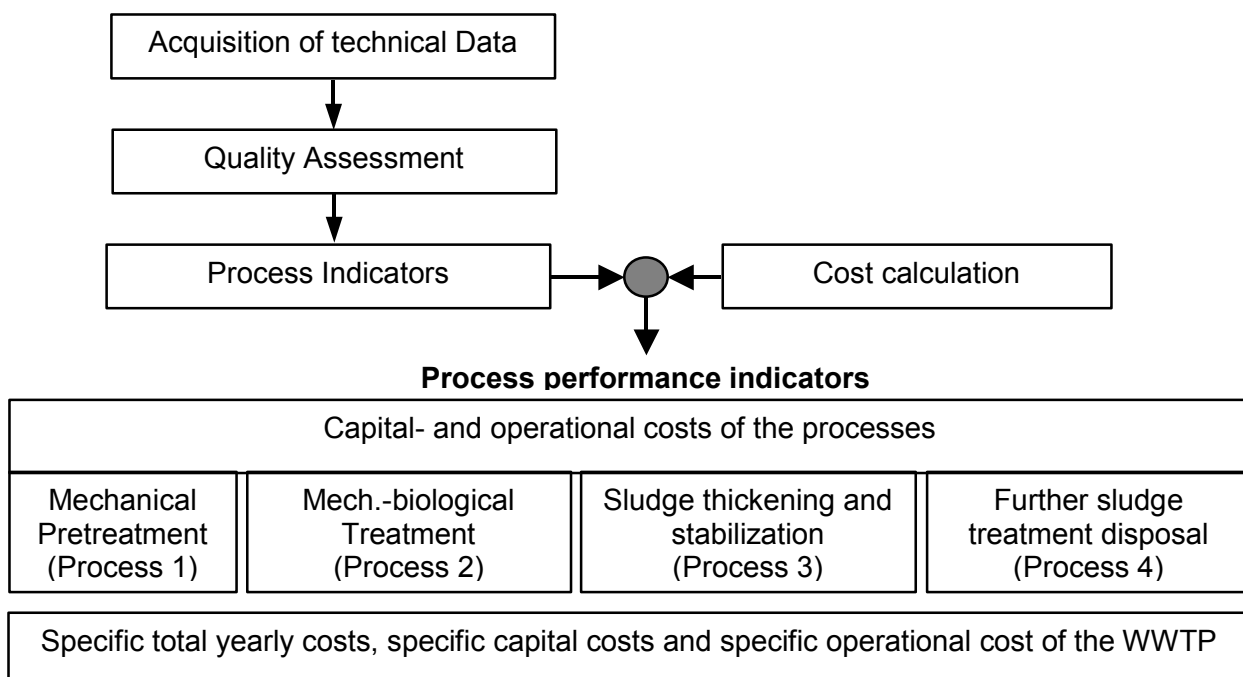

Figure 1: Methodology for the development of process performance indicators

Before the technical data are used for the calculation of process indicators it is essential to check the data in regard to plausibility. For this procedure the measured data and their numerical relation were checked against long-term experience in municipal waste water treatment. Another tool is the application of mass balances for adequate parameters such as COD, phosphorus, etc.

In order to calculate relevant and sensitive indicators it is necessary to relate the costs to the most sensitive technical parameters. A sensitivity analysis showed that the best technical parameter for process indicators related to total yearly costs, total operating costs and operating costs for the 4 processes is the <u>mean yearly organic load **(MYL-COD)**</u> in the influent of the treatment plant. Total nitrogen could also be used quite effectively but the availability of data was not satisfactory. In this investigation the definition of the organic load is based on population equivalents (pe) defined by a

daily COD load of 110g in the influent. The 110g COD corresponded best to 60 g of BOD_5/pe/d, the latter commonly agreed world-wide.

