TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of environmental sciences, department of hydrosciences

Institute of residential and industrial water management, professor of urban water management

FINAL REPORT

Verification of investigation studies of air diffusers from Prodeko-Elk Sp. z o.o.

Dresden, February 2016

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Final report

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Dresden, 25.02.2016

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1 Purpose and scope

The air diffusers of the firm Prodeko-Elk have already been evaluated extensively in the context of oxygen transfer and pressure loss tests at a test station of the Institute for residential and industrial water management of the TU Dresden.

For the scientific verification further tests will be carried out with a tube aerator with a length of 2.06 m. The oxygenation capacity, the specific oxygen transfer rate and transfer efficiency as well as separately the amount of pressure loss depending on airflow were identified.

The firm Prodeko-Elk (AG) (Corp.) commissioned the Institute for residential and industrial water management of the TU Dresden (AN) (contractor) with the execution of the appropriate tests.

2 Principles and test execution

2.1 Aeration elements

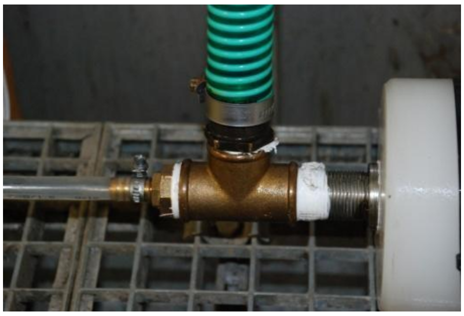
The to-be-examined aeration element is to be classified as tube aerator and it shows the characteristics summarized in the table 2-1. The tube aerator consists of an outer fiber pipe made of polyethylene and a perforated inner pipe made of PVC. The general lengths of the equipment amount approximately 1.0 and 2.0 m. Considering the design of the test reactor the effective length of the aerator has been reduced to 27.5 cm. The AG was informed in advance about the related restriction on the transferability due to the pressure distribution in the pipe and therefore the equal distribution of gas distribution.

Table 2-1: Properties of the aeration element

Property	The firm Prodeko Elk
Diameter	120 mm
Material	Polyethylene and PVC
Length (total / effective)	206.6 cm / 193.4 cm
Connection	External threads made of metal 3/4"
Check valve	no
Range of the evaluation for oxygen transfer tests according AG	8-24 Nm^3/aerator

The to-be-examined aeration element has been installed comparable with previous tests on the air pipe and it has been attached to the floor panel. The connection of the pressure loss measurement was made in the same way (table 2-2).

Table 2-2: Photo documentation of the aeration element

Aerator	Photo documentation
Top view	
Side view	
Detail	

2.2 Test reactor

The test reactor with the set-up of the tube aerator and the measurement points for airflow, pressure and oxygen are shown in figure 2-1. At a length of 3.24 m and a width of 0.79 m with an effective length of 1.934 m of the AE the occupancy rate is approx. 0.285 m²/m² and 0.756 m/m². The reactor shows in all tests an identical water level h_{ges} of approx. 2.37 m and thus has a volume of approx. 6.07 m³.

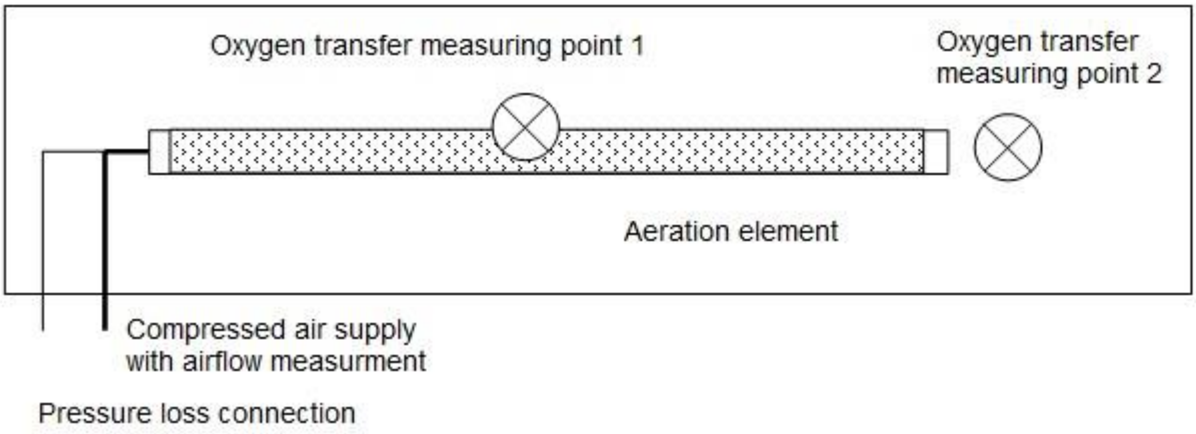


Figure 2-1: Test reactor with aeration element and measuring points for airflow, pressure and oxygen

The control of the airflow rate is carried out with two MFC-controller units ('mass flow control') of the firm Bürkert in a range of 0 to 12 Nm³/h which are connected with a T-connector and thus have an airflow range of 0-24 Nm³/h.

2.3 Experimental procedure oxygen transfer

The oxygen transfer tests were carried out in accordance with the German DWA M 209 (2007) guideline as absorption tests under clean water conditions. For the tests the cobalt chloride-hexahydrate catalyst was added in advance. Due to the use of drinking water and a basin volume of approx. 6.1 m³ the added amount was 1.2 g. The needed amount of approx. 1.0 kg of dissolved sodium sulfite for the oxygen binding and an appropriate lead time was added prior to each test.

The oxygen transfer tests for the aeration element were carried out in case of 3 airflows of 8, 16 and 24 Nm³/h. This was followed by temperature and salt content normalization as well as by the calculation of the specific input values.

The oxygen concentrations were recorded continuously with in the interval of 10 seconds on the measuring points shown in figure 2-1. Over the blow-in depth of approx. 2.22 m per each measuring points 2 oxygen probes (HQ 40D MULTI made by the firm Hach-Lange) were installed (depth distribution of the probes, see table 2-3).

Table 2-3: Depth distribution of the oxygen probes and conductivity probe

Measuring point	Probe number	Probe type	Immersion depth of the probe
1	1	LDO (Hach-Lange)	0.7 m
	2		1.4 m
2	1		0.7 m
	2		1.4 m

The transfer tests were carried out in accordance with the German DWA-Merkblatt (Instruction sheet) M-209 (2007) by measuring the $k_L a$ -values and oxygen supply.

The following diagrams describe examples of the evaluation as well as the calculation of the oxygen transfer values. Figure 2-2 shows by way of example the increase of the oxygen concentration of the oxygen probe 1 on the measuring point 1 in the clean water test in case of an airflow of 16 Nm³/h as well as of the test saturation value.

