MAIN CONDITIONS OF WASTEWATER AERATION UNIT DESIGN PARAMETERS SELECTION

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Abstract. The research paper discusses importance of wastewater aeration as one of the most important parts of wastewater biological treatment from energy point of view because of high energy consumption and non-stop operations. Thus proper choice of constructive parameters of the wastewater aeration system is not only a technical, but also an economic problem. Research on the impact of the design parameters of aeration system on the efficiency of oxygen dissolving was done, and the increase of the aeration tank depth as a solution to decrease air blower capacity and electrical power consumption was used observed and evaluated. The research showed that through increase of aeration tank depth from 4 meters to 6 meters results in the decrease of air blower capacity from 2466 m^3/h to 1565 m^3/h, and summary decrease of necessary electrical power of electrical motor from 39 kW to 37 kW. This results in direct savings from electrical power consumption and additional savings from reduced number of diffusers per m^3 of aeration area.

Key words: wastewater, aeration unit, air blower, capacity, parameters design.

Introduction

Wastewater aeration units provide uninterruptible and sufficient air oxygen supply to the aeration tanks of wastewater biological treatment systems (WBTS) in order to supply the water treatment microbes with the necessary amount of oxygen. The air supply system including the air blower powered by high-power asynchronous electrical motors, and the wastewater aeration tank with aeration diffusers for unified and equal air distribution within the wastewater are the main and most important parts of the wastewater aeration unit. Optimal control of wastewater aeration electrical motors and choice of appropriate constructive and technological parameters of wastewater aeration tank are very important in order to get an optimal technical, technological and economically viable construction of the wastewater aeration unit [1, 2].

Currently there are different wastewater aeration tanks in use in Latvia. Usual depth of these aeration tanks is in the range from 4 to 6 meters. The research was done to find out the impact of constructive parameters of the wastewater aeration tank on the technical and economical parameters of aeration and wastewater treatment quality.

Research object and methods

The research object chosen is the wastewater aeration unit, which includes a wastewater aeration tank, aeration supply and delivery system and an air blower. The aim of the research – to find out how the change of constructive parameters of the wastewater aeration tank (geometrical dimensions of aeration tank, density of aeration diffusers in the aeration tank, positioning of these aeration diffusers in the tank, etc.) change the efficiency of air oxygen use in the wastewater treatment process, and what is the impact of these parameters on the capacity of the air blower.

The research done previously [3, 4] allows to create quasi empirical equations and formulas which allow to present the principles of interconnection between oxygen utilization efficiency η, capacity of the air blower L_g and wastewater and aeration system parameters. In order to find out these principles, physical parameters of wastewater (temperature, supply of wastewater, concentration of dissolved oxygen and biological consumption of oxygen for the given type of wastewater), were assumed as constant.

Dependence of air oxygen utilization efficiency on the constructive parameters of the aeration tank

Air oxygen utilization efficiency η_o can be calculated using the quasi empirical formula (1) which was created using the company *Flygt* catalog for wastewater aeration systems [3]:

$$\eta_o = [1-\exp(-0.083\cdot h)]\cdot\exp[-(0.11-0.008\cdot h)\cdot\lambda_d\cdot\exp(-2.2\cdot\sigma_s)], \quad (1)$$

where h – wastewater aeration diffuser submerging depth, m;

$\lambda_d = \dfrac{L_g}{n_d \cdot S_a}$ – air supply through one disk diffuser, m^3/h;
n_d – number of disk diffusers on one square meter of the aeration tank surface, m^{-2};
S_a – area of the aeration tank surface, m^2;
L_g – air capacity supplied to the aeration tank, m^3/h;
$\sigma_s = n_d \cdot S_a$ – density of disk diffusers on the aeration tank surface;
S_a – area of disk diffuser active surface of, m^2.

Using formula (1), the characteristics of the aeration efficiency η as a function of different constructive parameters of wastewater aeration system – h, λ_d, σ_s, were presented (Fig. 1).