For the total capital costs and the capital costs of Process 2, the process indicators (specific costs) are related to a <u>standard design load **(SDL-COD)**</u>, expressed in pe. SDL-COD represents the maximum load of the treatment plant at which the effluent standards of the Austrian regulation for municipal waste water treatment can be met with the existing plant. The calculation of this "standard design load" is based on the ATV design guideline A 131 (2000). In this way the costs are related to the same efficiency requirements which enable a direct comparison of the related costs. It has to be stated the Austrian effluent standards require full nitrification down to 8°C at any time, a 70% nitrogen removal and 1 mg total P as yearly means. For the Processes 1, 3 and 4 the costs were related to the <u>real design load **(RDL-COD)**</u> of the treatment plant expressed in pe of organic loading.

Table 1: Relations used for process indicator calculation

	Capital costs	Operational costs	Yearly costs
Total	SDL-COD		MYL-COD
Process 1	RDL-COD		
Process 2	SDL-COD	MYL-COD	
Process 3	RDL-COD		
Process 4			

Classification of treatment plants according to their size (MYL) in groups

The investigation comprised a very heterogeneous sample of 76 treatment plants spread all over the country. In order to obtain comparable indicators it was necessary to subdivide the plants according to their size expressed as the mean yearly organic loading (MYL-COD). The range of sizes within the groups was selected in a way that the influence of the size on related costs can be neglected because it is below the accuracy of the data.

Definition of Benchmark bands, Benchmarks, and Benchmark plants

Benchmark bands have been defined for external use only, i.e. for publication of the results of the study. A benchmark band exists only for total costs and not for specific process indicators, which are for internal use at the treatment plants. Benchmark bands are defined for each group and represent the lowest specific costs achieved in a benchmark plant increased by a percentage which has been fixed on the basis of experience in regard to data quality and inaccuracies of the whole procedure (Table 2). The goal was to present lowest specific cost figures for public use which can be achieved taking into account the inaccuracies of the data and the methodology used.

Table 2: Percentage increase used fort he calculation of the benchmark bands

	Groups 1 & 2	Groups 3, 4 & 5
Operational costs	20 %	10 %
Capital costs	10 %	10 %
Yearly costs	15 %	10 %

Going more into detail the percentage increase takes care of the following uncertainties: quality of the data, frequency of measurements, yearly fluctuations of organic loading of the plants,

uncertainties regarding the assignment of costs to processes and different cost elements as e.g. personal, repair and maintenance costs. At smaller treatment plants (group 1 and 2) the uncertainties are more relevant than at large plants which is taken into account by the values shown in Table 2.

Benchmark plants have to meet the following criteria:
- The effluent quality must comply with the legal requirements laid down in the respective Austrian regulation (comparable to EU directive 271/91 for sensitive areas).
- Compliance with technical quality criteria (mass balance check, etc.).
- Waste water characteristics have to be municipal (no dominant influence of industrial waste water).
- Specific costs within the benchmark band.

One benchmark is defined for the specific operating costs for each of the Processes 1 to 4 (process performance indicator) within each of the groups depending on the size. The benchmark corresponds to the lowest specific costs for a benchmark plant within one group. Data uncertainty is not considered for the benchmarks as it plays a minor role for the processes as compared to the total costs.

Cost analysis showed that the data quality of investment costs for processes does not allow calculating reliable figures for a benchmark. Therefore benchmarks for capital costs of processes were omitted.

RESULTS AND DISCUSSION

Benchmark bands for operating, capital and total yearly costs

Benchmark bands for operating costs calculated on the methods described above range from 10 € to 22 € per population equivalent and year (Table 3 and Figure 2). As these costs are related to the mean pollution load in the influent, this also corresponds to the real operating costs caused by one inhabitant.

Table 3: Benchmark bands for different indicators and groups

Benchmark band	Group 1	Group 2	Group 3	Group 4	Group 5
MYL-COD [pe]	< 5,000	5,000 to 12,000	12,000 to 25,000	25,000 to 50,000	> 50,000
Operating costs [Euro/pe MYL/a]	22.0	18.8	15.9	12.7	10.3
Capital Costs [Euro/pe SDL/a]	37.2	20.6	19.0	13.7	10.7
Yearly costs [Euro/pe RDL/a]	70.9	66.4	35.4	34.7	26.0

