Assessment of diffuser pressure loss on WWTPs in Baden-Württemberg

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Abstract Aeration of activated sludge is a critical treatment step for the operation of activated sludge plants. To achieve a cost effective treatment process, assessing and benchmarking of aeration system performance are important measures. A simple means of gauging the relative condition of a fine bubble diffused aeration system is to evaluate the pressure loss of the diffusers as oxygen transfer tests are rarely applied during the lifetime of an aeration system.

This paper shows an assessment of fine bubble diffuser systems in Baden-Württemberg, Germany, based on the results of a questionnaire sent to 941 WWTPs. Apart from the results in regards to the diffuser pressure loss, this paper also presents information about the current state of diffuser technology such as types and materials as well as the diffuser cleaning methods used in Baden-Württemberg.

The majority of the WWTPs were equipped with tube diffusers (71%) with 50% of all plants having EPDM membranes installed. Regular mechanical cleaning is the most common cleaning method followed by regular pressure release / air-bumping programs during operations. In regard to the diffuser pressure loss it was found that 50% of the evaluated plants had a diffuser pressure loss that was twice as high as measured for new diffusers.

Keywords Aeration systems, diffuser cleaning, diffuser material, pressure loss

INTRODUCTION

The energy consumption of diffused fine bubble aeration systems depends on the oxygen transfer efficiency of the diffuser system and the pressure loss of the whole system. Usually an increasing pressure loss of the diffusers is a very good indicator of the deterioration of the oxygen transfer efficiency, as several authors report extensive fouling and clogging (Boyle and Redmon, 1983, Frey and Thonhauser, 2004, Wagner, 2001 and 2004, Kaliman et al., 2008, Rosso et al., 2008) which will result in increasing backpressure of diffusers. However, there is evidence that the performance of the aeration efficiency can drop without changes in the backpressure (US EPA, 1999; Krampe, 2011). Under operational conditions the efficiency of aeration systems can be monitored by key performance indicators (KPIs) such as the specific energy consumption for the aeration system (e.g. kWh/kg BOD_5) or the diffuser pressure loss. The specific energy consumption is influenced by several factors such as wastewater temperature, sludge retention time, specific airflow per diffuser etc. but enables a good evaluation of individual aeration system performance over time. As many smaller wastewater treatment plants (WWTPs) do not measure the electricity consumption of the aerations system separately, the diffuser pressure loss may be the sole indicator to assess the performance of the aeration system.

A detailed assessment of the diffuser backpressure requires a set of instruments to consider the actual airflow and the water level in the tanks. These instruments are usually not available on WWTPs; however, WWTPs typically have a pressure gauge at common air manifolds or at the blower outlet which allows a first indicative assessment of the backpressure. This approach was first used in Austria as part of a regular benchmarking process of WWTPs (Frey, 2003). This paper outlines the first benchmarking approach for Baden-Württemberg, a state in the south west of Germany. The aim is to establish baseline data and a method which allows comparison between simple pressure readings with the expected diffuser performance.

The evaluation is based on a questionnaire which was sent to 941 WWTPs in Baden-Württemberg to get a sufficient data basis. The data evaluation was based on the method used by Frey (2003) in Austria to make the results comparable and to get a broad data basis. Apart from the required data to calculate the backpressure of the diffusers, additional information such as the type and material of the diffusers, regular diffuser cleaning methods and details about the process configuration was collected. This paper therefore presents the current state of technology in regards to fine bubble aeration systems in Baden-Württemberg, Germany.

STRUCTURE OF THE QUESTIONAIRE AND BASICS OF EVALUATION

For the data evaluation a questionnaire was developed. The questionnaire was divided into four main sections:

- General information
  The process layout of the wastewater treatment plant was requested in the section. In addition to the preliminary mechanical treatment this section was primarily focused on chemical phosphorus elimination (precipitant, dosing points etc.), as some plants had experienced problems related to precipitants prior to the survey (Krampe, 2003).
- Aeration system
  This part of the questionnaire requested the diffuser type, the operation of the aeration system and material and manufacturer of the diffusers. The installation date of the diffusers and diffuser changes were also queried to obtain information regarding the lifetime of the various materials.
- Water- / diffuser depth at dry weather flow, blowers
  The questions in the third section were required to calculate the theoretical pressure loss and to compare the results with the pressure measurements of the WWTP.
- Measures to reduce the backpressure
  This part focused on gathering information regarding regular measures which were already applied on some WWTPs to reduce the backpressure.