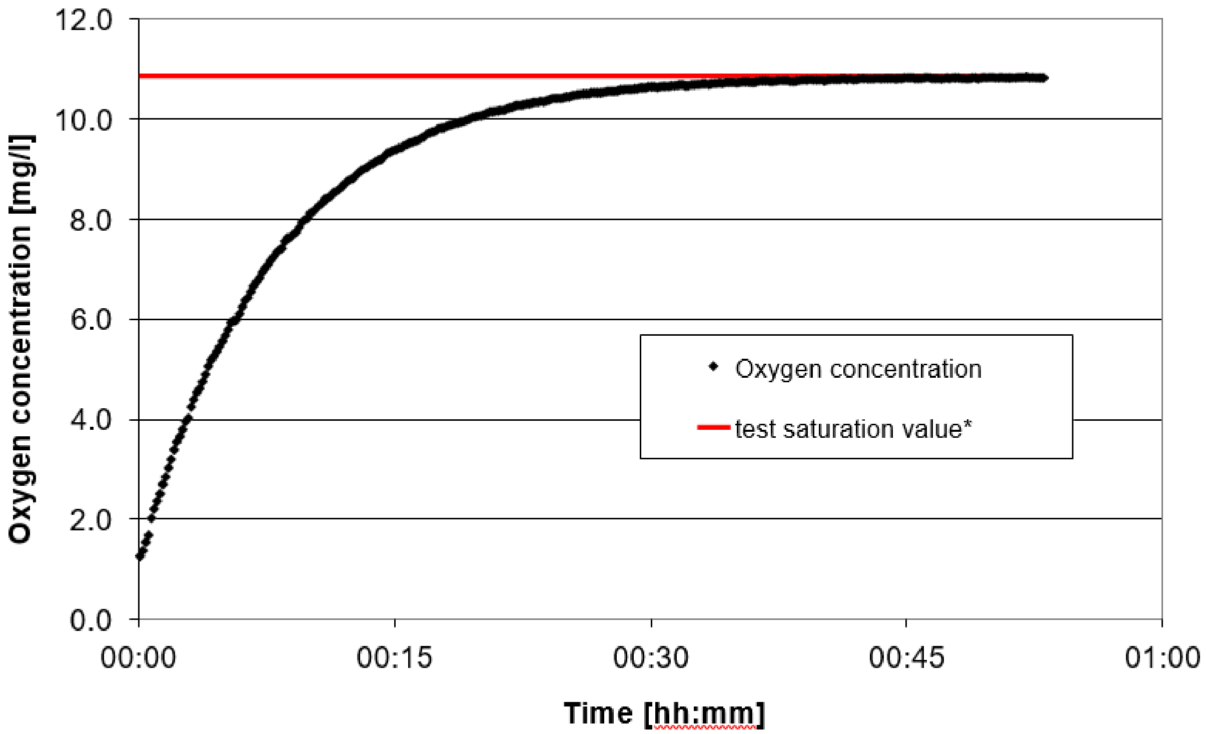


Figure 2-2: Oxygen concentration behavior of the probe 1 on the measuring point 1 of the test with 16.0 Nm³/h

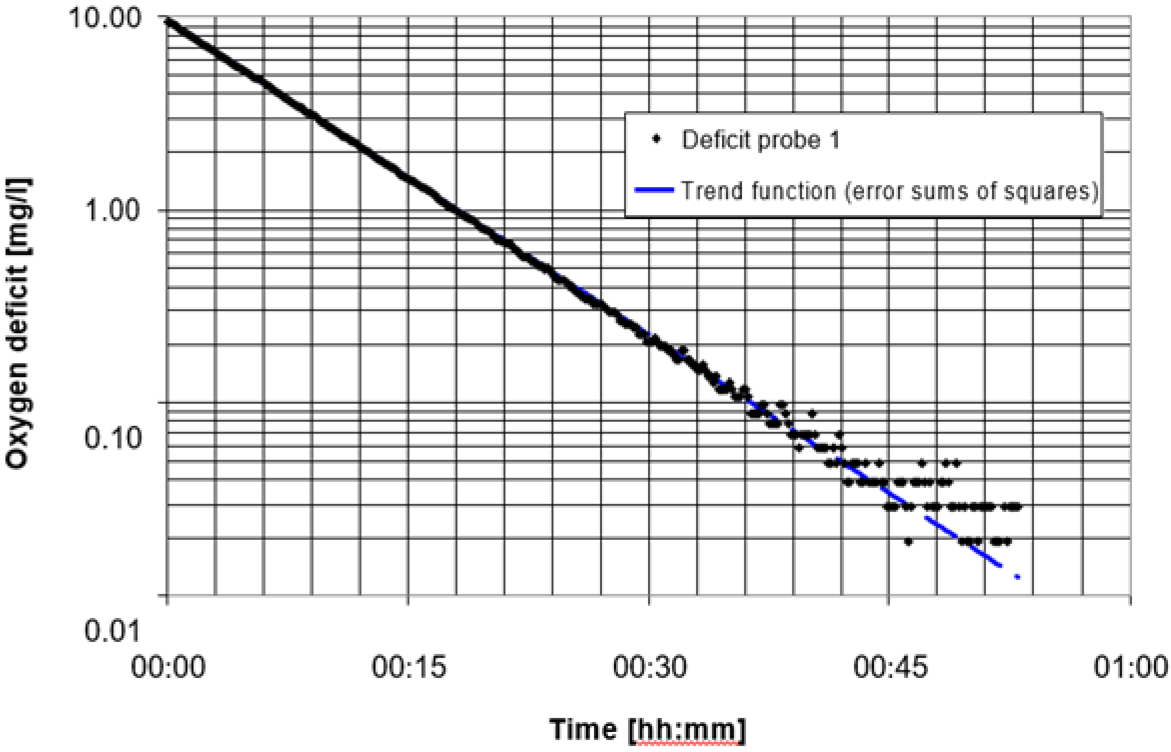


Figure 2-3: Oxygen deficit of the probe 1 on the measuring point 1 of the test with 16.0 Nm³/h

The semi-logarithmic scale of the oxygen deficit is shown in the figure 2-3. The reduction of the deficit follows an exponential function of the form $y = a \cdot e^{(b \cdot x)}$. For the measurement of the increase a trend function was determined based on the sum of square of errors and it was used for additional calculations.

The evaluation of the oxygen deficit for determination of the $k_L a$-value requires a random distribution of the residuals of the oxygen concentration of the actual values of the trend function. Figure 2-4 shows the course of the residuals. Considering the distribution of the residuals systematic similarities are almost impossible to detect, which are indicating a systematic error in the logging process of the measurement value. Therefore the oxygen transfer test can be evaluated mainly on the basis of slight deviations.

