ENERGY EFFICENCY PARAMETERS OF AERATION SYSTEMS IN WATER TREATMENT

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INTRODUCTION

Biological wastewater treatment in aeration tanks with activated sludge involves different types of processes, aeration systems (extended aeration, standard aeration, stepped cascade aeration, contact stabilization process, high loaded aeration, oxygen aeration) and methods of aeration (surface or deep aeration). The processes, systems and methods are chosen according to the flow and the composition of wastewater, and demanded quality after treatment.

Characteristic aeration systems parameters are: the capacity of introducing oxygen (kg O^2/h); the organic load for aeration tanks corrected in relation to tank volume (kg BOD/m^3·d); active sludge load (organic matter and dry sludge mass ratio) (kg BOD/kg DM·d); aeration process duration (h), recirculated sludge quantity from secondary precipitator into aeration tank (%); BOD reduce effect (%).

If the type of aeration process and method of aeration have previously been chosen, characteristic dimensions and tank form is determined according to designed capacity. Wastewater treatment plant should occupy the less possible construction land.

Aeration process and aeration equipment (supplying bacterial cultures in activated sludge reactors with oxygen) proper selection provides optimal working conditions and also the lowest exploitation costs.

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Performance indicators and the deep aeration system efficiency with different air distributor constructions were discussed. Main advantage of deep aeration is possibility of air flow regulation according to needs, which allows lower energy consumption. These systems also provide safety during winter period (there is no risk of installations freezing).

AERATION SYSTEMS IN WATER TREATMENT

Processes and equipment design involves: aeration method and equipment choice, aerator design data analyses and working industrial plants characteristics.

There are different criteria for systematization of aeration equipment in biological wastewater treatment.

Deep aeration or aeration under pressure and surface or mechanical aeration are in use for introducing air into aeration tanks. Deep aeration systems are consisted of compressors and submerged distributors which introduce air in form of bubbles. Surface aeration is performed using turbine aerators which mechanically provide contact between air and water surface in aeration tank. There are different combinations of these aeration systems, and types of submerged turbine aerators with air suction.

Different aeration systems are illustrated in Figure 1, and their basic characteristics are given in Table 1.

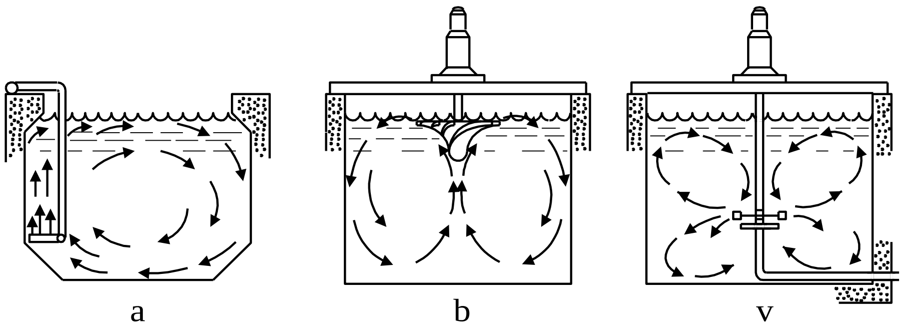

FIGURE 1. AERATION SYSTEMS: A - DEEP AERATION BY AIR DIFFUSERS; B - SURFACE AERATION; C - COMBINED AERATION [1]

Different materials are used in construction of air distributors: stainless steel, ceramics, porous plastics, thermoplastic materials, elastomers, etc. (Table 2).

According to type of material and design, distributors are classified: porous, with different perforations, tubular and nozzle type. Porous distributors are made of various porous materials (ceramics plates, porous tubes made of ceramic and plastic materials). Distributors with perforations are in the shape of pipe, plate or membranes with slits or pores.

Different sized bubbles are formed in air flow through porous distributors and distributors with perforations. Tubular distributors make inlet air flow that allows circulation of suspension and air in distributor body. Jet distributors are of injector type and they enable air and water mixing inside the nozzle mixing chamber.