The evaluation of the survey focuses primarily on the experience of Frey (2003 and 2005) who did similar studies in Austria. The current pressure loss can be calculated using the following formula:

$$\Delta p = p_T - p_{depth} - p_{pipe}$$

Δp = pressure loss of diffuser
p_T = total air supply pressure
p_{depth} = the hydrostatic pressure resulting from injection depth
p_{pipe} = pressure loss of pipes and valves

Based on this equation and the measured pressure (p_T), the pressure loss of the diffusers (Δp) was calculated with the data from the questionnaires. The pressure loss of diffusers can be determined most accurately if the pipe losses do not have to be included, i.e. the pressure measurement occurs as close as possible to the diffusers. Depending on the position of the pressure measurements, pressure losses according to Table 1 were taken into account.

Table 1: Adopted pipe losses (Frey, 2005)

Position of measurement	Pipe losses in mbar
At the blower (incl. air control valves etc.)	15
Manifold at tank or downcomers	3

If the measurement location was not specified, the pressure loss was assumed to be 15 mbar for measurements close to the blowers. In the case where no information in regards to the depth of submergence for the diffusers was made available, but the water depth was given, the assumptions stated in Table 2 were made for the installation height of the diffusers.

Table 2: Adopted installation height of diffusers (Frey, 2005)

Type of diffuser	Installation height in cm
Disc and tube diffuser	25
Plate diffuser*	10

* All shaped diffusers including panels

For the RMU (Germany) and AQUACONSULT (Austria) plate diffuser, the height was set to zero if no information was available, as these systems are often installed directly on the aeration tank floor. The pressure loss calculated with these assumptions could then be compared with the pressure loss of comparable diffusers when new. Since in most cases it is not possible to determine the exact pressure loss of new diffusers, the assumptions as stated in Table 3 were made.

Table 3: Adopted pressure loss of new membrane diffusers (Frey, 2005)

Type of diffuser	Diffuser pressure loss in mbar*
Disc diffuser	35
Tube diffuser	45
Plate diffuser	55

* For ceramic and HDPE diffusers the pressure loss was reduced by 10 mbar

These values were derived from a series of datasheets from different manufacturers for typical air fluxes and the variations rarely exceed ±10%. Using these values allows a data evaluation without considering the air flux and the individual datasheets. (Frey, 2005)

As the energy consumption is directly proportional to the pressure loss it is possible to calculate the additional energy demand due to increased pressure loss. This can be calculated by dividing the measured air supply pressure with the theoretical air supply pressure using a theoretical diffuser pressure loss but the actual water depth and pipe losses. Additionally the efficiency of the diffusers is expected to drop as outlined earlier. This may have an even greater impact on the energy consumption but cannot be assessed using this method.

RESULTS OF THE SURVEY ON THE STATE OF AERATION IN BADEN-WÜRTTEMBERG

Return rates and plausibility checks

The data collection was done by the Institute for Sanitary Engineering, Water Quality and Waste Management (ISWA) of the University of Stuttgart in cooperation with the German Association for Water, Wastewater and Waste (DWA) Baden-Württemberg. 941 of the 1095 WWTPs in Baden-Württemberg are using the activated sludge process at least to some degree. The allocation of different process technologies is summarised in Table 4.

Table 4: Statistics of the considered wastewater treatment plants

Process	Number of wastewater treatment plants
Activated sludge process	379
Activated sludge process with extended aeration	519
Sequencing Batch Reactors	2
Activated sludge and Trickling Filter	31
Other installations	10
Total number of plants	941

In total, 643 operators are responsible for these 941 WWTPs. They were contacted and asked to complete the questionnaire for each of their WWTPs. 466 questionnaires were completed and sent back to the ISWA. This corresponds to a response rate of approximately 50% based on the number of plants.

42 responses indicated that the relevant plants had surface aerators installed. Two of the trickling filter plants and four rotating biological contactor plants used only an anoxic activated sludge stage for denitrification and therefore had no aeration system installed. Six facilities were no longer existent or under renovation. 12 units did not specify the installed aeration system and could not be used. The remaining data has been statistically evaluated.

For the detailed analysis of the pressure loss, a plausibility check on the data was necessary. The following criteria were applied:

- Measured average pressure must be greater than the back pressure resulting from depth of submergence of the diffuser
- Diffuser installation height must be plausible (as a function of the water level and the diffuser type).