The difference between the benchmark bands from group to group is relatively constant and amounts to about 3 €/pe/year (110 g COD/pe/d). It can be concluded that the specific operating costs can only be used for comparison within a group defined by a range of mean yearly organic load (MYL). The benchmark bands for the capital costs are shown in Table 3. There is a great difference between the specific capital costs of group 1 and 2. It can be attributed to two causes. The first is that the specific investment costs increase with decreasing size of the plants. The second is that the very small treatment plants tend to have more reserve capacity due to the uncertainty of

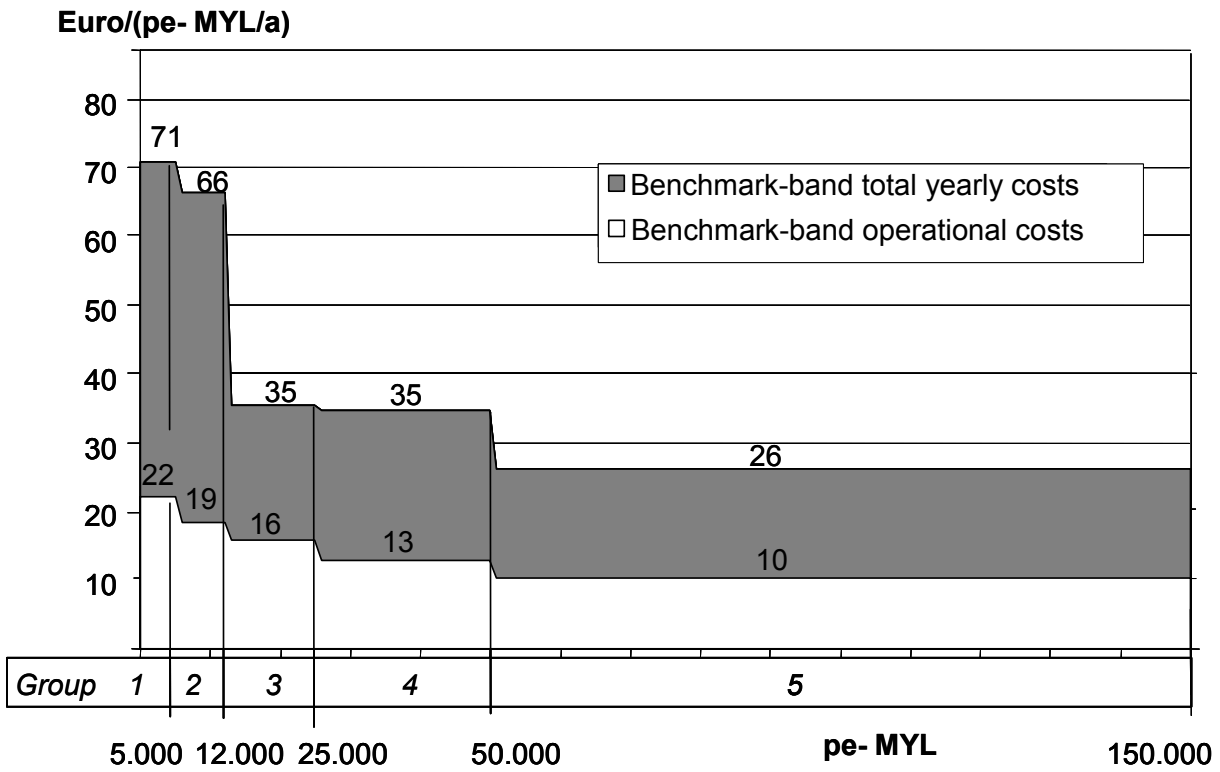future development of trade and industry. For the operating costs this seems to be not relevant.