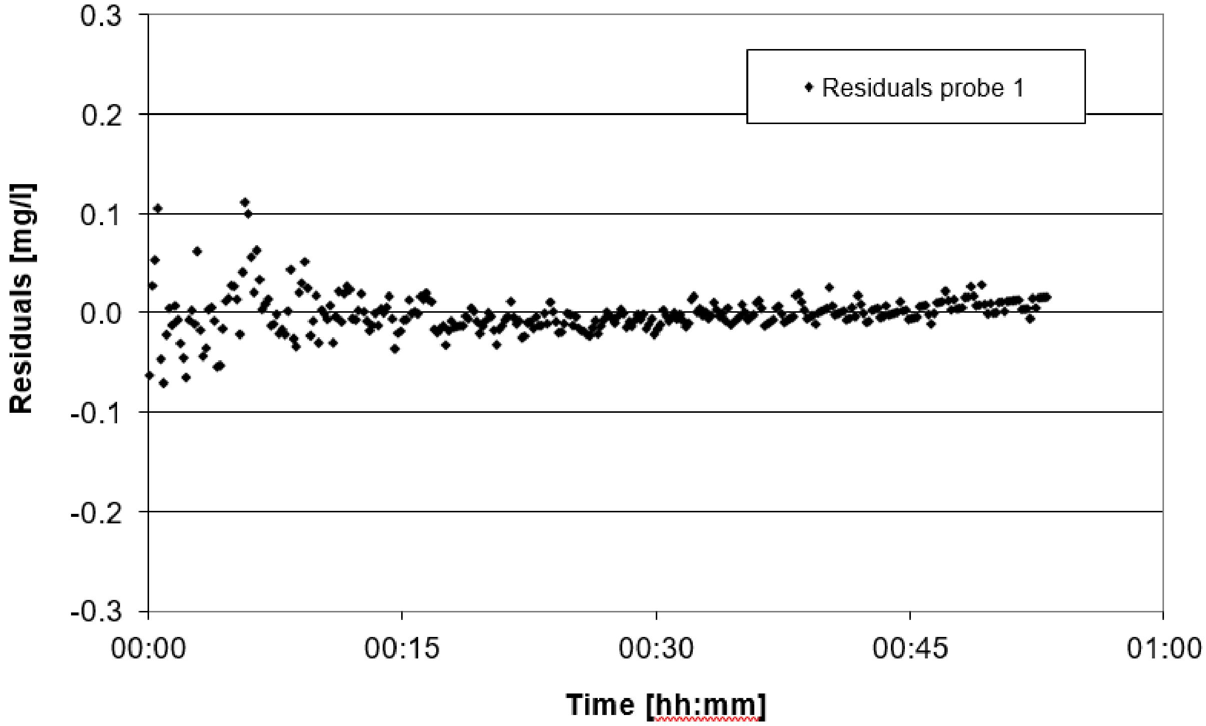


Figure 2-4: Residuals of the probe 1 on the measuring point 1 of the test with 16.0 Nm³/h

The k_La-value is calculated from the trend function in accordance with the German DWA M 209 (2007) guideline:

$$k_La = 2.303 \cdot 60 \cdot \log_{10} \cdot (c_s - c_1) - \log_{10}(c_s - c_2)/(t_2 - t_1) \qquad [1/h]$$

The normalization on 20°C follows the average temperature during the test:

$$k_La_{20} = k_La \cdot 1.024^{(20-T)} \qquad [1/h]$$

The normalization based on the salt content and the mean conductivity shall be performed using the following formula:

$$k_La_{20,1000} = 1.1 \cdot k_La_{20}/(1 + 0.1 \cdot (2 \cdot LF/3)/1000) \qquad [1/h]$$

The oxygen saturation value is calculated with the average temperature and the blow-in depth as well as the distance between aeration element and water level surface, which is needed for the SOTR-determination:

$$c_{s,20} = 2234.34/((20 + 45.93)^{1.31403} \qquad [mg/l]$$

$$c_{s,md,20} = c_{cs,20} \cdot (1 + h_D/(2 \cdot 10.35)) \qquad [mg/l]$$

Based on the following formula the oxygen transfer for 20°C and a salt content of 1.0 g/l is calculated by:

$$SOTR_{20.1000} = V_{Tank} \cdot k_La_{20.1000} \cdot c_{s,md,20}/1000 \qquad [kg\ O_2/h]$$

The evaluation of the oxygen supply and the oxygen yield should be performed with normalization via the airflow and the input energy:

$$SSOTR_{20.1000} = SOTR_{20.1000} \cdot 1000/(Q_{air} \cdot h_D) \qquad [g/(Nm^3 \cdot m)]$$

$$SSOTE_{20.1000} = SOTR_{20.1000} \cdot 100/(Q_{air} \cdot h_D \cdot 0.299) \qquad [\%/m]$$

It is fundamental to ensure, that the available test time for evaluation is higher than the 1.5-fold of the t_{90} time, as well as higher than $60 \cdot 3.5/k_L a$ (see DWA M-209, 2007). This was given in case of all tests.

2.4 Experimental procedure for the determination of the pressure loss

For the determination of the pressure loss of the aeration element this has been installed in the test reactor (see figure 2-1). In the course of this the pressure loss is determined for the whole range of the airflow from 6.0 to 24 Nm³/h.

For the evaluation of the pressure loss in case of various air supplies a U-tube manometer has been installed over the pressure loss connection for determining the pressure level in meter of water column (see table 2-2 and figure 2-1).

The schematic structure of the U-tube manometer and the practical implementation during the air supply are shown in figure 2-5. It shows the mounted air vent at the highest point after the connection to the air duct, the measuring scale as well as the adjacent air pressure as difference of water levels in m H_2O (water column). The difference between water levels and the height of the water column above the aeration element in the aeration basin's at-rest water level is the pressure loss calculated in m H_2O.