The plausibility check was performed at the beginning of the data evaluation. For all facilities that met the specified validation criteria it has been assumed that the data provided was correct. As a result of the plausibility checks the usable number was again significantly reduced from 400 to 123. There is a light dependency on the data quality of the design capacity. The median design capacity of all questionnaires was 30,290 PE but this had shifted to 35,153 PE after the plausibility checks. In conclusion, more smaller facilities have been removed during the plausibility check.

The total design capacity of all 123 considered WWTPs was 4.3 million PE. In relation to the total design capacity of all WWTPs in Baden-Württemberg (21.6 million PE) 20% were captured. Based on the number of WWTPs, only 123 of 1,095 wastewater treatment plants in Baden-Württemberg were considered, this corresponds to a portion of 11%.

Distribution of diffusers types and materials

The distribution of the various diffuser types is summarised in Table 5. These figures are based on the data of 400 wastewater treatment plants before the plausibility check. In all considered plants, fine bubble diffused aeration systems were installed. Information about the design capacity in PE of the relevant WWTPs is included in Table 5 as well.

Table 5: Summary of the diffuser types in regards to the number of WWTPs and design capacity

	Plate diffuser	Disc diffuser	Tube diffuser	Other

Number of WWTPs	76	23	283	18
Design capacity in mio PE	4.0	1.4	6.0	0.6
Number WWTPs in %	19	6	71	4
Design capacity in %	33	12	50	5

Table 5 shows for example that tube diffusers are often used on small WWTPs. They are installed on 71% of the captured WWTPs which only represent 50% of the captured design capacity. Similar observations arose from the Austrian data (Frey, 2003).

Table 6 shows the distribution of different diffuser materials. The questionnaire reveals that ceramic diffusers are more commonly installed on larger WWTPs. This can be explained by the process design, whereas smaller plants regularly use intermittent or alternating processes to achieve nitrification and denitrification in one tank which usually requires membrane diffusers. Larger plants have dedicated aeration and denitrification zones which allow the use of ceramic diffusers with all their advantages (Libra et al., 2002 and 2005).

Table 6: Summary of the diffuser materials in regard to the number of WWTPs and design capacity

	Ceramic	EPDM	Silicone	Other
Number of WWTPs	78	207	27	88
Design capacity in mio PE	4.419	4.112	0.510	2.977
Number of WWTPs in %	20	51	7	22
Design capacity in %	37	34	4	25

Comparison of the actual and theoretical pressure loss

Figure 1 shows the calculated pressure loss of all diffusers regardless of type and material as cumulative frequency. The figure also shows the usual pressure loss of new diffusers ranging from 25 to 55 mbar as well as an area of the usual pressure loss increase of diffusers after several years of operation (up to 95 mbar in total). These numbers are based on Frey (2005) whereby manufacturers usually specify pressure increases of 30-40 mbar after some years of operation.