According to the shape distributors are classified: plate, tubular, dome and disc shaped. According to bubble size distributors are classified: small sized (1 - 4 mm) made of ceramics and plastic; medium sized (5 - 10 mm) made of perforated tubes and big sized bubbles (more than 10 mm) made of vertical tubes opened on the bottom. Pores through which air flows depend on material porosity, or pores can be made by perforating of air distributor material.

With deep aeration (aeration under pressure) and different air distributor types many criteria are applied considering method and place of air distributors positioning in aeration tanks. Distributors can be placed over the entire bottom surface, on one side or on the particular deep of aeration tank. Layout of distributors must provide appropriate oxygen demands in aeration tank according to the chosen type of process.

TABLE 1. CHARACTERISTIC OF AERATION FACILITIES [1]

Equipment type	Equipment characteristics	Process	Advantages	Disadvantages
Porous deep aeration distributors	Dispersed air in form of small bubbles. Made of ceramic elements or pipes, pipes with plastic elements, synthetic material bags.	Regular process with active sludge.	High oxygen transfer efficiency. Good mixing.	High investment and exploitation costs. Pores soiling and failure.
Nonporous deep aeration distributors	Nozzles, ejectors, valves, slits, orifice plates. Bigger sized bubbles are formed.	Regular process with active sludge.	Minimal pores soiling. Low exploitation costs.	High investment costs. Low oxygen transfer efficiency.
Mechanical turbine aerators above water surface	Bigger diameter. Reduction drive is used. Small velocity on outlet shaft.	Regular process with active sludge and aeration in tanks.	Low investment and exploitation costs. High oxygen transfer efficiency.	Risk of installations freezing.
Mechanical screw-type aerators above water surface	High velocity on outlet shaft. Smaller diameter. Placed on platforms. Power is supplied directly from the engine.	Aeration in tanks.	Low exploitation costs. Simple assembly and exploitation. Moderate oxygen transfer efficiency.	Risk of installations freezing.
Submerged turbine or internal combustion engines	Compressed air is introduced through the air distribution ring.	Regular process with active sludge.	Full mixing. Higher energy consumption per tank volume. Used in deep tanks. Moderate efficiency. Wide range of air flow variation.	Reduction drive and compressor are required. Foam forming tendency. High installed power.

TABLE 2. TYPES OF AIR DIFFUSERS CONSIDERING THE TYPE OF PRODUCTION MATERIALS

Name		Material	
Perforated pipe		Stainless steel	
Ceramic distributor		Ceramics	- silicium based - aluminium based
Porous plastic distributors		Porous plastic	- rigid porous plastic: high density polyethylene (HDPE); styrene-acrylonitrile (SAN) - flexible porous plastic (polyethylene + rubber)
Membrane distributor	Flexible or perforated membrane air distributors	Thermoplastic material	- polyvinyl chloride (PVC) with additives
		Elastomers	- ethylene propylene dimer (EPDM) with additives

Liquid and gaseous phase contact time (efficiency of oxygen transfer) depends on distributor position and air flow velocity. Many other factors contribute to efficiency of oxygen transfer: water flow and water characteristics, aeration tank geometry, temperature, air bubble size, etc.

INDICATORS OF AERATORS OPERATION

In aeration systems 4 - 12 % of introduced oxygen mass brought by air is dissolved in water and used by microorganisms. Every single kWh of energy used by compressor or mechanical turbine allows to obtain 1,0 – 2,5 kg of dissolved oxygen.

Basic parameters of air distributor efficiency are: capacity of introducing oxygen, efficiency of oxygen transport, energy efficiency and specific energy consumption.

Capacity of introducing oxygen into wastewater should match oxygen consumption based on type of process and wastewater organic load. Oxygen consumption is defined by equation:

$$\dot{G}_{O_2} = r \cdot \left(BOD_5\right)_d \qquad , \frac{\text{kg O}_2}{\text{day}}, \tag{1}$$

where:

r , $\frac{\text{kg O}_2}{\text{kg BOD}_5}$, - oxygen transfer factor,

$(BOD_5)_d$, $\frac{\text{kg BOD}_5}{\text{day}}$, - daily wastewater organic load.

For chosen process type with active sludge there is recommended oxygen transfer factor (r), and daily wastewater organic load $(BOD_5)_d$ is calculated according to data on wastewater organic load (BOD_5) and water flow.

