TUBULAR POLYMERIC AERATORS FOR WASTEWATER TREATMENT

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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 be 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;

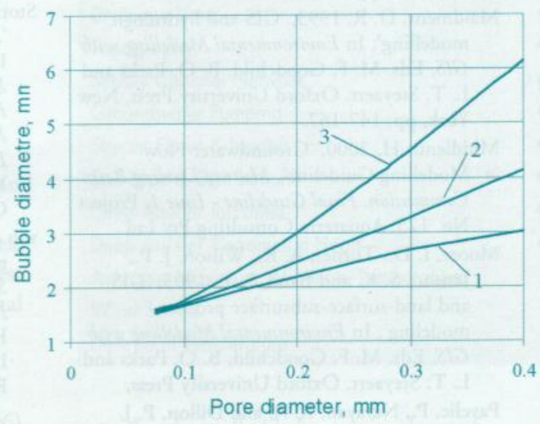

Figure 1. Dependence of bubble size (D_{sep}) on the pore diameter (d_p) at different speeds of air effusion (w_g): 1 - 6 m/s; 2 - 12 m/s; 3 - 20 m/s.

Tubular polymeric aerators, developed in Ukraine, work in a wide range of air flow rates and are easy to install.

- aerators should be interchangeable, easily mounted and adapted to the existing systems of air supply and air tank designs;

Analysis of existing aerators and theoretical investigation of the aeration process enabled the authors to develop a new type of aerator, which combines the functions of the air distributor and diffuser. This article describes the theoretical aspects of the design and calculation of the aeration systems, on which bases effective and reliable tubular polymeric diffusers have been developed.

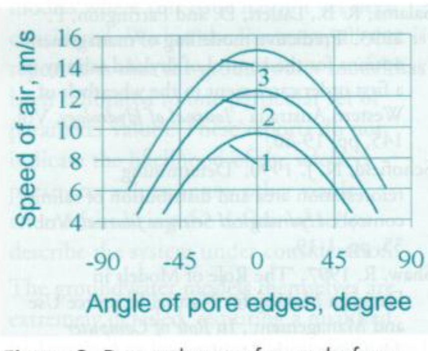

Figure 2. Dependence of speed of gas effusion on the angle of pore edges to horizontal at different airflow rate: 1 - 5 $m^3/(h*m)$; 2 - 7.5 $m^3/(h*m)$; 3 - 10 $m^3/(h*m)$.

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):

$$OTR = K_L a V_R (C^* - C)$$

where K_La is a volumetric mass-transfer coefficient, V_R - water volume in reactor, m^3, 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:

$$SOTE = \frac{SOTR \cdot 100}{0,2765 \cdot Q_S}$$

where SOTR - standard oxygen transfer rate, kg/s; Q_s - airflow rate at standard conditions (temperature 20°C, pressure 101,325 Pa, relative humidity 36%), m^3/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 air flow, air passes only through large pores and fine pores are flooded and closed for air. The increase of air flow 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 flow 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.

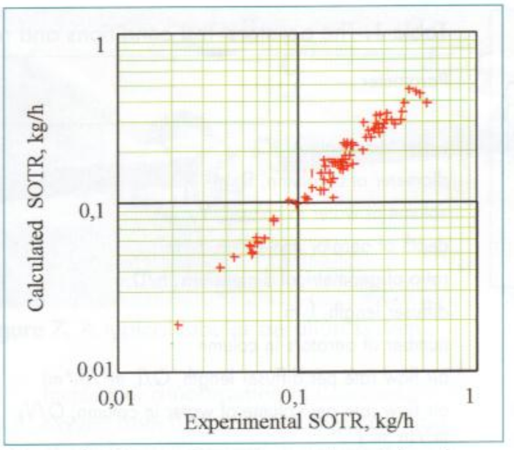

Figure 3. Comparison of experimental and calculated values of oxygen transfer rates.

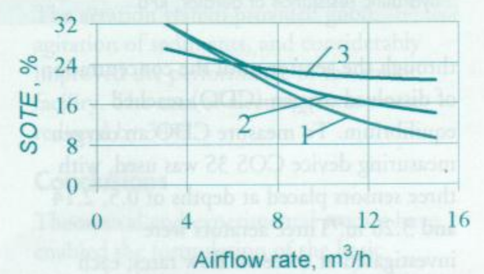

Figure 4. Dependence of SOTE on aerator airflow rate: 1 - elastic perforated membrane; 2 - rigid perforated membrane; 3 - porous polymeric diffuser.

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 air flow 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 aerator is a 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 m^3/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.

Figure 5. Tubular aerator: 1 - perforated casing; 2 - diffuser; 3 - clamping nut; 4 - sealing gasket; 5 - retaining ring; 6 - sealing rings.