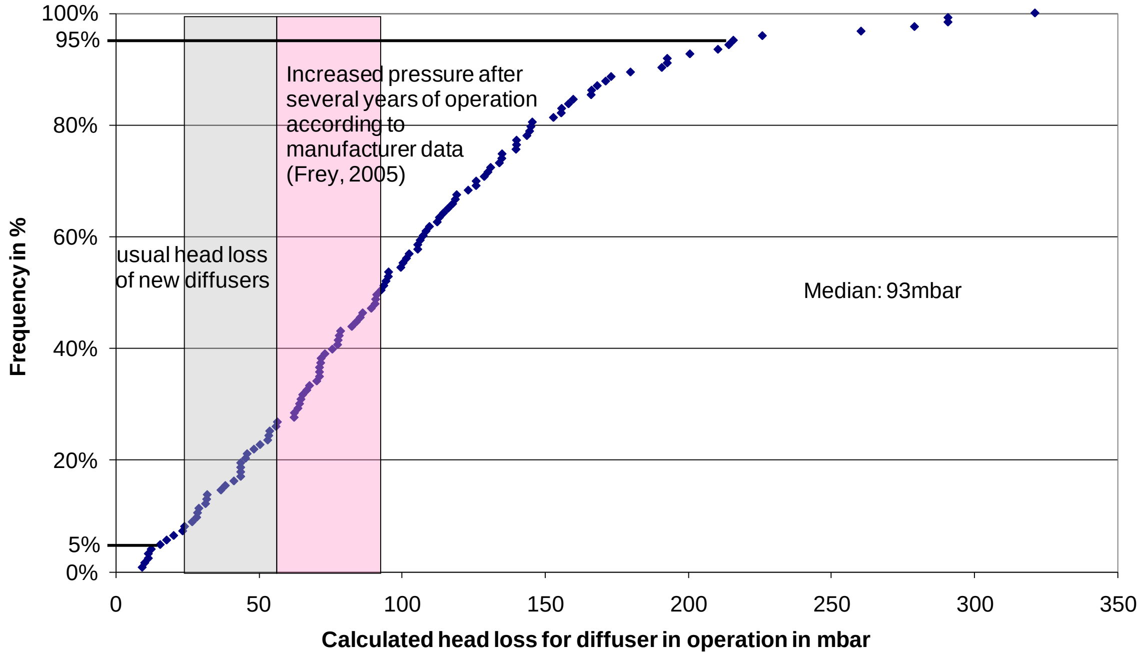

Figure 1: Cumulative distribution of the calculated pressure loss for all evaluated diffusers

The median pressure loss of all diffusers is 93 mbar. This means that 50% of the considered WWTPs have a higher pressure loss than expected for used diffusers after some years of operation. From the data and individual calculations for each plant, an increase in the pressure loss by 108% (median) based on the theoretical loss of pressure of new diffusers arises. This means that for half of the WWTPs the current pressure loss of the diffusers was twice as high as for new diffusers. Frey (2005) calculated a value of 166% for the Austrian WWTPs. It also aligns with Rosso et al. (2008) who recommend to size blowers to accommodate a two-fold larger increase in dynamic wet pressure (DWP) based on their findings.

The increase in total air supply pressure and therefore the additional energy consumption was calculated individually for each WWTP. The median value was subsequently determined and the additional energy consumption was calculated to be 12%. Based on an annual electricity consumption of all WWTPs in Baden-Württemberg of 470 GWh in 2005 (Schwentner, 2006) with an estimated portion for the aeration of 60%, an electricity demand of 282 GWh/annum results for the aerationsystem. With an additional energy consumption of 12% included in the 282 GWh/annum, approximately 30 GWh electricity annually consumed in Baden-Württemberg can be related to too high pressure losses of diffusers. Additionally deteriorated diffuser efficiency has to be expected for those diffusers which might even have a bigger impact on the energy consumption.

In Figure 2 the results are presented for the different diffuser types and materials. In addition to the usual pressure loss of new diffusers, the range for used diffusers according to Frey (2005) is presented as error bars.

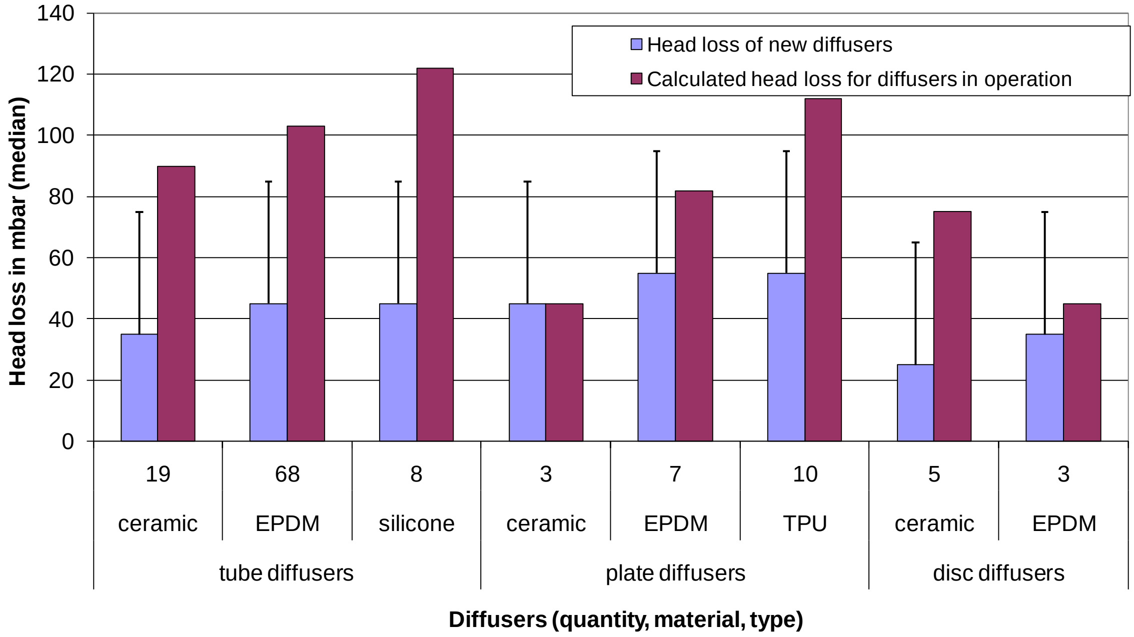

Figure 2: Comparison of the pressure loss of new and used diffusers for various types and materials

The most significant data set is available for tube diffusers. For all other diffuser types the data basis is fairly weak and the results are therefore bias.

