Predicting the sound power and impact of a wastewater treatment plant

B. De heyder*, P. Ockier*, R. Jansen and R. Huiberts****

* Aquafin NV, Dijkstraat 8, B-2630 Aartselaar, Belgium

** Adviesbureau Peutz & Associés BV, Paletsingel 2, Postbus 696, NL-2700 AR Zoetermeer

Abstract Several process units at a wastewater treatment plant (WWTP) can produce a significant level of sound and thus induce sound nuisance for nearby residents. The risk for sound nuisance should be considered by making a prognosis of sound impact in an early project phase (planning, design). A prognosis requires information with respect to the sound characteristics of the different process units. This paper reports the development of empirical models for the sound power of relevant process units in the water line at Aquafin WWTPs. The used methodology for model derivation and validation allowed us to minimize the required number of measurements. Besides the methodology, the paper describes in detail the derivation and validation of the empirical model for the splashing water of screw pumps. Also the use of all the derived empirical models to determine the sound impact of a wastewater treatment plant at close distance is illustrated with a case-study.

Keywords Sound; noise; nuisance; sound power; prediction

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Introduction

A wastewater treatment plant (WWTP) can include several process units that produce a significant level of sound (e.g. influent screw pumps, aerators, etc.). When located near a residential area, the risk for nuisance cannot be neglected, especially during night time when the background noise level (such as traffic noise) decreases (De heyder *et al*., 1999).

Once built, possible measures for reducing the sound impact of a WWTP are limited and can be relatively expensive (e.g. covering). The risk for nuisance should thus as much as possible be considered when planning and designing the WWTP. A prognosis of the sound impact of a WWTP requires underpinned information with respect to the sound characteristics of the different process units on the WWTP (sound power, sound directivity). In the literature, however, only a limited amount of recent data has been published.

This paper presents the results of a study performed to derive and validate empirical models for prediction of the immission relevant sound power of typical process units in the water line of WWTPs. Considered process units are: screw pumps (influent, sludge recirculation), grit removal (stepscreen), overflow weirs (channels, oxidation ditch, settlement tanks) and aerators (bubble aeration, surface aeration). This paper describes the general methodology of the study, the derivation and validation of the empirical model for the splashing water of screw pumps and a case study of prognosis of the overall sound impact of a WWTP.

Materials and methods

Methodology

The study was contracted to the consulting company Adviesbureau Peutz & Associés which owns a relatively large database of historical (1984–1997) sound measurements on WWTPs in the Netherlands. The methodology used in the study allowed us to minimize the number of measurements required to derive and validate the empirical models. The key factor was the combination of (i) the historical data owned by Peutz & Associés and (ii) extra

