The review of aeration systems for biological wastewater treatment

M Yu Dyagelev¹, I I Pavlov¹, A M Nepogodin¹, E V Grakhova² and A A Lapina³

¹Department of Water supply and water treatment, Kalashnikov Izhevsk State Technical University, Izhevsk, 426069, Russia
²Department of Industrial and civil engineering, Kalashnikov Izhevsk State Technical University, Izhevsk, 426069, Russia
³Municipal Unitary Enterprise of the city of Izhevsk "Izhvodokanal", Izhevsk, 426039, Russia

E-mail: mdyagelev@yandex.ru

Abstract. This article presents different aeration systems for biological wastewater treatment, their classification, also advantages and disadvantages of the most common aeration methods - pneumatic and mechanical are described. Also, proposals to reduce the energy consumption of aeration systems by maintaining the optimal range of dissolved oxygen concentration at different points of the aeration tank, depending on its type, have been prepared.

1. Introduction

Experience has shown, that in past, nowadays and in the foreseeable future, the main function of wastewater purification from organic and biogenic elements is performed by an aeration tank (an artificial biological treatment plant) equipped with an aeration system [1-5]. Experts believe that from 60 to 80% [6, 7] of operating costs of treatment facilities refer to the cost of aeration of the sludge mixture in aeration tanks [8, 9].

The efficiency of the aeration devices is assessed by energy indicators and oxidizing capacity, which characterizes the amount of dissolved oxygen in the air per unit of liquid during an hour. Aeration facilities is assessed by one of the energy indicators, such as the air consumption for treatment of 1 m³ of waste water [10]. This indicator depends on the efficiency of supplying air to the aeration tank and distribution in it, mixing in the tank, which depends on the type of aerator and aeration system. The choice of an aerator is made according to the comparison of indicators such as aeration efficiency and oxidizing capacity of aerators.

Aeration systems used in aeration tanks can be divided into some types: pneumatic, mechanical, pneumo-mechanical and jet or ejector (figure 1). The choice of an aeration system and a scheme for its implementation for special aeration tanks is carried out individually for the wastewater facilities, according to such factors as [11]:

- quality of wastewater and requirements for treated water;
- technology of biological wastewater treatment realised in aeration tanks (oxidation of carbon-containing compounds (with or without activated sludge regeneration), nitrification, nitri-denitrification and biological phosphorus removing);
- hydrodynamic characteristics of aerotanks (mixers, displacers, reactors of intermediate hydrodynamics of flows, aerotanks with dispersed water supply, etc.).

Contemporary energy efficient controlled blowing machines help to reduce the specific energy consumption per unit of produced air. The amount of air that has to be supplied to the aeration tanks to provide the required amount of oxygen for biological processes directly depends on the efficiency of the aeration system.

![Classification of aeration systems for aeration tanks.](image1)

**Figure 1.** Classification of aeration systems for aeration tanks.

2. Materials and methods

Pneumatic aeration system.

The pneumatic method of aeration is widespread at biological treatment plants in aeration facilities. (figure 2). Pneumatic aeration system works according to the following principle: oxygen-containing gas is supplied under a certain pressure through the main and air distribution pipelines to various kinds of dispersers installed at the appropriate points of the tank [12-15].

![Scheme of pneumatic aeration system.](image2)

**Figure 2.** scheme of pneumatic aeration system: 1 – air supply pipe; 2 - distribution collector; 3 – air distribution pipe; 4 – aerators; 5 – water discharge device with a tube; 6 – attachment of air distribution pipes; 7 – clamp; 8 – concrete post; 9 – flange connection; 10 – clamp; 11 – concrete post; 12 – blowout collector.
Pneumatic aeration system can be divided, according to the size of the air bubble, into aeration of fine dispersion (1-4 mm), medium (5-10 mm) and small (> 10 mm) \[1, 8, 12-14\]. The first type includes all designs of ceramic, fabric and plastic aerators. The second one includes perforated pipes, domes, slotted aerators, etc. The third one includes aerators in the form of pipes open from the bottom or a nozzle.

Mechanical aeration system

A mechanical aeration system is often used for biological wastewater treatment and takes the second place after pneumatic.

![Mechanical aerator](image)

**Figure 3.** Mechanical aerator: 1 – walls; 2 – vanes with holes; 3 – aeration zone; 4 – guiding partitions; 5 – visor; 6 – lightening zone; 7 – gutter; 8 – reflective plates; 9 – waste water supply system; 10 – aerators; 11 – symmetrical slits.

