The role of diffuser arrangement and mixing for efficiency optimisation of fine bubble aeration systems

Wilhelm Frey

AAB-Consulting, Hofgartenstraße 4/2, 2100 Korneuburg/Leobendorf, Austria; aab.frey@aon.at

Abstract – The introduction will deal with common installation instructions concerning the arrangement of diffusers and mixers in race tracks. On the basis of oxygen transfer and velocity measurements on the one hand, and observations made at full scale plants on the other, there will be suggested possible ways of improving the oxygen transfer, the aeration efficiency and the flow regime. Finally, recommendations will be made in regard to the design of fine bubble aeration systems in race tracks.

Keywords – Fine bubble aeration, race track, diffuser, mixer, aeration efficiency

Introduction

Usually, diffusers are positioned in the longitudinal zones of the channel. Mixers are deployed in order to achieve horizontal flow. Figure 1 exemplifies the minimal distances a mixer must keep to its side wall, the floor, diffusers, the water surface and other mixers respectively. These figures were given by mixer manufacturers. (Mantovani, 2000)



Figure 1 Minimal distances between mixers and diffusers, Mantovani (2000)

Basins which are not at least six times as long as the respective channel width, lack room for the arrangement of the diffusers. Plant designs often fail to consider this, arranging the diffusers very close to each other, which results in high floor coverage. This, in turn, affects the calculation of the oxygen transfer by using oxygen transfer efficiency based on high floor coverage.

Furthermore, in case of horizontal flow, some manufacturers tend to apply increase factors to the oxygen transfer, which is illegitimate without examining case-specific

circumstances. For example, increase factors are to be found in Rissler; Hahn (1995) and Gillot (1997).

Resulting from the procedure just mentioned, several oxygen transfer tests in race tracks with fine bubble aeration repeatedly showed that the calculated oxygen transfer cannot be accomplished.

Cause end effect

In fact, the power induced by air flow is five to fifteen times higher than the mixer power. Thus, each diffuser grid is a flow barrier. The brake-effect increases in proportion to the tightness of floor coverage and the force of the air flow. Furthermore, air distribution pipes placed diagonally to the flow cause greater resistance than longitudinal placed air distribution pipes. (see figure 2)



Figure 2 Diffuser arrangement (left: bad; right: good)

In front and behind each diffuser grid, flow rolls occur. Operating by the same principle as the spiral roll aeration system, owing to the upward direction of the flow, bubbles only last briefly within these marginal rolls. This diminishes the oxygen transfer efficiency.

A close-knit diffuser grid leaves only a small area in its centre where vertical bubble rise goes at normal speed. Figure 3 shows the development of flow rolls as well as the relation between normal and accelerated vertical bubble rise. Doubling the velocity of vertical bubble rise within the rolls of a close-knit diffuser grid where a third of the bubbles rises normally, the oxygen transfer would be reduced to 67% of the efficiency of a basin with an equally sized base area and perfect vertical bubble rise. Connecting the grids under the assumption that the size of the flow rolls remains constant, the oxygen transfer only decreases to 83%. By increasing the size of the diffuser grids and thus diminishing the number of roll flows, the reductive effect of the roll flows can be lessened.



Figure 3 Impact of spiral roll in front and behind a diffuser grid

Most attempts of the manufacturers proved futile to increase the mixer power in order to avoid marginal rolls and direct the horizontal flow. But instead, these attempts generally increased the marginal oncoming flow roll.

Remedial actions and examples

Measures to ensure the demanded oxygen transfer proved the advantages of larger diffuser grids which provide more diffusers. Regarding short basins (length/channel width < 6), this procedure presupposes the mounting of diffusers in the bend. Furthermore, connecting the diffuser grids to decrease the number of marginal rolls to two, effects the highest oxygen transfer possible.

Diffuser manufacturers refuse the installation of diffusers in bends, arguing that it causes increased coalescence of bubbles, which leads to a decrease of oxygen transfer efficiency. In the course of my tests, this phenomenon did not occur. Therefore, I recommend the mounting of diffusers in the bend, since it brings about several advantages:

- There is more floor space to install diffusers, which means a larger base area of the basin can be equipped with diffusers. Within these areas, the floor coverage may be decreased in order to reduce the flow resistance. In this case, it is of great importance not to exceed the maximal distances (between the diffusers) to avoid the development of flow rolls inside the diffuser grid (Thiersch, 2001).
- The enlarged diffuser grids provide a spacious area where bubbles may rise at normal speed. The connection of the diffuser grids diminishes the number of flow rolls. Besides, the influence of marginal rolls decreases.
- The water-air mixture in the bend results in lower friction losses. Moreover, even assuming low mixer power, the horizontal flow gets stable.
- Increasing the number of diffusers (at equal air flow, this means a reduction of the air flow per diffuser), diminishing the effects of the marginal rolls and stabilising the horizontal flow pushes the substance transmission and heightens the oxygen transfer efficiency.