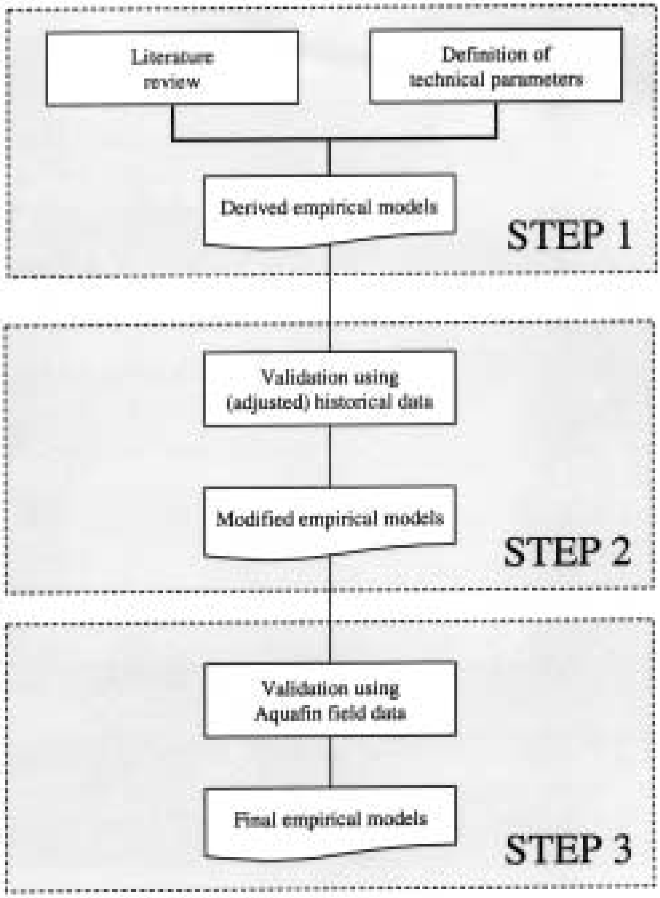

Figure 1 Schematic of the methodology to derive and validate the empirical models

data collected at Aquafin WWTPs. The methodology considered 3 steps which are shown schematically in Figure 1 and described below.

STEP 1: A first derivation of empirical models was made. This derivation was based on: (i) empirical models described in literature, (ii) knowledge about relevant technical parameters of the process units and (iii) practical experience.

STEP 2: The models obtained in STEP 1 were validated using the historical data. For this, the historical data were, where necessary, adjusted for the typical configuration of process units at WWTPs of Aquafin. Based on this evaluation, the empirical models obtained in STEP 1 were eventually modified.

STEP 3: The models obtained in STEP 2 were validated using field data obtained at Aquafin WWTPs. For this, the sound characteristics of the process units at 6 Aquafin WWTPs were measured. Based on this validation, the models obtained in STEP 2 were eventually modified.

Sound calculations

The (i) correction of the historical data set and (ii) calculation of the immission relevant sound power level from the measured or calculated sound pressure levels or vice versa were based on the methods described by VROM (1981). These methods are based on the relevant ISO standards (ISO 3740, ISO/DIS 3744.2, ISO 3746, ISO 4872 and ISO/DIS 3989.1).

Basically, the calculation of the sound power level is based on the relationship (Maling *et al.*, 1992):

$$L_W = L_{p,S} + 10 \log S \qquad (1)$$

where L_W: sound power level (dB(A))
$L_{p,S}$: sound pressure level averaged on a mean-square basis over measurement surface (dB(A))
S: area of measurement surface (m^2)

The immission relevant sound power level $L_{W,R}$ equals L_W in the case of omnidirectional sound sources. For directional dependent sound sources a correction (directivity index) is taken into account as described in the Step 1 example for the splashing water of screw pumps.

Sound measurements

All measurements were performed as much as possible according to ISO 2204-1973, ISO 140/V and according to the guidelines given by VROM (1981). Measurements were performed using the following equipment: precision sound level meter RION NL 11 with microphone RION UC-53 and wind shield, sound calibration source Bruël & Kjaer 4230, digital audio tape recorder Sony DTC-D10. Figure 2 illustrates the performance of a measurement. The computerised analysis of the measurements in the acoustical lab was done using the following equipment: digital audio tape recorder Sony DTC-55ES, level recorder Bruël & Kjaer 2307, real time analyze Nortronic 830 and band pass filter Bruël & Kjaer 1615.

Results and discussion

In this paper, the derivation and validation of an empirical model and the boundary conditions for its use are only illustrated for the sound produced by the splashing water of screw pumps. In addition, an example is given of the calculation of the sound impact of a WWTP at close distance using all derived empirical models.

Figure 2 Illustration of the measurement of the overflow weir in the oxidation ditch of the WWTP of Boom

Screw pumps (splashing water) – STEP 1

The basic equation for the derivation of the empirical model was Equation 1.

In practice, the minimal sound pressure levels nearby screw pumps varies in the range between 80–86 dB(A). Also a threefold increase of the rotational speed of screws results in an increase of the sound pressure level of 5–6 dB(A). Therefore, Equation 1 was modified to:

$$L_W = 80 + 10 \log S + 10 \log (N/N_{min}) \tag{2}$$

where N: Rotational speed of the screws (rpm)
N_{min}: Minimum rotational speed (rpm)
S: Area of the surface considered nearby the screws, including the influent pit (m^2).