Operation principle of mechanical aerators is based on (figure 3) is adding of atmospheric air into the treated liquid by rotating elements of the aerator. Main advantages of mechanical aerators are:

- simple to manufacture,
- no need to install blower stations,
- high oxidizing ability.

In addition, the advantage of mechanical aeration system is simplicity in production and operation, high oxidizing capacity, low power consumption (1.35-1.4 kWh for decreasing of 1 kg biological oxygen demand in 5 days). But besides the advantages, mechanical aerators have insufficiently high operation reliability, and in case of significant level of wastewater, larger number of aerators is required, as well as a metal-consumming working body that can quickly be broken. Stirring of water can be difficult if the tanks depth is more than 2 m \[16-18\].

There are also airlift or jet type among the aerators (figure 4). Among them, we can single out pneumatic aeration systems operating in a dedicated volume with pumping liquid (airlifts) and systems, which stirring water (static aerators). During the operation of such devices, the energy of compressed air supplied to the aeration tank is used \[19\].

These aerators are widespread in the chemical, food and petrochemical industries, since when using pneumatic systems, cases of clogging with salt deposits or oil pollution are observed in aerators. Jet-type aeration is also used in operation of highly loaded sewage treatment plants, as an additional aerating mean \[12\]. But at the same time, jet-type aerators are less effective than fine-bubble aerators, but more effective than medium-bubble ones.

Jet-type aerators are quite effective, occupying an intermediate position between fine- and medium-bubble aerators \[19\]. Moreover, jet-type aerators can be used to recirculate activated sludge in a nitrifier. It helps to refuse pumps. The use of conventional bubblers in the design of jet-type aerators makes the generation of small monobubbles difficult, and therefore the efficiency of water saturation with atmospheric oxygen is lower. Also, a significant disadvantage of jet-type aeration is the requirement for the installation of blowing devices.
3. Results
From the considered methods of wastewater aeration, it can be noted that the pneumatic method of aeration is distinguished by a high cost compared to the mechanical one due to the need of installation, and maintaining of additional equipment – blowing stations.

Maintenance costs of the pneumatic aeration system will also depend on the size of the produced bubbles (figure 1).

Distinctive technical features of fine dispersion aerators (bubble diameter 1-4 mm), are aerator membrane resistance to the formation of sediment, high oxygen throughput and the ability to provide uniform aeration without loss of air pressure. The body pipe is resistant to the processed liquid, and provides a simple and quick installation. At the same time, the saturation efficiency ranges from 20-25% at a water depth of 4 m, and the total specific oxygen supply is 3-3.5 kgO₂ / kWh in clean water, and in real conditions, it is equal 1.8-2.1 kgO₂ / kWh [6, 7, 8, 17].

The experience of using medium-bubble aerators (bubble diameter 5-10 mm) shows that after a while the holes become clogged with corrosion products. Therefore, it is recommended to use pipes which are made of non-corrosive material such as plastic, copper or stainless steel to avoid fouling with corrosive products [8].

Unlike medium-bubble aerators, large-bubble ones (bubble diameter is more than 10 mm) always are not clogged up and do not fouled with corrosion products, but due to the jet flow of a liquid, there is a significant decrease in the efficiency of saturation with oxygen, which impairs the process of oxygen mass transfer [12].

Mechanical aeration systems are mostly used with the same rotational speed [6]. To reduce energy consumption during aeration tanks using with mechanical aeration systems, it is recommended to use a two-speed regulator or, it would be preferable to use frequency converter [6, 11]. It allows to maintain the specified range of dissolved oxygen concentration and to exclude excessive consumption of electricity in real conditions, fluctuations in the incoming load both for organic compounds and for nitrogen compounds [20, 21].

4. Discussion
The choice of an effective aeration system is one of the crucial factors of reducing energy consumption in sewage treatment plants. The aeration system has to provide the required oxygen regime of the aeration tank under conditions of real nonstationarity of the input load, that is, to provide the required amount of oxygen during the hours of maximum load and to prevent excessive consumption of electricity during the hours of minimum load [17].
The easiest and most effective algorithm for controlling the aeration system is to maintain a predetermined range of dissolved oxygen concentrations at significant points in the aerobic zones of aeration tanks. For aeration tanks which implement technologies for the oxidation of organic compounds, the optimal range of dissolved oxygen concentration is 1.2-1.5 mg/l at a point located at a distance of 2/3 of the length from the beginning of the aeration tank-displacer; for aeration tanks with a dispersed wastewater supply, the significant point is located at a distance of 1/2 the length of the aeration tank, for aerotanks-mixers, the analyzer of the dissolved oxygen concentration is installed at any point of the aerotank, but not closer than 1/3 from the wastewater supply point [6].