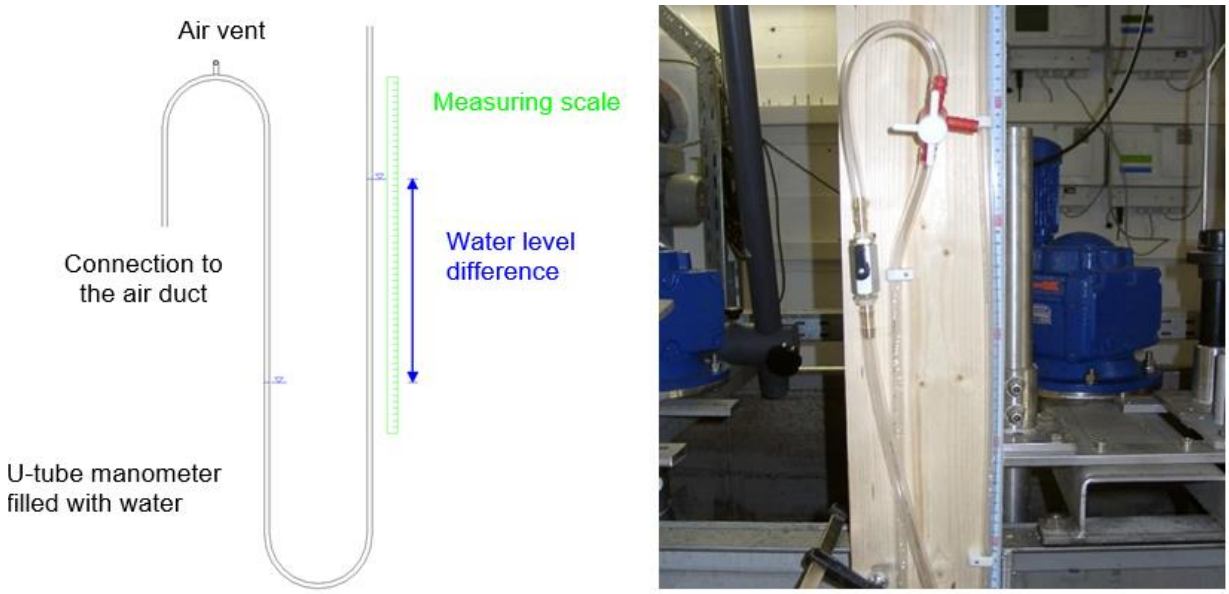


Figure 2-5: Schematic structure of the U-tube manometer and practical implementation

3 Results and evaluation of the oxygen transfer tests

3.1 General remarks

The oxygen transfer tests and the corresponding evaluations are described in chapter 2.3.

In the following the results for all airflow rates are presented. The data, calculation tables and graphical evaluations are to be found in the appendix.

With due regard to the semi-industrial test facility and the theoretically insufficient distance of the probes from the wall of the basin acceptable and evaluable courses of the residuals appear in accordance with DWA M-209 (2007).

For a qualitative evaluation of results the test with 24 Nm³/h was carried out as a duplicate determination.

3.2 Results in case of an airflow of 8 Nm³/h

The evaluation and calculation of the oxygen transfers under clean water conditions of the aeration element in case of an air volume flow of 8 Nm³/h are shown in table 3-1.

Table 3-1: Calculation tables in case of an airflow of 8 Nm³/h

Parameter	Unit	MS1_S1	MS1_S2	MS2_S1	MS2_S2	MW	SA	A
V	m³	6,07	6,07	6,07	6,07	6,07		
$k_L a$	1/h	4,317	4,303	4,296	4,305	4,30	0,008	0,2%
T_{avg}	°C	12,58	12,60	12,64	12,63	12,61	0,023	0,2%
$k_L a_{20}$	1/h	5,15	5,13	5,12	5,13	5,13	0,011	0,2%
LF	µS/cm	1711	1711	1711	1711	1711		
$k_L a_{20,1000}$	1/h	5,08	5,06	5,05	5,06	5,06	0,011	0,2%
h_D	m	2,224	2,224	2,224	2,224	2,224		
$c_{s,md,20}$	mg/l	10,07	10,07	10,07	10,07	10,07		
$SOTR_{20,1000}$	kg/h	0,311	0,310	0,309	0,309	0,310	0,001	0,2%
Q_{Air}	Nm³/h	8,00	8,00	8,00	8,00	8,00		
$SSOTR_{20,1000}$	g/(Nm³·m)	17,46	17,40	17,35	17,39	17,40	0,039	0,2%
$SSOTE_{20,1000}$	%/m	5,84	5,82	5,80	5,82	5,82	0,013	0,2%

An average oxygen transfer rate of 0.310 kg O_2/h appears in case of a percentage standard deviation of 0.2 % in accordance with table 3-1. The corresponding specific oxygen transfer rate is 17.4 g/(Nm³·m) and the specific oxygen transfer efficiency is 5.82 %/m.

3.3 Results in case of an airflow of 16 Nm³/h

The evaluation and calculation of the oxygen transfers under clean water conditions of the aeration element in case of an airflow of 16 Nm³/h are shown in table 3-2. Because of the data logging issues of the oxygen probe 2 on the measuring point 2, 3 probes are available for evaluation.

An average oxygen transfer rate of 0.571 kg O_2/h appears in case of a percentage standard deviation of 0.1 % in accordance with table 3-2. The corresponding specific oxygen transfer rate is 16.04 g/(Nm³·m) and the specific oxygen transfer efficiency is 5.36 %/m.

Table 3-2: Calculation tables in case of an airflow of 16 Nm³/h

Parameter	Unit	MS1_S1	MS1_S2	MS2_S1	MS2_S2	MW	SA	A
V	m³	6,07	6,07	6,07		6,07		
$k_L a$	1/h	7,525	7,515	7,519		7,52	0,004	0,1%
T_{avg}	°C	11,09	11,04	11,00		11,05	0,037	0,3%
$k_L a_{20}$	1/h	9,30	9,29	9,31		9,30	0,006	0,1%
LF	µS/cm	1434	1434	1434		1434		
$k_L a_{20,1000}$	1/h	9,33	9,33	9,34		9,34	0,006	0,1%
h_D	m	2,225	2,225	2,225		2,225		
$c_{s,md,20}$	mg/l	10,07	10,07	10,07		10,07		
$SOTR_{20,1000}$	kg/h	0,571	0,571	0,571		0,571	0,0004	0,1%
Q_{Air}	Nm³/h	16,00	16,00	16,00		16,00		
$SSOTR_{20,1000}$	g/(Nm³·m)	16,03	16,03	16,05		16,04	0,010	0,1%
$SSOTE_{20,1000}$	%/m	5,36	5,36	5,37		5,36	0,004	0,1%

3.4 Results in case of an airflow of 24 Nm³/h as a duplicate determination

The evaluations and calculations of the oxygen transfers under clean water conditions of the aeration element in case of an airflow of 24 Nm³/h are shown as a duplicate determination in table 3-3 and table 3-4. Because of the data logging issues of the oxygen probe 2 on the measuring point 2, 3 probes are available for evaluation in case of the first test.