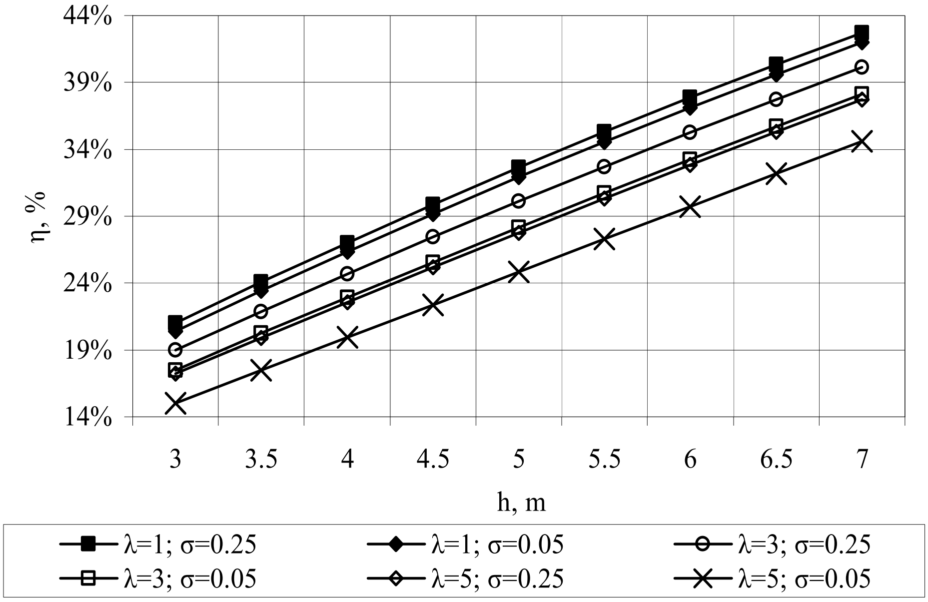

Fig. 1. **Air oxygen utilization efficiency η_o as a function of the wastewater aeration diffuser submerging depth h, density of disk diffusers on the aeration tank surface σ_s and air supply through one disk diffuser λ_d**

The constructive parameters of wastewater treatment systems are very different, although we can separate them in three groups – large – for large towns and cities, medium size – for small and medium towns, and small size – for villages and private use. The depth of aeration tanks for small size treatment systems is usually between 3 and 4 meters, for medium size – between 4 and 6 meters, and for large – between 6 and 9 meters. The usual size of wastewater treatment systems in Latvia cities with the population between 10 and 70 thousands is medium size with the depth of aeration tank between 4 and 6 meters.

The graph (Fig. 1) shows that the wastewater aeration diffuser submerging depth h and air supply through one disk diffuser λ_d have reasonably high impact on air oxygen utilization efficiency η. Air oxygen supply at the same time is influenced by the density of disk diffusers on the aeration tank surface σ_s. As the number of disk diffusers per square meter of the aeration tank surface is higher, as lower intensity of air supply through one diffuser, and the efficiency of oxygen utilization is higher.

Air oxygen utilization efficiency is being calculated as a proportion of dissolved air oxygen against supplied air oxygen by aeration system, because the microbes, which are the main players in the wastewater treatment, can use only dissolved oxygen. Oxygen, which was supplied through the aeration system, but did not dissolve during the air bubble contact with wastewater, is floating to the surface of the wastewater in the aeration tank, and disappears in the atmosphere. As the smaller the air bubbles coming out from disk diffusers into the wastewater, the higher the contact area, and the longer the contact time of the air bubble with the wastewater, the higher is the concentration of oxygen in the wastewater.

These are the main reasons why with the increase of the aeration tank depth h the air oxygen utilization efficiency η is increasing. Accordingly, with the decrease of air supply through one disk diffuser, as well as with decrease of air pressure in the aeration system the kinetic component of air bubbles floating through the wastewater layer is decreasing, resulting in longer contact time of the air bubble with the wastewater.

At the same time diffusers density increase is directly connected with increase in investments. For that reason in order to choose proper technological and technical parameters of the wastewater aeration system, one should make thorough technical and economical analysis. The main criteria for the decision making must be investment payback period for particular wastewater aeration model, which is strongly influenced by the system electric energy consumption, especially because the wastewater aeration system is working 24 hours a day whole year round.

Air supply reduction options

The research results about the influence of different factors to the air oxygen utilization efficiency [3, 5], allow to design the formula (2) for the necessary air supply intensity L_g taking in account wastewater and aeration system conditions and constructive:

$$L_g = \frac{Q \cdot (L_a - L_t) \cdot \exp\left[(0.11 - 0.008 \cdot h) \cdot \lambda_d \cdot \exp(-2.2 \cdot \sigma_s)\right]}{5.8 \cdot \left[1 - \exp(-0.1 \cdot h)\right] \cdot (0.02 \cdot T + 0.6) \cdot \left[(0.0025 \cdot T^2 - 0.3 \cdot T + 14.2) \cdot (1 + 0.05 \cdot h) - C\right]}, \quad (2)$$

where Q – wastewater supply, m^3/h;
L_a – biological oxygen need BON for wastewater treatment, g/m^3;
L_t – remaining BON after wastewater treatment, g/m^3;
h – wastewater aeration diffuser submerging depth, m;
λ_d – air supply through one disk diffuser, m^3/h;
σ_s – density of disk diffusers on the aeration tank surface;
T – wastewater temperature, ^oC;
C – oxygen concentration in the wastewater, g/m^3.