Results of site visits for data verification

Based on the significant fluctuations in the calculated individual pressure losses as shown above, it was decided to visit individual WWTPs and to double check the data from the questionnaires. During these inspections the differential pressure was measured in various places of the aeration system. A Thommen digital pressure gauge with a measuring range of 0-200/2000 mbar and an accuracy of 0.5/0.2% was used to measure the total supply pressure. The results of these inspections are shown in Figure 3 in comparison to the theoretical pressure loss of the installed new diffusers and the calculated results based on the questionnaires.

For WWTPs with bigger differences between the results of the questionnaire and the measurements (plants A, C, E and H) either the pressure gauges were faulty or the water depths stated were incorrect. In one case, both problems were evident. The outcome of the random audit showed that it is more likely the extent of the problems has been underestimated. In only one case a slightly lower pressure loss was measured compared to the calculated value (plant D). In six of the eight examined plants the diffuser pressure loss was higher than determined by the operating personnel.

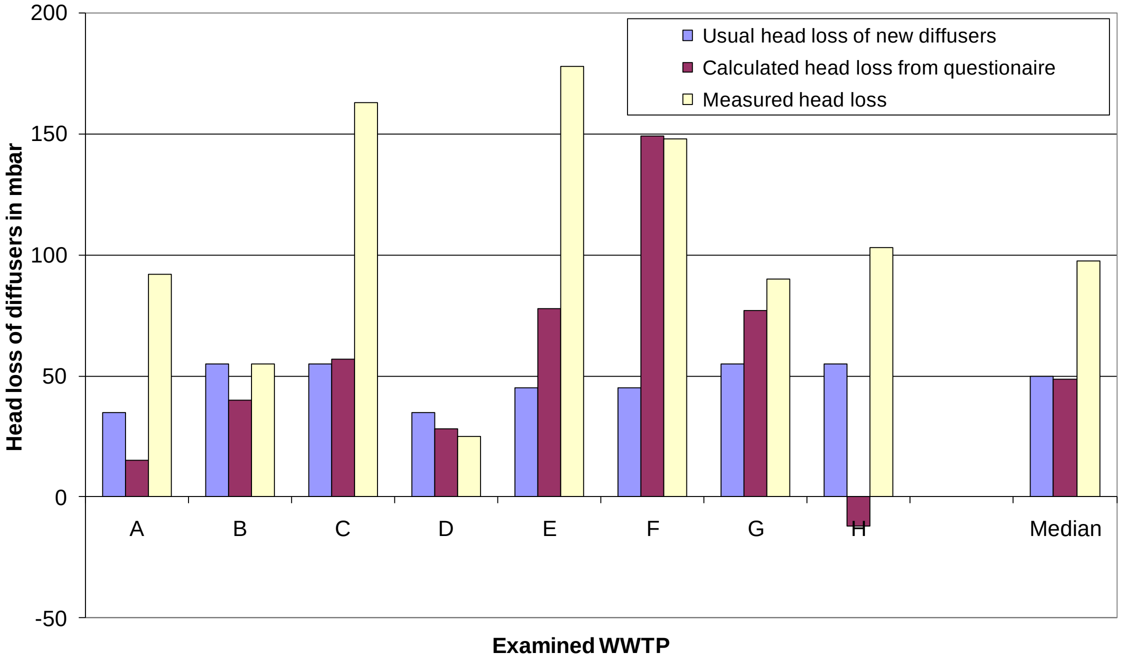

Figure 3: Comparison of pressure losses of diffusers in new condition, calculations of the questionnaires and as a result of own measurements