Table 3-3: Calculation tables in case of an airflow of 24 Nm³/h

Parameter	Unit	MS1_S1	MS1_S2	MS2_S1	MS2_S2	MW	SA	A
V	m³	6,07	6,07	6,07		6,07		
$k_L a$	1/h	10,740	10,760	10,751		10,75	0,008	0,1%
T_{avg}	°C	10,89	10,82	10,80		10,84	0,037	0,3%
$k_L a_{20}$	1/h	13,33	13,38	13,37		13,36	0,021	0,2%
LF	µS/cm	1120	1120	1120		1120		
$k_L a_{20,1000}$	1/h	13,65	13,69	13,69		13,68	0,021	0,2%
h_D	m	2,225	2,225	2,225		2,225		
$c_{s,md,20}$	mg/l	10,07	10,07	10,07		10,07		
$SOTR_{20,1000}$	kg/h	0,835	0,837	0,837		0,836	0,0013	0,2%
Q_{Air}	Nm³/h	24,0	24,0	24,0		24,00		
$SSOTR_{20,1000}$	g/(Nm³·m)	15,63	15,68	15,68		15,66	0,024	0,2%
$SSOTE_{20,1000}$	%/m	5,23	5,24	5,24		5,24	0,008	0,2%

Due to the occurring discrepancy significantly below of 1% in case of the duplicate determination both tests were averaged. This shows the available data quality for both tests.

An average oxygen transfer rate of 0.839 kg O_2/h appears in case of a percentage standard deviation of 0.2 % in accordance with table 3-3 and table 3-4. The corresponding specific oxygen transfer rate is 15.72 g/(Nm³·m) and the specific oxygen transfer efficiency is 5.26 %/m.

Table 3-4: Calculation tables in case of an airflow of 24 Nm³/h (Duplicate determination)

Parameter	Unit	MS1_S1	MS1_S2	MS2_S1	MS2_S2	MW	SA	A
V	m³	6,07	6,07	6,07	6,07	6,07		
$k_L a$	1/h	11,993	11,963	11,987	11,927	11,97	0,026	0,2%
T_{avg}	°C	12,76	12,80	12,80	12,80	12,79	0,017	0,1%
$k_L a_{20}$	1/h	14,24	14,19	14,22	14,15	14,20	0,034	0,2%
LF	µS/cm	2012	2012	2012	2012	2012		
$k_L a_{20,1000}$	1/h	13,81	13,76	13,79	13,72	13,77	0,033	0,2%
h_D	m	2,224	2,224	2,224	2,224	2,224		
$c_{s,md,20}$	mg/l	10,07	10,07	10,07	10,07	10,07		
$SOTR_{20,1000}$	kg/h	0,844	0,841	0,843	0,839	0,842	0,0020	0,2%
Q_{Air}	Nm³/h	24,0	24,0	24,0	24,0	24,00		
$SSOTR_{20,1000}$	g/(Nm³·m)	15,82	15,76	15,79	15,72	15,77	0,038	0,2%
$SSOTE_{20,1000}$	%/m	5,29	5,27	5,28	5,26	5,28	0,013	0,2%

3.5 Summary of the results

An average oxygen transfer rate of 0.310 kg O_2/h appears in case of 8 Nm³/h, 0.571 kg O_2/h in case of 16 Nm³/h and 0.839 kg O_2/h in case of 24 Nm³/h in accordance with table 3-5. The corresponding specific oxygen transfer rates are 17.40 g/(Nm³·m), 16.04 g/(Nm³·m) and 15.72 g/(Nm³·m). The specific airflows are the result of the effective length of the aeration and the diameter of the air diffuser.

Table 3-5: Calculation tables of oxygen transfers in case of various airflows

Parameter	Unit	Q_A = 8 Nm³/h	Q_A = 16 Nm³/h	Averge value Q_A = 24 Nm³/h
$Q_{A,spec\_1}$	Nm³/(m·h)	4,1	8,3	12,4
$Q_{A,spec\_2}$	Nm³/(m²·h)	11,0	21,9	32,9
$SOTR_{20,1000}$	kg/h	0,310	0,571	0,839
$SSOTR_{20,1000}$	g/(Nm³·m)	17,40	16,04	15,72
$SSOTE_{20,1000}$	%/m	5,82	5,36	5,26

The overall results of the examination are shown in figure 3-1 as an average value of the specific oxygen transfer rate depending on the specific airflow rate per m of the air diffuser. A functional correlation appears of a high coefficient of determination between airflow rate and the specific oxygen transfer rate.

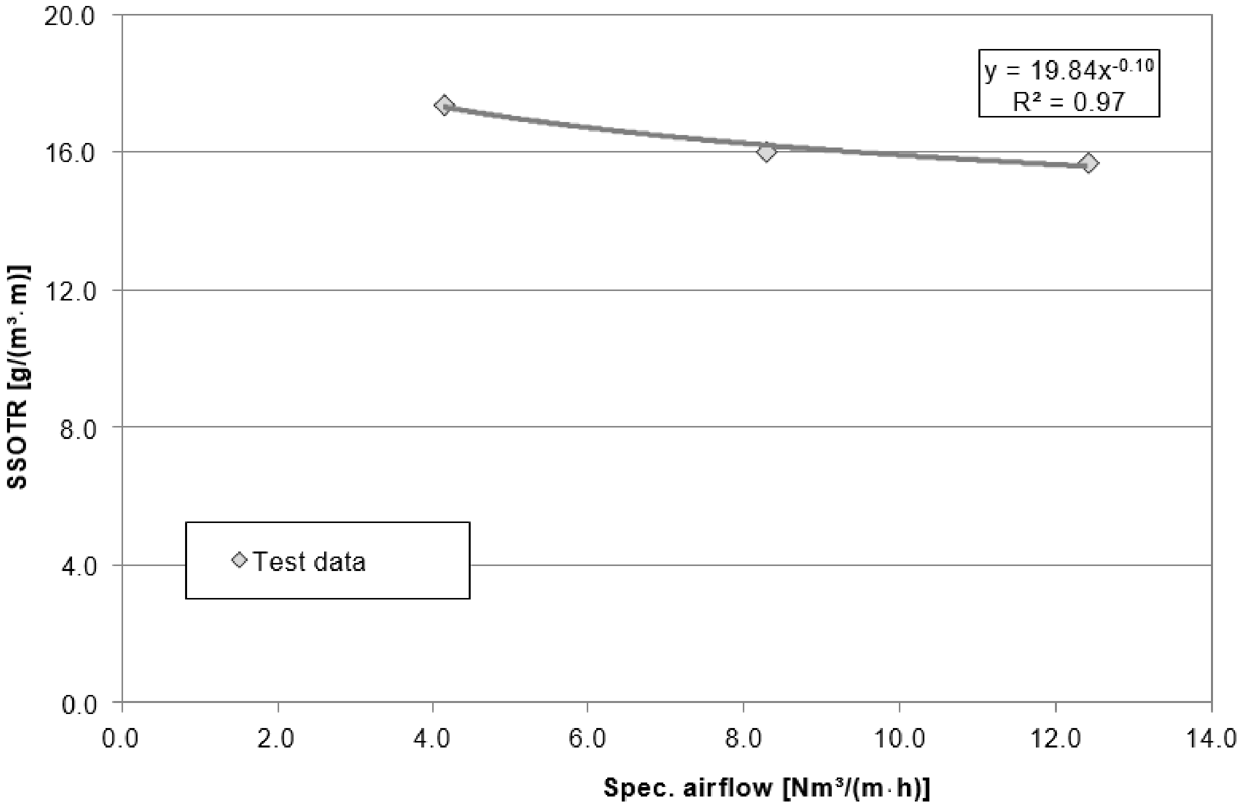


Figure 3-1: Results of specific oxygen transfer rate depending on the specific airflow rate per m of the air diffuser