The actual capacity of introducing oxygen (OC) should be equal to oxygen consumption:

$$OC \approx \dot{G}_{O_2} \ .$$

The oxygen mass transfer coefficient under the standard conditions is determined in the following way [1]:

$$\left(k_L a\right)_s = \frac{\left(k_L a\right)_{t_L}}{\theta^{t_L - 20}} \text{ ,1/s,} \qquad (2)$$

where

- $\left(k_L a\right)_{t_L}$,1/s, - oxygen mass transfer coefficient obtained experimentally,
- t_L ,°C, - temperature of water in the course of experiments,
- θ = 1,024 - temperature correction factor [2].

Basing upon the known oxygen mass transfer coefficient $\left(k_L a\right)_s$ the following technical characteristics of aeration systems in which the wastewaters aeration is performed are calculated:

- actual capacity of introducing oxygen (*OC*);
- specific capacity of introducing oxygen (OC_h);
- actual efficiency of oxygen transport *E*;
- actual energy efficiency of oxygen transport E_e.

The actual capacity of introducing oxygen into the wastewater is determined basing upon expression [3]:

$$OC = \alpha \cdot \left(OC\right)' \cdot \frac{\beta \cdot \left(c^*\right)_h - c_o}{c_s^*} \cdot \theta^{\left(t_L - 20\right)} \text{, kg } O_2\text{/h,} \qquad (3)$$

where

- $(OC)'$, kgO_2/h, - standard capacity of introducing oxygen into the wastewater,
- α = 0,8 ÷ 0,94 - relative degree of oxygen transfer in relation to clean water,
- β = 0,90 ÷ 0,97 - relative degree of saturation in relation to clean water,
- $(c^*)_h$,kgO_2/m^3, - equilibrium volume mass concentration of oxygen dissolved in clean water under actual conditions, corrected in relation to the liquid column height above the air distributor and the molar part of oxygen in the air

$$\left(c^*\right)_h = c_s^* \cdot \left[1 + \frac{\rho_L \cdot g}{p_n} \cdot \left(H - h\right)\right],$$

- c_s^* ,kgO_2/m^3, - equilibrium volume mass concentration of oxygen dissolved in clean water,

- $p_n = 101300 Pa$ - pressure corresponding to normal conditions,
- H , m, - total height of the water column above the air distributor,
- h ,m, - height of the water column above the air distributor for which the equilibrium concentration of oxygen in water is attained.

The actual capacity of introducing oxygen (*OC*) into the wastewater should correspond to the oxygen consumption in the biological treatment.

The specific capacity of introducing oxygen into the wastewater is determined by using the following expression [2]:

$$OC_h = \frac{1000 \cdot (OC)'}{(\dot{V}_G)_n \cdot H}, \frac{\text{g O}_2}{\text{m}^3 \cdot \text{m}}, \tag{4}$$

where

- $(\dot{V}_G)_n$, m^3/h, - air flow under normal conditions.

The actual efficiency of oxygen transfer is expressed in percent and is defined by the relationship of the real capacity of introducing oxygen and the total oxygen flow delivered by the aeration device, i.e. [4]:

$$E = \frac{OC}{\left(\dot{G}_{O_2}\right)_{aeration}} = \frac{OC}{(\dot{V}_G)_s \cdot \rho_G \cdot y_{O_2}} \cdot 100 \text{ ,\%}, \tag{5}$$

where

- $\left(\dot{G}_{O_2}\right)_{aeration}$,kg/h, - oxygen mass flow introduced into the water by the aeration system,
- $(\dot{V}_G)_s$,m^3/h, - volume air flow at p_n=1,013 bar and t_G=20^{o}C,
- ρ_G , kg/m^3, - air density at p_n=1,013 bar and t_G=20^{o}C,
- y_{O_2} = 0,232 kgO_2/kgG - oxygen content in the air.

The actual efficiency of oxygen transfer in air distributor is in relation with position (depth) of air distributor and oxygen flow (Figure 2).

The actual energy efficiency of the transfer of oxygen represents the relationship of the actual capacity of introducing oxygen and the engaged power necessary for driving the aeration device, i.e.,

$$E_e = \frac{OC}{\sum_i P_i} \text{ , kg/kWh,} \qquad (6)$$

where

$\sum_i P_i$,kW, - sum of power consumption for all electric motors (for driving aerator, blowing pump, etc.).