Diffusers cleaning strategies

400 WWTPs were considered for the evaluation of the diffuser cleaning. The results are given in Figure 4.

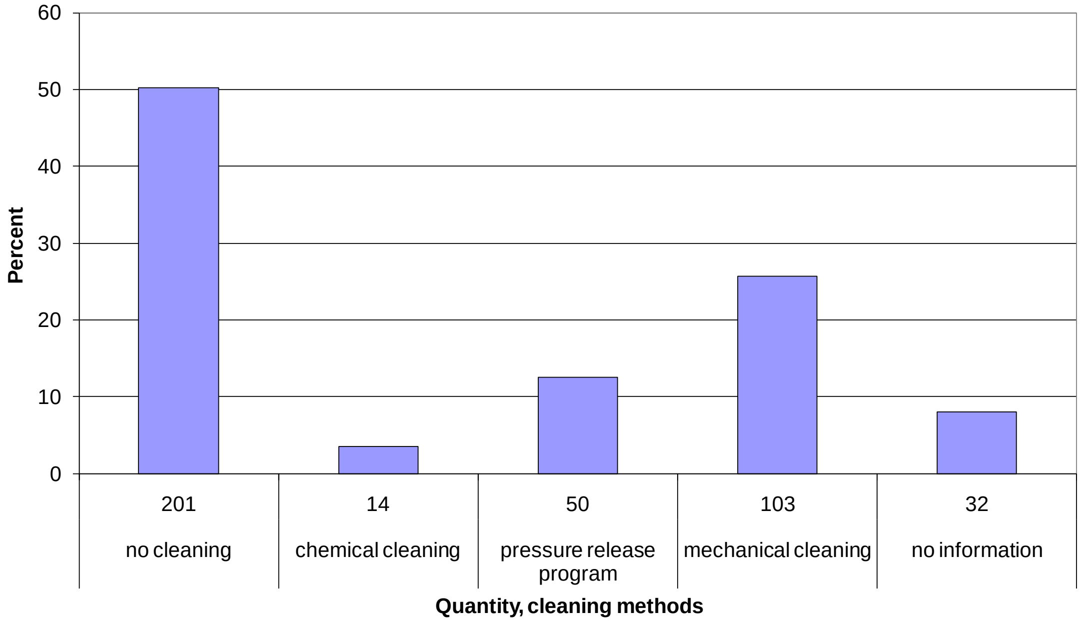

Figure 4: Cleaning strategies on the considered sewage treatment plants

Only about half of all WWTPs take measures against excessive pressure losses of the diffusers. The most common method of diffuser cleaning is mechanical cleaning with high pressure water jet cleaners. 50 WWTPs indicated that they operate with a pressure release / air-bumping program. The frequency of pressure releases varies between several times a day and one to four times a year. 14 WWTPs regularly use acid vapour to clean their diffuser system. Eight of those plants had ceramic diffusers, four were using EPDM diffusers and two TPU diffusers.

SUMMARY AND CONCLUSIONS

The presented survey achieved a very good response rate for the questionnaire. However, a significant part of the questionnaires provided implausible, mismatched data so that the evaluable data base was significantly reduced. Site visits to double check the selected results with own measurements showed that most of the implausibilities can be related to defective pressure gauges and a lack of knowledge of the water depth and diffuser heights. Ultimately the data of approximately 10% of all sewage treatment plants or 20% of entire design capacity in Baden-Württemberg could be used for evaluation.

Based on the remaining data it became obvious that there was a significant increased pressure loss with the used diffusers compared to new diffusers on many WWTPs. About 50% of the evaluated WWTPs showed a pressure loss twice as high as expected for new diffusers. By relating this additional pressure loss to the whole energy consumption of all WWTP in Baden-Württemberg, Germany it was possible to estimate the additional electricity consumption as a result of the increased pressure loss to be approximately 30 GWh/annum. This is not considering the additional energy consumption as a result of deteriorated diffuser efficiency which is expected to be even higher.

Diffuser performance is an ongoing issue for WWTPs and needs lots of attention from all sides. The presented methods and data allow an easy evaluation of operational data. This is based on the calculation of the pressure loss which is based on the depth of submergence of the evaluated diffusers, typical pipeline losses and common pressure losses of new diffusers. The calculated data can be used as a trigger to conduct a detailed assessment in cases where the backpressure is too high. In cases where the resulting pressure losses are above the normal range, cleaning measures for the diffusers should be taken into account. As shown by the questionnaire, preventive cleaning of diffusers is quite common. A more detailed description of cleaning methods can be found in Frey and Thonhauser (2004). However, the ultimate measure to improve the energy efficiency is the replacement of the diffuser elements.

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