The results are shown in figure 3-2 as an average value of the specific oxygen transfer efficiency per m of the air diffuser. A functional correlation appears in case of a high coefficient of determination between airflow rate and the specific oxygen transfer efficiency.

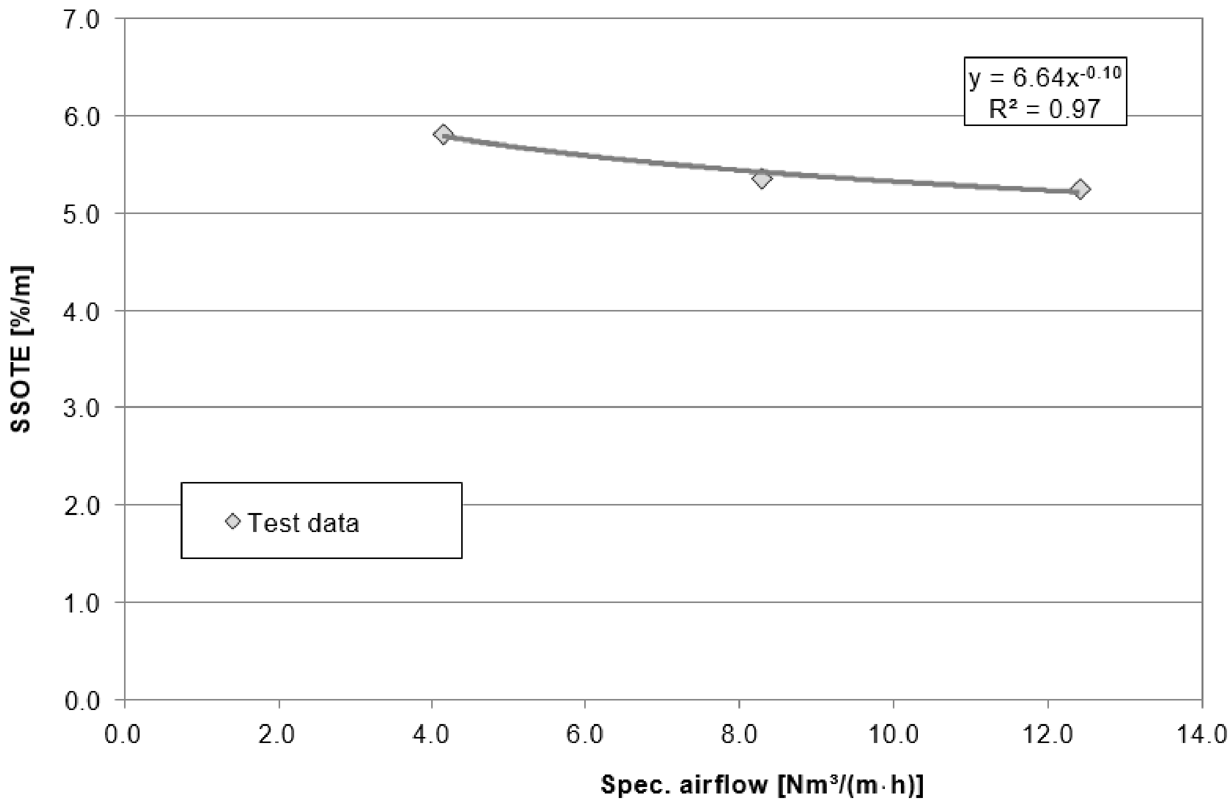


Figure 3-2: Results of specific oxygen transfer efficiency depending on the specific airflow rate per m of the air diffuser

4 Results and evaluation of the determination of the pressure loss

The procedure for the determination of the pressure loss is described in chapter 2.4.

Figure 4-1 shows the summarized results of the determination of the pressure loss depending on the specific airflow rate. In case of higher airflows the pressure losses are increasing exponentially.

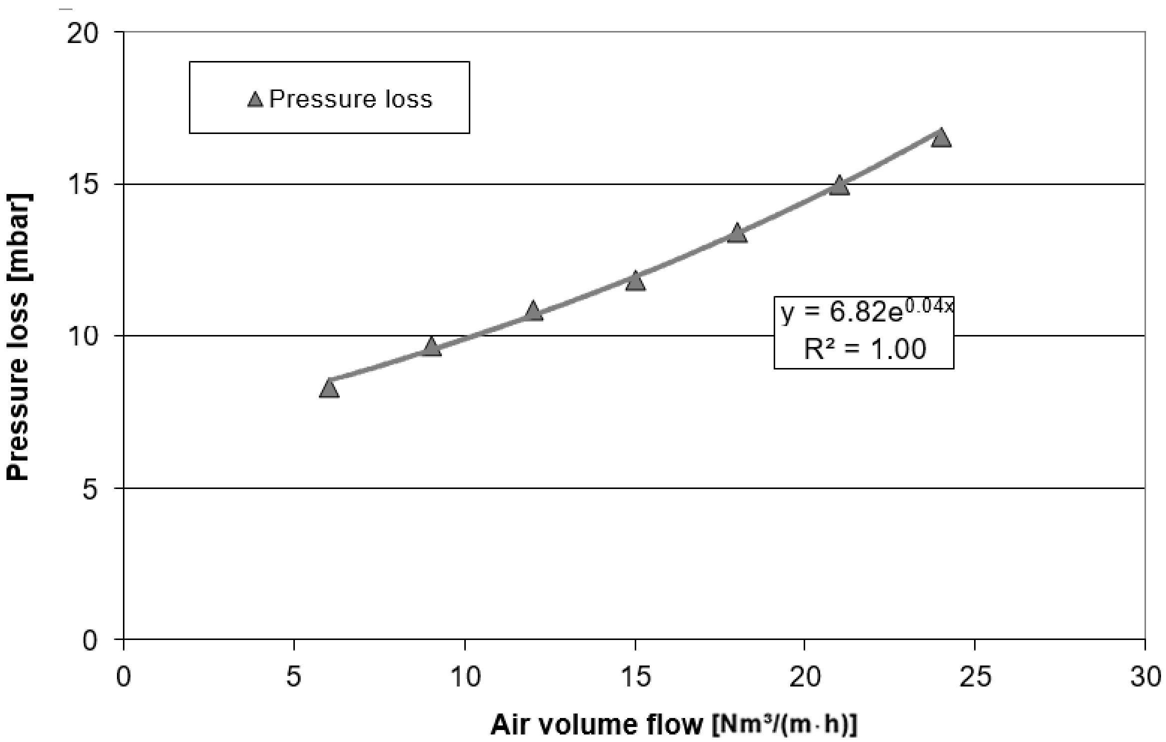


Figure 4-1: Results of the pressure loss depending on the specific airflow rate.