Euro/(pe- MYL/a)

Figure 2: Benchmark bands for operating and total yearly costs for the 5 groups

The benchmark bands for the specific total yearly costs range from 26 €/pe MYL/a for group 5 to 71 €/pe MYL/a for group 1 (Figure 2). The great difference in total yearly costs between group 2 (66 €/pe MYL/a) and 3 (35 €/pe MYL/a) was not expected and needed further investigations. It turned out that the actual loading of the treatment plants of the first two groups is markedly lower than the design load, while all the other treatment plants are actually loaded close to the design (Figure 3).
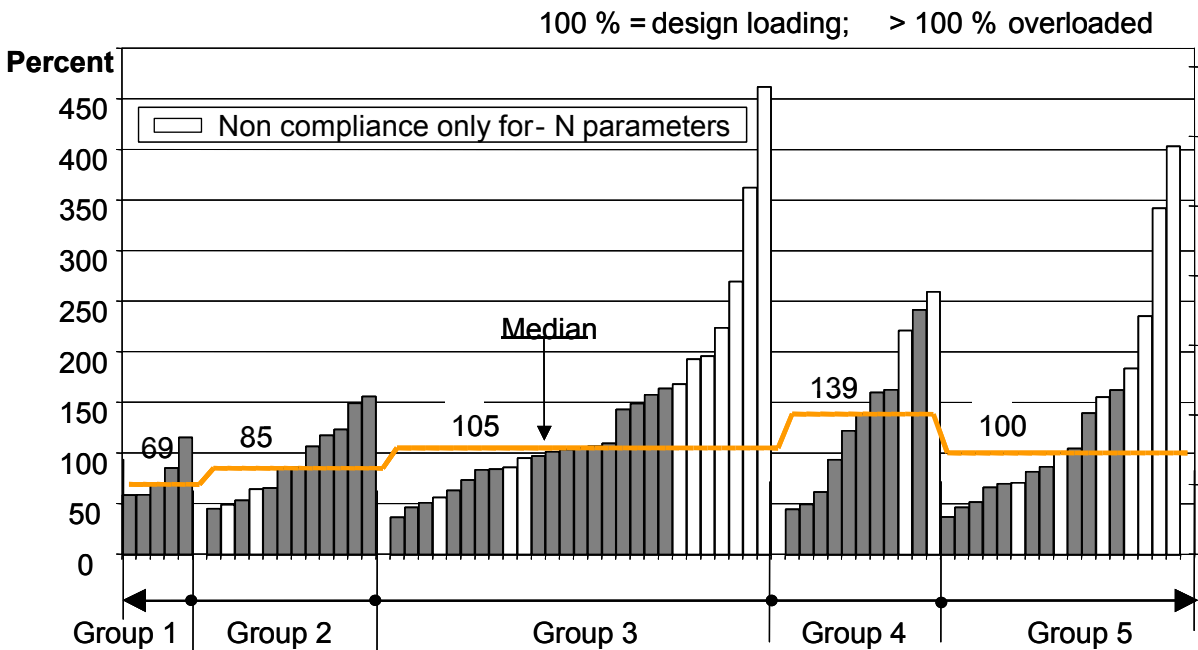

Figure 3: Actual loading as percentage to the standard design load (SDL)

Benchmarks for operating costs for the 4 processes (P1 to P4)

Analysis of the operating costs for the different processes revealed that about 45% of these costs can be attributed to the mechanical-biological waste water treatment and the sludge stabilisation (Processes 2 and 3). Most of the rest of 55% can be attributed to additional sludge treatment and disposal. The benchmarks for the operating costs for the different processes are listed in Table 4.

Table 4: Benchmarks for operating costs

[Euro/pe MYL/a]	Group 1	Group 2	Group 3	Group 4	Group 5
Benchmark P1	1.2	1.7	1.4	1.0	0.9
Benchmark P2	10.0	8.1	6.5	3.1	2.3
Benchmark P3			1.82	0.7	0.9
Benchmark P4	7.3	5.5	5.7	5.5	3.8

Theoretical cost reduction potential and cost benefit relation for water protection

The theoretical cost reduction potential was calculated as the sum of the differences between the benchmark bands for the operating costs and the actual specific costs. If the actual costs are below the benchmark band because of heavy overload (non-compliance with effluent standards) this difference becomes negative and reduces the reduction potential. It will turn out in the future to which extent the theoretical cost reduction potential can be realised in practice, because the specific local conditions (e.g. bad design) can have a great influence.