5. Conclusion
The aeration systems of biological wastewater treatment, described in this paper can be considered by specialists in the field of water management to select the appropriate equipment.

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References
[1] Dan N H, My Phe T T, Thanh B X, Hoinkis J and Luu T L 2021 The application of intermittent cycle extended aeration systems (ICEAS) in wastewater treatment Journal of Water Process Engineering 40 101909
[2] Zhao Y, Liu D, Huang W, Yang Y, Min J, Nghiem D L, Trinh T Q and Ngoc H T 2019 Insights into biofilm carriers for biological wastewater treatment processes: current state-of-the-art, challenges, and opportunities Bioresource Technology 288 121619
[3] Lianga J, Maia W, Tang J and Wei Y 2019 Highly effective treatment of petrochemical wastewater by a super-sized industrial scale plant with expanded granular sludge bed bioreactor and aerobic activated sludge Chemical Engineering Journal 360 15-23
[4] Akn B and Ugurlu A 2005 Monitoring and control of biological nutrient removal in a sequencing batch reactor Process Biochemistry 40(8) 2873-8
[5] Fang F, Han H J, Zhao Q, Xu C Y and Zhang L H 2013 Bioaugmentation of biological contact oxidation reactor (BCOR) with phenol-degrading bacteria for coal gasification wastewater (CGW) treatment Bioresource Technology 150 314-20
[6] Kharkina O 2015 Efficient operation and calculation of biological wastewater treatment facilities Volgograd, Panorama p 433
[7] Dyagelev M Y, Isakov V G and Grakhova E V 2019 α-factor experimental determination of aeration system in aeration tanks IOP Conference Series: Materials Science and Engineering 687(6) 066071
[8] Serpokrilov N and Smolyanichenko A 2010 Reduction of energy consumption of wastewater aeration systems Bulletin TGASU 3 192-9
[9] Moga I C, Ardelean I, Donțu O G, Moisescu C, Băran N, Petrescu G and Voicu I 2018 Materials and Technologies Used in Wastewater Treatment IOP Conference Series: Materials Science and Engineering 374 012079
[10] Kim S Y, Garcia H A, Lopez-Vazquez C M and et al 2020 Oxygen transfer performance of a supersaturated oxygen aeration system (SDOX) evaluated at high biomass concentrations Process Safety and Environmental Protection 139 171-81
[11] Chen X, Ding Z, Ding J and Wang Y 2018 Study on low intensity aeration oxygenation model and optimization for shallow water IOP Conference Series: Earth and Environmental Science 113 012203
[12] Orlov A V 2009 Intensification of the work of wastewater treatment plants using pneumohydraulic aerators Irkutsk p 181
[13] Hudenko B M and Shpirt E A 1973 Aerators for wastewater treatment Moscow, Stroyizdat p 231
[14] Esperança M N, Mendes C E, Rodriguez G Y and et al 2020 Sparger design as key parameter to define shear conditions in pneumatic bioreactors Biochemical Engineering Journal 157 107529

[15] Munz Ch and Roberts P V 1989 Gas- and liquid-phase mass transfer resistances of organic compounds during mechanical surface aeration Water Research 23 589-601

[16] Kirke B and Gezawy A E 1997 Design and model tests for an efficient mechanical circulator/aerator for lakes and reservoirs Water Research 31 1283-90

[17] Dyagelev M Y, Isakov V G and Grakhova E V 2019 Denitrification rates determination in the process of removing nitrogen from wastewater IOP Conference Series: Materials Science and Engineering 687(6) 066072

[18] Pino-Herrera D O, Fayolle Y, Pageot S and et al 2020 Gas-liquid oxygen transfer in aerated and agitated slurry systems with high solid volume fractions Chemical Engineering Journal 350 1073-83

[19] Andreev C I, Grishin B M and Hazov S P 2004 Highly efficient pneumatic aerator designs for biological wastewater treatment Penza p 10.

[20] Nepogodin A M, Isakov V G, Grakhova E V and Dyagelev, M.Y. 2020 The experience of laboratory flotation equipment for treating wastes from dairy IOP Conference Series: Earth and Environmental Science 548(5) 052070

[21] Dyagelev M Y, Nepogodin A M and Grakhova E V 2020 Determination of the flotation effectiveness of industrial waste water in a laboratory IOP Conference Series: Materials Science and Engineering 962 042077