5 Summary

During the investigation, depending on the airflow rate, the oxygen transfer and the pressure loss of the aeration tubes of the firm Prodeko-Elk with an effective length of 1.93 m were determined. The determination of the oxygen transfer was made on the basis of the current DWA-Merkblatt (Instruction sheet) M 209 (2007) in case of airflow rates of 8, 16 and 24 Nm³/h. The quality of data turned out - due to the positive evaluation of the residuals for the further calculation of the specific values - as sufficient. The functional correlation between specific input values, like oxygen transfer rate and oxygen transfer efficiency as well as airflow, have been comprehensively documented.

The pressure loss of the airflow in a range from 6 to 24 Nm³/h has been confirmed and it has been demonstrated trough a functional correlation.

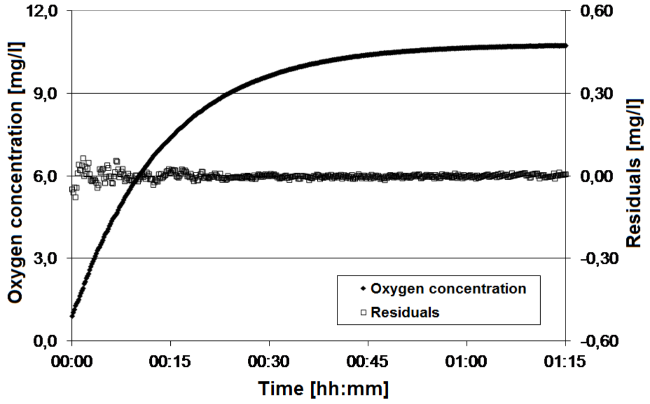
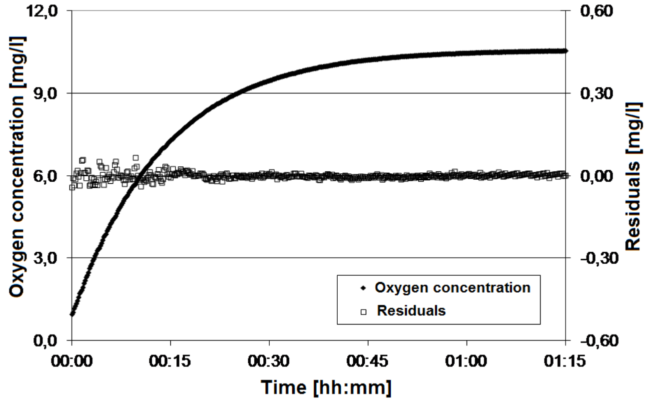
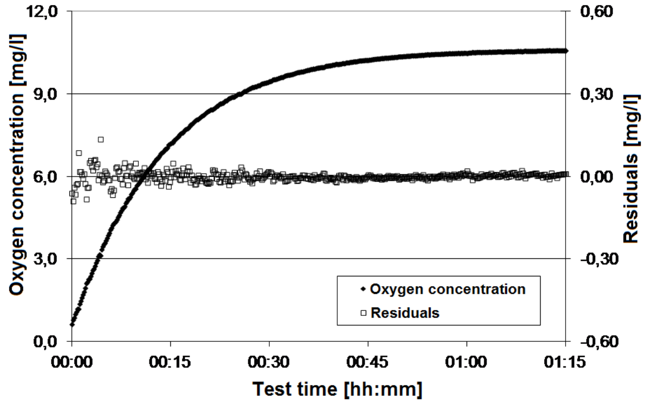
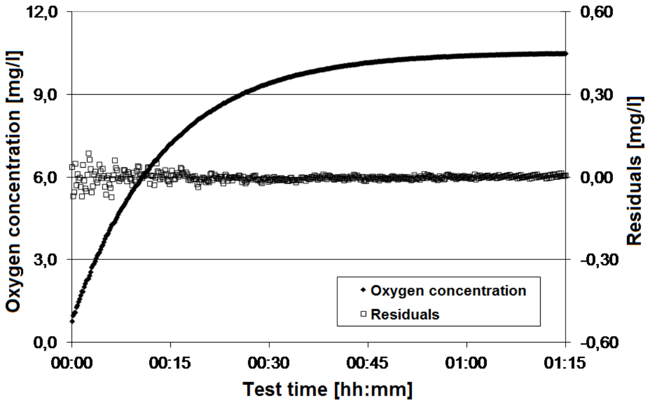
Signs of aging and various material changes cannot be evaluated based on this examination.

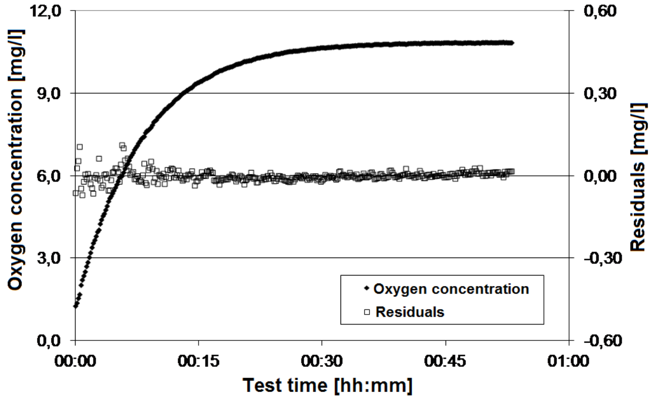
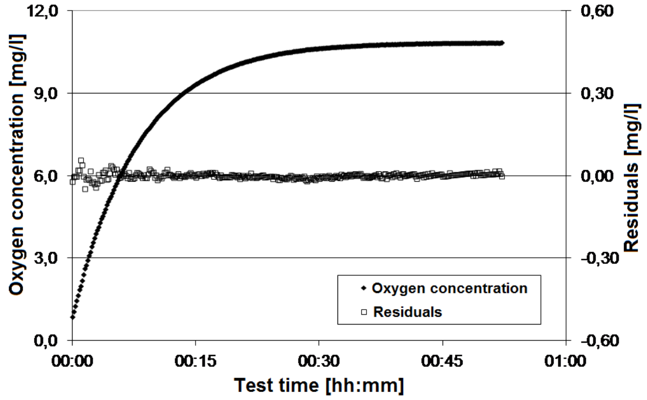
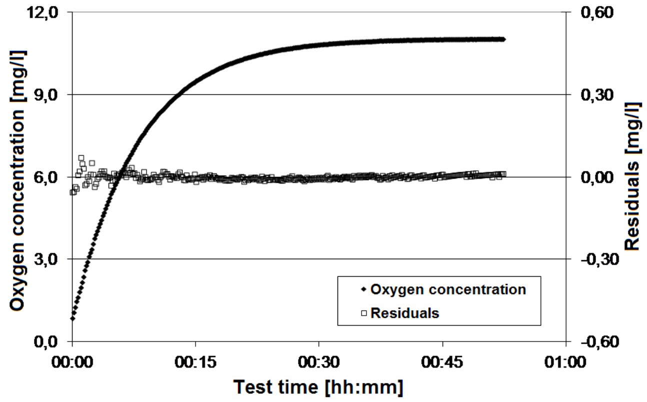
The tested tube aerator with a length of 1.93 m shows for the specific oxygen transfer efficiency a range of approx. 5-6 % and it is in the range of the already tested tube aerator with a length of 0.275 m.