In order to check the cost-benefit relation in regard to water protection of different plants, the treatment efficiency was plotted against the operating costs. The overall treatment efficiency (COD, NH_4-N, total N and total P) was defined using a similar method suggested by Ødegaard (1995) based on total oxygen consumption in the receiving water including eutrophication. It clearly turned out that there is no correlation between the two variables, this means that cost-benefit relation is line with optimising treatment efficiency. It can be argued from this investigation that treatment plant operator quality is the most relevant parameter.

Analysis of the sub-processes – aeration and sludge dewatering

For different aeration control systems process performance indicators have been determined: 8 treatment plants with manual control, 6 plants are equipped with automatic aeration control based on ammonia concentration in the aeration tank, 4 plant have an automatic redox potential feedback control system, 12 plants have an aeration control system with fixed time program and 30 plants are equipped with an automatic intermittent aeration feedback control system based on DO monitoring. For the rest no special information was available. It turned out that the aeration control system has little influence on the specific energy consumption. But there is a remarkable correlation between the non-compliance with the effluent standards and the plants having either manual control or where there was no information about the control system used.

Also the influence of different aeration systems, either fine-bubble aeration or surface aeration, has been analysed. It turned out that the energy consumption of Process 2 at plants equipped with surface aerators is only about 7 percent higher than the energy consumption at plants with fine-bubble aeration.

Detailed analysis of sludge dewatering process achieved the following results. The specific operational costs for sludge dewatering with belt filter presses are the lowest with 28 € per ton of dry solids. The comparable costs for chamber filter presses and centrifuges are 33.5 € and 36.5 € respectively, the difference is only about 10%. The specific costs for sludge disposal are of the same order as the total costs for sludge dewatering. As the operational costs for dewatering can only be little influenced in most of the cases, the main cost factor for Process 4 which can be influenced is additional sludge handling and sludge disposal.

Representativeness

An important question is whether the sample of treatment plants investigated in this study is representative for all treatment plants in Austria. It can be stated that the results of the study are representative for about 75% of the total design capacity of municipal treatment plants in Austria, which actually is about 18 million pe. It is representative for plants between 5,000 and 500,000 pe design capacity. For the relatively large number of small plants < 5,000 pe and the three plants > 500,000 pe in Austria the results are not representative.

CONCLUSION

A new methodology for the comparison of technical and economical process indicators was developed. It revealed a series of interesting relationships and new insights, which are mainly useful for the plant managers who took part in the investigation. But also from the scientific and the political point of view the results represent useful information which also can be interesting for the customers.

- The public utilities for waste water discharge and treatment have shown that they are willing and active in optimising cost-effect relationship. Despite the stringent requirements in regard to treatment efficiency (nutrient removal compulsory) comparable specific costs are low on an international scale.
- The fees related to one cubic meter of drinking water cannot be used for a rational comparison of cost effectiveness. The costs have to be related to the mean yearly organic load (MYL), expressed e.g. in 110 g COD/pe/a or the standard design load (SDL).
- There is now statistical correlation between the specific operational costs and the effluent quality achieved.
- The theoretical cost reduction potential for operating costs calculated from the evaluation of 76 plants in this study (approx. 25% of the Austrian plant capacity) is between 4 and 20% depending on the size of the plants (groups), this corresponds to about 5,500,000 € per year.
- The cost reduction potential achievable at each plant can only be determined after a detailed analysis on site of the plant. General statements on cost reduction potentials have to be made in a responsible and careful way taking into account that only one year was investigated and that the database still contains a number of inaccuracies regarding technical and economical parameters.

The methodology developed on the basis of theoretical considerations and practical experience represents a good tool for treatment plant managers. It enables them to find concrete and detailed cost reduction potentials. By the comparison with the benchmarks and by information exchange between the benchmark plant managers it will be possible to increase cost-efficiency relation. For all the experts in the waste water field the detailed analysis of the cost efficiency revealed new insights and some surprises.

Benchmarking has to be seen as a continuous process and the investigation presented here has to be

interpreted as the starting point of a development. For the continuation of the process new effort will be necessary. It is planned to continue the project on a cost recovery basis with the participants in the study but also to extend the process to most of the treatment plants in Austria. The methodology will have to adapted to the small plants (< 12,000 pe) and for the very large plants (>500,000 pe).

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