Considering that the minimum rotational speed is about 20 rpm, Equation 2 becomes:

$$L_W = 67 + 10 \log (N \times S) \tag{3}$$

Equation 3 can be considered as a simplified version of the model given by Schuller (1981). Considering the typical configuration of influent screws (Figure 3), the immission relevant sound power level $L_{W,R}$ can be calculated using:

$$L_{W,R} = L_W + DI \tag{4}$$

where DI: Directivity index (dB(A)).

The directivity index DI depends on the angle between the screw pumps and the considered immission point (Figure 4, Table 1). This dependency is based on the principles given by VROM (1981).

Screw pumps (splashing water) – STEP 2

The historical data set contained 25 relevant measurements. Figure 5 shows the fit of

Figure 3 Illustration of the sound measurements and typical configuration of screw pumps at the WWTP Hove (to be renovated)

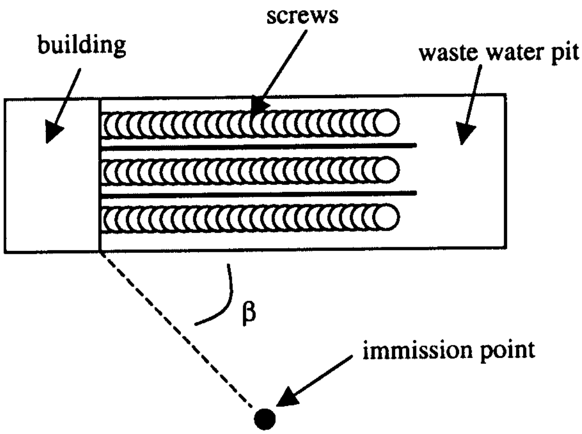

Figure 4 Top view of a screw pump configuration with definition of the angle β for calculation of the directivity index DI (Table 1) (VROM, 1981)

Table 1 Dependency of the directivity index DI (Equation 4) on the angle β between screw pumps and immission point (Figure 4) (VROM, 1981)

β (°)	DI (dB(A))
0–85.0	3
88.6–132.5	3–10 log (0.4 × (β–90) + 3)
≥ 132.5	–10 to –20

Equation 3 to this historical data and illustrates the validity of Equation 3. Making a linear regression of the historical data results in a model comparable to Equation 3:

$$L_W = 68 + 10 \log (N \times S) \tag{5}$$

Therefore, it was concluded that no modification of Equation 3 was required on the basis of the historical data.

Screw pumps (splashing water) – STEP 3

To validate Equation 3 to field data of Aquafin WWTPs, the sound power level of in total 12 screw pumps at 6 Aquafin WWTP's was determined. Figure 4 illustrates the fit of Equation 3 to this field data. Based on these results Equation 3 could be accepted as valid for description of the sound power level of screw pumps at Aquafin WWTPs.

Prediction of the overall impact of a WWTP

Not all derived and validated empirical models are described in this paper (see Introduction). Yet, it can be illustrated that, combining all the derived empirical models, the sound impact of a WWTP on residential areas can already be evaluated using simple acoustical calculation principles. The latter is illustrated in Figure 6 and Table 2 for the WWTP of Landen. The total predicted sound pressure level (L_p) at the border of the WWTP is 60 dB(A). The measured L_p value corresponds to 59 dB(A). The prognosis of the sound impact can be further refined at longer distance using the spectral characteristics of the sound power of the different process units in combination with more complicated calculation methods for sound propagation.

