TUBULAR POLYMERIC AERATORS FOR WASTEWATER TREATMENT

R Galich, Y Meshengisser, V Los, P Spiridonov

Abstract
This article summarises theoretical methods for the design and calculation of aerators and aeration systems, on which bases tubular polymeric aerators have been developed, which combine the functions of the air distributor and diffuser. Recent tests by an independent German university have shown that these aerators have higher oxygen transfer rates, more stable size of air bubbles, lower hydraulic resistance and work with a wider range of airflow rates. Since 1999 they have been employed in 15 countries around the world, serving 120 million people.

Key words: diffuser, wastewater, aeration system, oxygen transfer efficiency

Introduction
In wastewater purification aeration is crucial and is one of the most energy consuming processes, accounting for more than 50% of all costs. Therefore the analysis of theoretical methods for the design of aerators and aeration systems, to guide the development of advanced, effective and reliable devices, is extremely important.

Aerator design should meet a combination of contradictory and sometimes mutually exclusive requirements:
- air bubble diameter should be minimal to ensure high mass exchange rate, but simultaneously large enough to provide energy for water agitation;
- diffuser resistance should ideally be equal to zero;
- the resistance of all aeration systems should be sufficient to maintain even air distribution along air tank length;
- aerators should be designed in such a way that in the case of air supply stoppage and filling of diffusers with water, hydraulic impacts on resumption of air supply would be eliminated or reduced;
- diffusers should not be blocked by airborne particles from the inside or be exposed to biofouling from the outside;

Figure 1. Dependence of bubble size (D0) on the pore diameter (dp) at different speeds of air effusion (wj): 1 - 6 m/s; 2 - 12 m/s; 3 - 20 m/s.

Figure 2. Dependence of speed of gas effusion on the angle of pore edges to horizontal at different airflow rate: 1 - 5 m³/(hm); 2 - 7.5 m³/(hm); 3 - 10 m³/(hm).

Design and calculation of the aeration systems, on which bases effective and reliable tubular polymeric diffusers have been developed.

Theoretical Aspects of Aerator Design
A system of equations for the behaviour of an air bubble at stages of its formation and growth has been developed and solved by standard numerical methods (Meshengisser, 2002).

Figure 1 shows that the diameter of the formed bubbles depends not only on the pore diameter, but also on the speed of the air effusion through the pores.

These calculations are valid for the case where the pore edges are horizontal. Pores in tubular aerators are located at an angle from horizontal and at different distances from the water surface.

The speed of the gas effusion has been correlated with the angle of pore edges by modification of the above equations. As shown in Figure 2 the bubble diameter decreases with the increase of the angle of pore edges, which remains typical for different airflow rates.

These calculations have shown that with an identical pore diameter, a tubular aerator produces, on average, smaller bubbles than a flat one.

Oxygen transfer rate
The parameter used in aerator calculations is oxygen transfer rate (OTR)

$$ OTR = K_{ij} aV_{ijk}(C^* - C) $$

where $K_{ij}$ is a volumetric mass-transfer coefficient, $V_{ijk}$ - water volume in reactor, m³, $C^*$ - dissolved oxygen saturation concentration, C - dissolved oxygen concentration.

If the members of equation are determined at normal pressure and temperature, and the dissolved oxygen concentration is zero, the value obtained is termed the standard oxygen transfer rate (SOTR).

A common criterion for comparison and design of aeration systems is the standard oxygen transfer efficiency (SOTE). The physical meaning of this parameter is percentage of oxygen absorbed by water
when air passes through water that does not contain oxygen.
SOTE, %, according to ASCE (1992), can be expressed as follows:

$$SOTE = \frac{SOTR \times 100}{0.2765 \times Q_s}$$

where SOTR - standard oxygen transfer rate, kg/s; Qs - airflow rate at standard conditions (temperature 20°C, pressure 101,325 Pa, relative humidity 36%), m³/s.

Meshengisser and Marchenko (2000) have compared experimental values of oxygen transfer rates and values obtained by calculations based on bubble size, floating speed and pattern of contact between the rising bubbles and accompanying water flow.

The results are shown in Figure 3. The deviation between calculated and experimental data of oxygen transfer rate was no more than 8%, which is within experimental error.

Hence, their theoretical model of oxygen transfer quite precisely describes the physical process and can be used for the comparative analysis of aerators of various designs.