Important indicator for compressor plant and the whole aeration system is pressure drop on one distributor. Most often distributor manufactures provide this parameter in the form of diagrams (Figure 5). Pressure drop increases with increase of air flow.

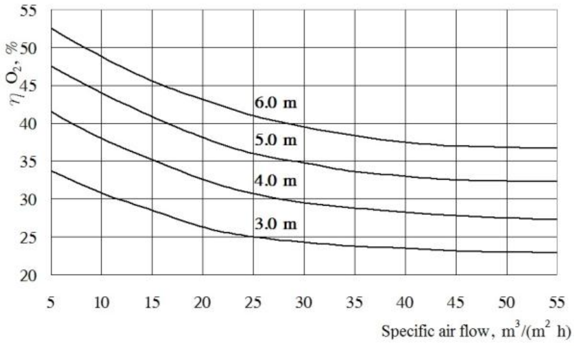

FIGURE 2. STANDARD OXYGEN TRANSFER EFFICIENCY IN FUNCTION OF AIR FLOW [2, 3]

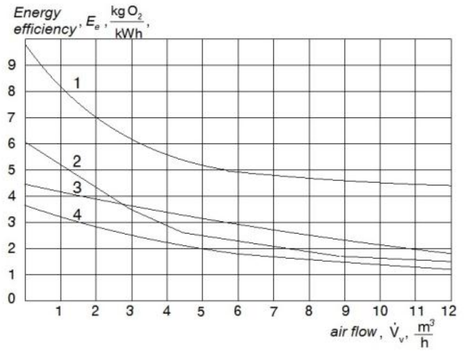

FIGURE 3. STANDARD ENERGY EFFICIENCY IN FUNCTION OF AIR FLOW FOR FOUR DIFFERENT TYPES OF AIR DIFFUSER [2]

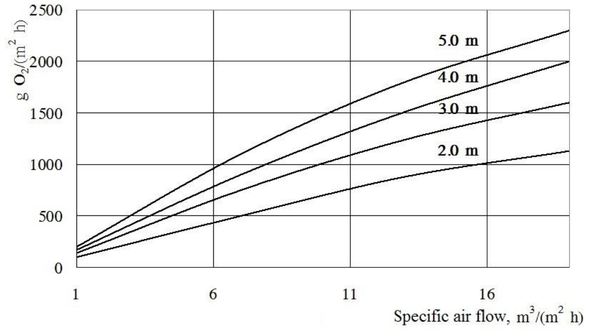

FIGURE 4. STANDARD OXYGEN SPECIFIC CAPACITY IN FUNCTION OF AIR FLOW [3]

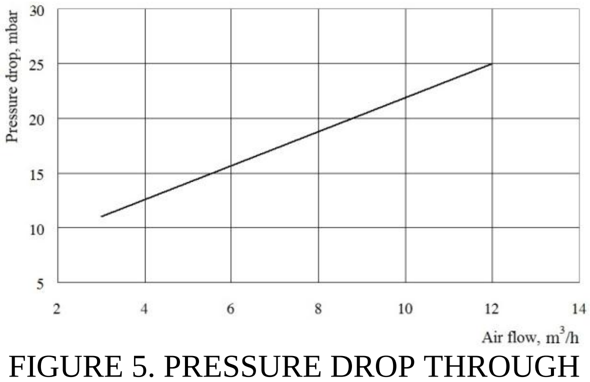

FIGURE 5. PRESSURE DROP THROUGH AIR DIFFUSER [4]

CONCLUSION

Basic parameters of aeration efficiency were analyzed in this paper in order to determine a unique approach to compare energy efficiency of different system constructions.

Basic construction and operational characteristics of aeration equipment that are used in aerobic biological treatment of municipal and industrial wastewater were discussed in this paper.

Analyzed parameters that define air distributor efficiency (for deep aeration systems) are: capacity of introducing oxygen, efficiency of oxygen transport, energy efficiency and specific energy consumption.

Given relations for specified indicators represent examples from aeration equipment manufactures catalogues.

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