I chose two plants where the aeration efficiency has been measured, to illustrate the points just made. Table 1 shows the basic data of the two treatment plants (both are race tracks) and the details of the measurements.

		Thalgau	Thalgau	Vienna	Vienna	Vienna	Vienna
		before	after	before	before	after	after
		retrof.	retrof.	optim.	optim.	optim.	optim.
test tank	m ³	2080	2080	5000	5000	5000	5000
floor area	m²	347	347	962	962	962	962
length	m ³	30	30	62	62	62	62
width	m ³	12,4	12,4	16	16	16	16
channel width	m ³	6,0	6,0	7,8	7,8	7,8	7,8
water depth	m ³	6	6	5,2	5,2	5,2	5,2
submergence	m	5,8	5,8	5,0	5,0	5,0	5,0

Table 1 Plant description and technical data

		Thalgau	Thalgau	Vienna	Vienna	Vienna	Vienna
		before	after	before	before	after	after
		retrof.	retrof.	optim.	optim.	optim.	optim.
length/channel width	-	4,9	4,9	7,8	7,8	7,8	7,8
diffusers	piece	210	443	1201	1201	1613	1613
diffuser area	m ² /piece	0,041	0,041	0,041	0,041	0,041	0,041
total covered area 1	%	20%	45%	38%	38%	54%	54%
floor coverage ²	%	12,5%	11,7%	13,5%	13,5%	12,8%	12,8%
air flow	m _N ³ /h	1100	1060	2500	7500	2500	7500
superficial velocity 3	$m_N^3/m^2/h$	15,9	6,8	6,8	20,5	4,8	14,4
air load ⁴	m _N ³ /h/pc	5,2	2,4	2,1	6,2	1,5	4,6
number of flow rolls	-	2	2	6	6	4	4
mixer	piece	2	2	4	4	4	4
mixer diameter	m	2,2	2,2	2,5	2,5	2,5	2,5
mixer power	kW	5,0	2,8	8,9	8,9	8,9	8,9
spec. mixer power	W/m ³	2,4	1,3	1,8	1,8	1,8	1,8
blower power	kW	38	38	52	160	52	160
blower power/							
mixer power	kW/kW	7,6	13,6	5,8	17,4	5,8	17,4
manufacturer information							
SSOTR	g/m _N ³/m	13,6	15,3	19,1	15,7	19,7	16,4
theoretical change	%	-	12,5%	-	-	3,0%	4,6%
measurement							
SSOTR	g/m _N ³ /m	12,2	19,2	20,5	15,5	23,0	17,8
real change	%	-	51,3%	-	-	12,1%	14,6%

¹ floor area covered by diffuser grids
² area of the diffuser grids covered by active diffuser area

³ airflow rate per total area covered by diffuser grids

⁴ air flow per diffuser

The Thalgau Plant

The Thalgau plant is designed for 23,500 PE. The race tracks of the plant were extremely short. Therefore, the base area lacked space to hold the diffusers. According to the recommendations of diffuser and mixer manufacturers, diffusers (Sanitair 9"; air flow control orifice 7,5 mm) were only mounted on one side and set in a small grid. Two mixers (Flygt 4430) were installed to execute the horizontal flow.

The rated value of the oxygen transfer efficiency could not be reached in the course of the oxygen transfer measurement. There was an attempt to augment the horizontal flow by installing more powerful mixers, but this attempt failed. An oxygen transfer test could not verify an increase of oxygen transfer efficiency. As a next step, additional diffusers were mounted in the bend. By doubling the number of diffusers, the theoretical oxygen transfer efficiency should be increased from 13,6 to 15,3 $g/m_N^3/m$. The measurement showed an increase of the oxygen transfer efficiency from 12,2 to 19,2 g/m_N³/m (which is an increase of 51%!). The reason for this is to be found in the completely changed flow regime.

Figure 4 depicts the flow before and after the retrofitting. Extreme flow rolls occurred before the retrofitting, whereas afterwards, the mounting of additional

diffusers resulted in a stable horizontal flow. Unfortunately, the plant design did not allow an oxygen transfer test including the diffusers in the bend only.