Analysis of modelling results

To check the developed mathematical model the authors performed calculations for three different types of diffusers: rigid perforated membrane, elastic perforated membrane and porous polymeric diffuser.

The calculation results are given in Figure 4.

Despite the fact that the average pore diameter was stipulated to be equal for all diffusers, their SOTE characteristics are different.

The calculations have confirmed the known fact that SOTE depends on airflow rate and reduces when airflow rate increases. This is explained, first of all, by the increase of the diameter of air bubbles upon increase of speed of gas effusion from the pores. Such phenomena are also relevant for membranes with the same pore diameter, which do not depend on the airflow rate.

In practice such diffusers are very rare and possibly may include rigid metal plates with apertures of equal diameter. Elastic perforated membranes stretch with an increase of airflow rate, their pore size is increased and, accordingly, SOTE is drastically reduced.

The opposite picture is observed for diffusers with non-uniform pore structure. They include ceramic and porous polymeric diffusers. At low airflow, air passes only through large pores and fine pores are flooded and closed for air. The increase of airflow rate results in the increase of air pressure in the diffuser which leads to opening of finer pores. Thus, the average pore diameter is reduced when airflow rate is increased; accordingly, the SOTE dependence on airflow rate is less.

Diffusers with polydisperse pore structure (such as porous polymeric diffusers) have lower saturation efficiency at smaller airflow rates. However, due to opening of finer pores with increase of the airflow rate, the SOTE dependence on the air flow is smoother, and the saturation efficiency of porous polymeric diffusers becomes higher than that of perforated membranes.

Thus, the theoretical analysis allows statement of the following:
1) Tubular aerators are preferable to flat ones; with similar pore diameters they provide smaller bubbles and therefore larger specific area of liquid-gas interface and hence oxygen transfer efficiency;
2) Diffusers with polydisperse pore structure provide a constant oxygen transfer rate within a wide range of airflow rates.

Characteristics of the Designed Tubular Polymeric Aerators

Design features

On the bases of their research, tubular polymeric aerators (Figure 5) have been designed by the authors and manufactured by Ecopolymer in Ukraine.

The aerators have a number of attributes, which give them advantages over other aerators:
- Innovative technology allows the production of a polydisperse diffuser which provides fine bubble aeration and minimises hydraulic resistance, down to 200-300 mm of water column.
- A distinctive feature of the designed aerators is the gap between the casing and the diffuser, which provides steady and reliable operation of aerators due to the redistribution and levelling of airflow along the aerator axis, reduction of pressure losses at the dispersing element, and increase of dust holding capacity.
- Due to the change of the aeration zone width and opening of pores of different diameters, the tubular aeration is self-adjusting system, which minimises energy consumption used for forcing air through the pores.
- The aerators have an extremely wide range of steady operation - from 2 to 30 m³/h of airflow per metre of aerator length.
- The combination of air pipe and diffuser functions allows simpler and faster installation of aeration system and provides increased reliability. They can be manufactured as long aeration beams (up to 50 meters).
- The aerator structure is demountable. It allows regeneration (washing) or replacement of the diffusers without dismantling the whole system.
Table 1. The aerators’ test conditions and results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ISAH</th>
<th>RLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>water temperature, °C</td>
<td>12.5–19.5</td>
<td>19.72–22.5</td>
</tr>
<tr>
<td>diameter of a column, D, m</td>
<td>1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>volume of water in column, Vw m³</td>
<td>5.09</td>
<td>1.67</td>
</tr>
<tr>
<td>depth of aerator immersion, h, m</td>
<td>4.28</td>
<td>3.0</td>
</tr>
<tr>
<td>ratio of geometrical dimensions, h/D</td>
<td>3.57</td>
<td>3.75</td>
</tr>
<tr>
<td>diffuser length, l, m</td>
<td>0.86</td>
<td>0.2</td>
</tr>
<tr>
<td>number of aerators in column</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>air flow rate per diffuser length, Q/l, m³/h</td>
<td>4.1 – 12.2</td>
<td>4.3 – 15.3</td>
</tr>
<tr>
<td>air flow rate per volume of water in column, Q/Vw m³/ (m³/h)</td>
<td>0.69 – 2.06</td>
<td>0.51 – 1.84</td>
</tr>
<tr>
<td>oxygen transfer efficiency per 1 m of depth of aerator immersion, SOTE₆ %/M</td>
<td>8.64 – 4.86</td>
<td>8.09 – 4.77</td>
</tr>
<tr>
<td>hydraulic resistance of aerator, kPa</td>
<td></td>
<td>1.3 – 2.0</td>
</tr>
</tbody>
</table>

Tests in RLE were conducted in tap water in a column reactor by a desorption method according to the ASCE Standard (1992). Deoxygenation of water was carried out by purging technically pure nitrogen through the aerator, fixed near the bottom of the column. CDO was measured with an oxygen measuring device YSI-57, whose sensors were placed at a depth of 0.6 m in the middle of the column.