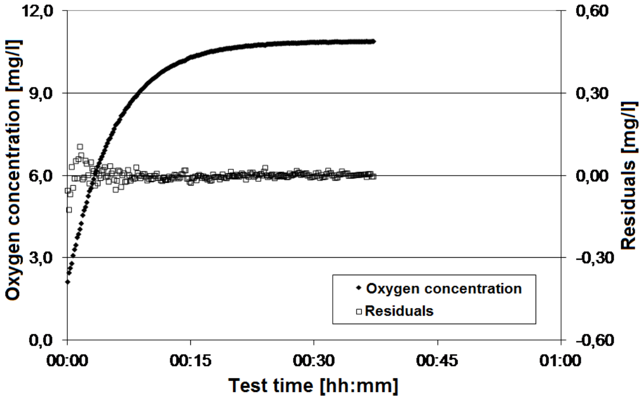
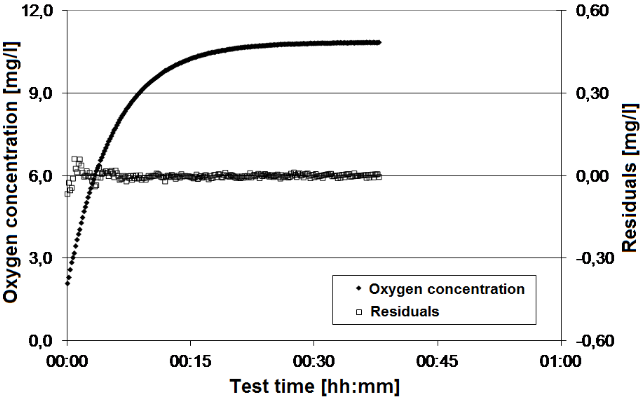
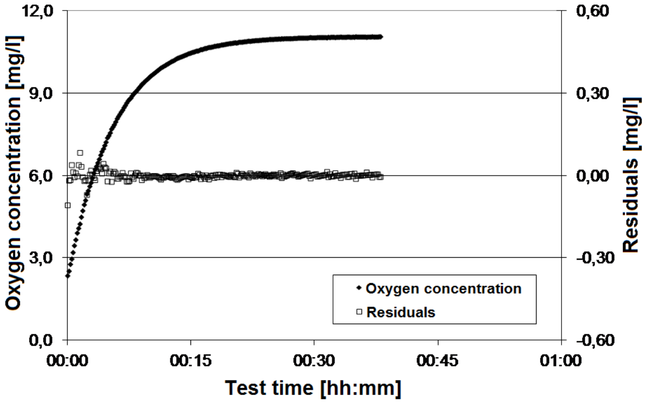
6 List of references

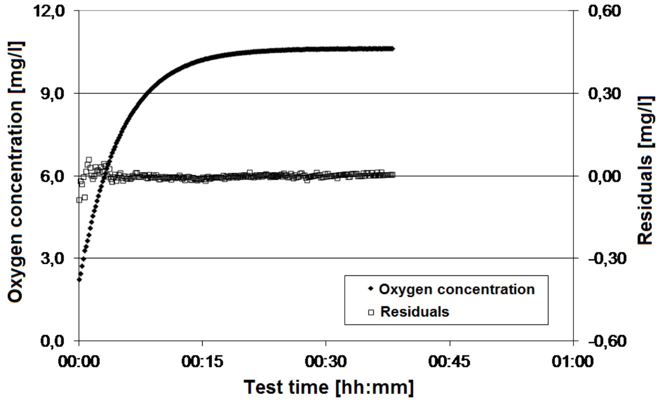
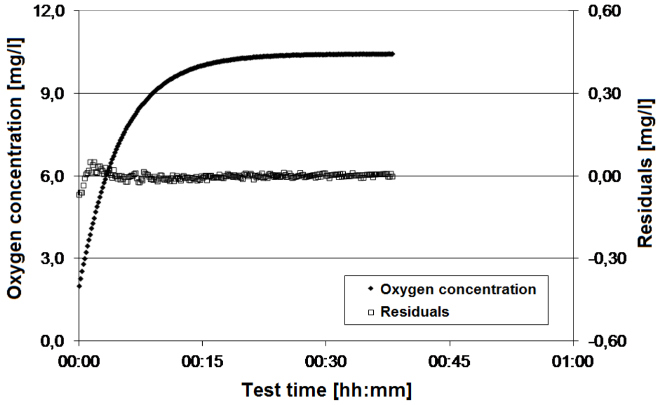
DWA (2007). DWA Merkblatt (Instruction sheet) M 209: Measurement of Oxygen Transfer of Aeration Equipment in Clean Water and Activated Sludge (*Messung der Sauerstoffzufuhr von Belüftungseinrichtungen in Belebungsanlagen in Reinwasser und in belebtem Schlamm*)

Appendix - Evaluation of the tests

MS_Probe	1 Aerator Q_A = 8 Nm^3/h
1_1	
1_2	
2_1	
2_2	

MS_Probe	1 Aerator Q_A = 16 Nm³/h
1_1	
1_2	
2_1	
2_2	

MS_Probe	1 Aerator Q_A = 24 Nm³/h
1_1	
1_2	
2_1	
2_2	

MS_Probe	1 Aerator Q_A = 24 Nm³/h (Duplicate determination)
1_1	
2_1	
2_2