Figure 4 Thalgau – top view of the aeration tank; flow regime before and after retrofitting

The Vienna Main Treatment Plant

The Vienna main treatment plant is designed for 4,000,000 PE. The plant constitutes a two stage activated sludge system. The second stage consists of 15 basinblocks with 4 cascades each. The second and third cascades are race tracks which feature a fine bubble aeration system and separate mixing. The measurement took place in these race tracks. The number and position of diffusers and mixers were determined in a two-step procedure. Firstly, the outfitter could test and optimise his arrangement in one of the 30 race cascades. Moreover, the oxygen transfer and the velocity of the flow were measured, in order to prove that guaranteed standards could be fulfilled. Secondly, the remaining 29 race cascades were mounted with diffusers and mixers after the model of the test cascade.

Before the optimisation, three separate areas were equipped with 1201 diffusers (Sanitair 9") and 4 mixers (Flygt 4430). Figure 5 shows the plan of the basin, the arrangement of the diffusers and the position where the velocity measurement took place.



Figure 5 Vienna, before optimisation; Top view of the aeration tank; position of the velocity measurements.

Before the optimisation, the aeration system reached the oxygen transfer efficiency which the design was based on, at both 2500 $m_N^{\,3}/h$ and 7500 $m_N^{\,3}/h$. But the results of

the velocity measurements at 7500 $m_N^{3/h}$ were not satisfactory. The velocity of the horizontal flow was measured at 20 different spots (measurement device: Marsh-McBirney Flow-Mate 2000). Four devices were adhered to a rod and deployed simultaneously. 30 minutes of average values were recorded at five positions each. The average velocity was 0.17 m/s with a median of 0.03 m/s. Figure 6 depicts the flow profile. In the lower part of the basin, powerful back flows are to be found.



Figure 6 Flow profile (1201 diffusers; 7500 m_N³/h)

After the optimisation-tests, the configuration shown in figure 7 was set. Essentially, two instead of three areas were equipped with bottom aerated zones (1613 diffusers; Sanitair 9"). The number, position and power of the mixers were not changed.



Figure 7 Vienna after optimisation; top view of the aeration tank, position of the velocity measurements

After the optimisation, the aeration system exceeded the oxygen transfer efficiency which the design was based on, at both 2500 m_N^3/h and 7500 m_N^3/h . The increase in regard to the number of diffusers should result in an increase of the oxygen transfer efficiency of 3% and 5% respectively. The measurement recorded an increase of the oxygen transfer efficiency of 12% and 14% respectively. Again, the reason for this is to be found in the altered flow regime. The average velocity of the flow amounted to 0.27 m/s with a median of 0.27 m/s too. Figure 8 depicts the flow profile.



Figure 8 Flow profile (1612 diffusers; 7500 m_N^3/h)

Summary and Conclusions

Common mounting instructions concerning diffusers in race tracks with fine bubble aeration only allow small diffuser grids in short basins. With the help of measurements and observations made in full scale plants, it was shown that it bears advantages not to confine diffusers to longitudinal channel zones. The oxygen transfer efficiency was increased more effectively by mounting diffusers in a bend than a calculation with SSOTR based on the increased number of diffusers (and therefore the resulting reduction of air flow per diffuser) has shown.

In order to improve the oxygen transfer rate and the flow profile, I recommend to:

- Spread the diffusers over the available area on the bottom of the aeration tank.
- Mounting the air distribution pipes in longitudinal direction.
- Place the diffuser grids side by side to decrease the number of flow rolls.
- And also mounting the diffusers in the bend of race tracks.

References

- Gillot, S. (1997): Transfer d'oxygene en boues activees par insufflation d'air mesure et elements d'interpretation Ecole doctorale de Sciences Physiques et Chimiques, et d'Ingenierie, Université Paris XII Val de Marne
- Mantovani, A. (2000): Aeration efficiency in horizontal flow systems and other nonfull floor coverage aeration systems. Aeration conference der Firma Nopon Oy in Helsinki am 02.10.2000
- Rissler S., Hahn T. (1995): Effect of horizontal flow on aeration, Scientific Impeller, Flygt Firmenschrift, No.3
- Thiersch, B. (2001): Der Zusammenhang von Strömungsstrukturen und Sauerstoffeintrag bei druckbelüfteten Belebungsbecken, Mitteilung Nr. 67, Hydraulik und Gewässerkunde, Technische Universität München