As can be seen from Table 1, the tests conditions in ISAH and RLE can be considered similar for the following reasons. First, the equality of mixing intensities (Q/Vw) and geometrical similarity (h/D), and consequently the hydrodynamic conditions of mass-transfer process were equal. Secondly, equal air flow rate per diffuser length (Q/l) was provided and therefore equal conditions of air dispersion – which influences the size of air bubbles and the distribution of bubble diameters - the major factors determining mass-transfer efficiency.

The results of ISAH and RLE tests presented in Figure 6 agree well. It was established that unlike the majority of modern fine bubble aerators the designed tubular aerators have a constant SOTE mode within a wide range of airflow rate. This confirms the theoretical results.

Airflow rate per 1 m of aeration system
An airflow rate within 14 – 20 m³/h is recommended for the aerators. However these rates can differ slightly depending on tank design, configuration of aeration system, working depth, temperature of wastewater, etc. A one metre long tubular aerator aerates approximately 3 m³ of air tank.

Hydraulic characteristics
The pressure losses on aerators depend on the air flow rate. The pressure losses on the
designed aerators vary from 1.5 to 3.0 kPa. This value is for a new aerator immersed in pure water.

While in service, the resistance of the dispersing element grows (which is typical for all porous aerators). The suspended substances penetrate into a porous layer and partially increase its resistance. The design of the tubular aerators allows minimisation of the influence of these processes. The blockage of the pores usually leads to the increase of pressure losses, however in the designed aerators it results in the reduction of air bubble diameter and, therefore, increase of oxygen transfer rate. Hence, the increase of pressure losses is compensated by reduction of the required air flow and the operation cost does not increase.

Case Studies and Economic Benefits

The possibility of assembling long beams of aeration units reduces air piping network installation to a minimum, requires a smaller quantity of air intake pipes and reduces the quantity of stop valves and fittings (see Figure 7) and assembly takes minimal time.

For example, in a regional wastewater facility in Ohio, USA, an 8000 m$^3$ air tank was equipped with a tubular aeration system within two days. It took 10 days to re-equip 2 air tanks (19,000 m$^3$ each) with the tubular aerators in Kharkov and Kiev, Ukraine. For comparison, re-equipment of 3 aeration basins (3,800 m$^3$ each) with ceramic disc diffusers required 4 labour days per tank, which is as twice as long in relation to the volume.

Usually, after retrofit of conventional aerators by the tubular system, one in three operating blowers can be disconnected without deterioration of water quality. In some cases, when the preceding aeration system consisted of perforated pipes, the installation of the tubular aerators allowed savings of up to 50% of electric power costs.

Another example was published in Operations Forum, No 1, January 1998. In 1996 an aerobic mineraliser at a wastewater treatment plant in Ohio, USA, was re-equipped with the designed aerators. The reconstruction resulted in increase of concentration of dissolved oxygen from 0.5 to 1.5-2.0 mg/l; the time of solid particles retention decreased to 18 days; and the percentage of the removed organic substances increased up to 56%. The aeration system provided good agitation of sediments, and considerably improved the performance of the entire facility. The cost of electric power was reduced by 34%.

Conclusions

Theoretical and experimental studies have enabled the formulation of the basic principles for a new generation of aerators:

- a tubular design which combines air pipe and diffuser;
- aerators with a gap between construction casing and diffuser element;
- diffusers made of porous polymeric materials with a polydisperse pore structure; Thus a new tubular polymeric aerator has been developed and patented. (Galich, 1999, Meshengisser, 1996). The aerators are highly efficient and work in a wide range of air flow rates.

Since 1999 the tubular aerators have been put into operation in 15 countries around the world and currently serve 120 million people. They are used to treat 25,000,000 cubic meters of wastewater a day.

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