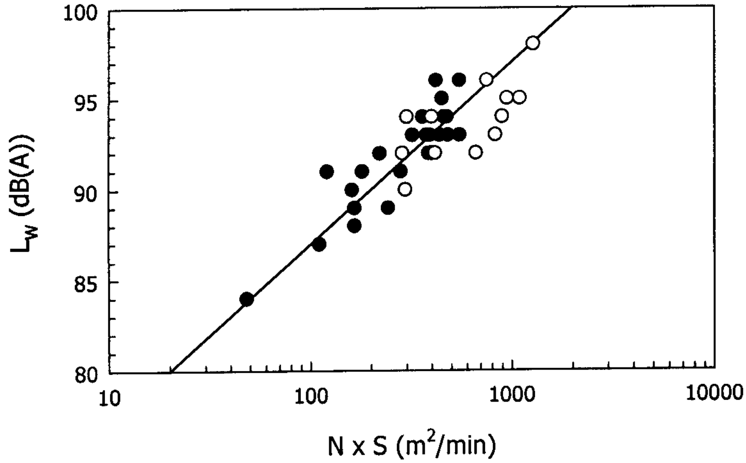

Figure 5 The sound power level (L_W) of the splashing water of a screw pump (—) (Equation 3) in comparison to the (corrected) historical data owned by Peutz & Associés (●) and the field data measured at the Aquafin WWTP's (O)

Conclusions

Empirical models were derived and validated for prognosis of the sound power for the most relevant sound sources in the water line of an Aquafin WWTP. The methodology used for model derivation and validation allowed us to minimize the required number of measurements by combination of available (corrected) historical data and new field data collected at Aquafin WWTPs. The use of the empirical models allows us to make a prediction of the sound impact of a wastewater treatment using both simple and advanced acoustical calculation principles.

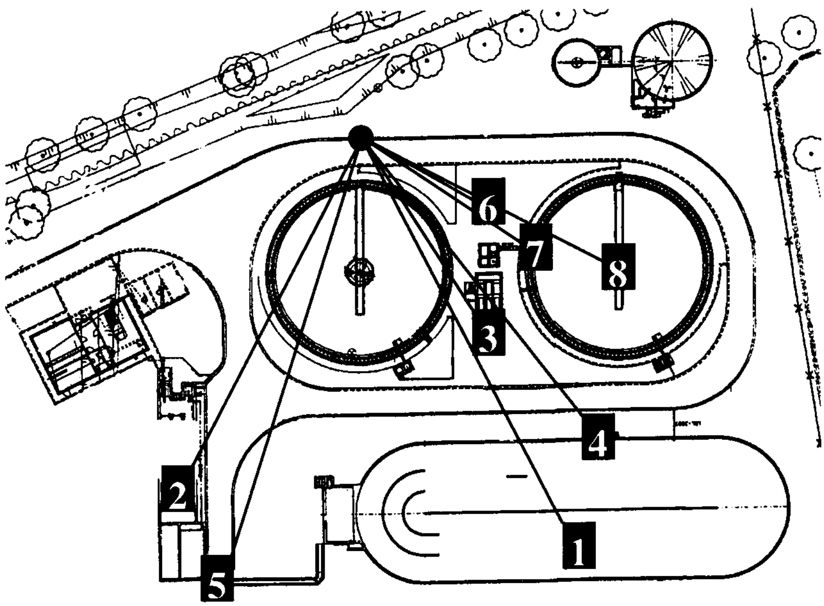

Figure 6 Lay-out of the WWTP of Landen with location of the immision point (●) and the different sound sources and considered in Table 2: (1) areator, (2) screw pump, (3) screw pump, (4) overflow weir, (5) overflow weir, (6) overflow weir and (7) overflow weir

Table 2 Prediction of the sound pressure level (L_p) at the border of the WWTP of Landen (Figure 6)

Sound source	*R* (m)	$L_{W,R}$ dB(A)	DI dB(A)	A_{geo} dB(A)	A_{gr} dB(A)	L_p dB(A)
1. aerator	65	101	0	45	1	55
2. screw pump	58	96	3	44	1	54
3. screw pump	33	92	3	39	0	56
4. overflow weir	55	80	0	44	1	35
5. overflow weir	65	83	0	45	1	37
6. overflow weir	21	88	0	35	0	53
7. overflow weir	29	57	0	38	0	19
8. overflow weir	42	74	0	41	0	33
					Total: 60	

R: Distance from the immission point to sound source
DI: Directivity index of the sound source
A_{geo}: Sound attenuation due to geometrical divergence
A_{gr}: Sound attenuation due to ground effects
L_p: Sound pressure level at the immission point = $L_W + DI = A_{geo} = A_{gr}$

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