In order to reduce uncertainty, wastewater parameters are set constant. Then the parameters of the real wastewater biological treatment system (WBTS) of Tukums city are used to calculate the model. They are the following:

- wastewater supply Q = (146-258) m^3/h;
- biological oxygen need BON for wastewater treatment L_a = (108-320) g/m^3;
- remaining BON after wastewater treatment L_t = (8-10) g/m^3;
- wastewater aeration diffuser submerging depth h = 4 m;
- calculated air supply through one disk diffuser λ_d = 2 m^3/h;
- number of disk diffusers on the aeration tank surface n_d = 1.5 m^{-2}, which is equal to σ_s = 0.063 or 6.3%.

For calculation purposes the mean values had been used: Q = 200 m^3/h, $L_a - L_t$ = 200 g/m^3, T = 10 ^oC, C =2 g/m^3, λ_d = 1.5 m^3/h, h = 4 m, σ_s = 0.063. Calculation results are presented in Fig. 2. The variable was the wastewater aeration diffuser submerging depth h. The values of λ_d and σ_s remain constant only for the basic curve. An adjusted curve was created when λ_d recalculated to adjust the change of the aeration tank geometry – with the increase of the depth the value of λ_d decreased proportionally.

In this model σ_s remained constant also for the adjusted curve, which means that with increase of the aeration tank depth (and increase of the wastewater aeration diffuser submerging depth h accordingly) the overall number of disc diffusers decreases proportionally. If the wastewater aeration diffuser submerging depth h increases from 4 meters to 6 meters (i.e. 1.5 times), the number of diffusers decreases 1.5 times or by 33.3%. This summarizes in the decrease in the money investments for disc diffusers also by at least 33.3%.

Calculations using data from Tukums city WBTS show that by increasing aeration the tank depth (and increase of the wastewater aeration diffuser submerging depth h accordingly) from 4 meters to 6 meters reduces the air supply intensity L_g from 2466 m^3/h to 1565 m^3/h or 1.576 times.

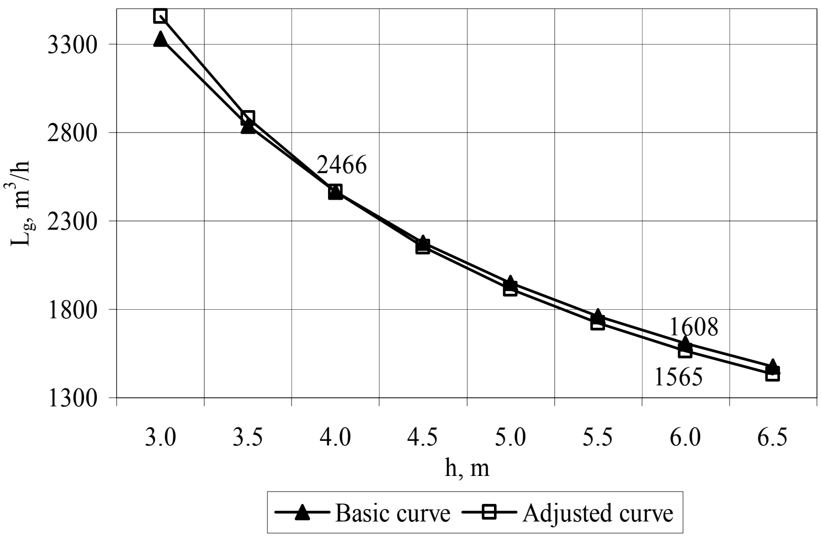

Fig. 2. **Air supply intensity L_g as a function of the wastewater aeration diffuser submerging depth *h*, density of disk diffusers on the aeration tank surface σ_s and air supply through one disk diffuser λ_d**

Wastewater aeration unit constructive parameters impact on the electrical energy consumption

The aeration units of the latest WBTS are designed using air blowers powered by asynchronous electrical motors with frequency converters. Observation of the energy transfer process where electrical power taken from the grid P_t is being converted into mechanical energy P_m to turn the air blower shaft, and provide the necessary air supply intensity in the aeration system (Fig. 3).

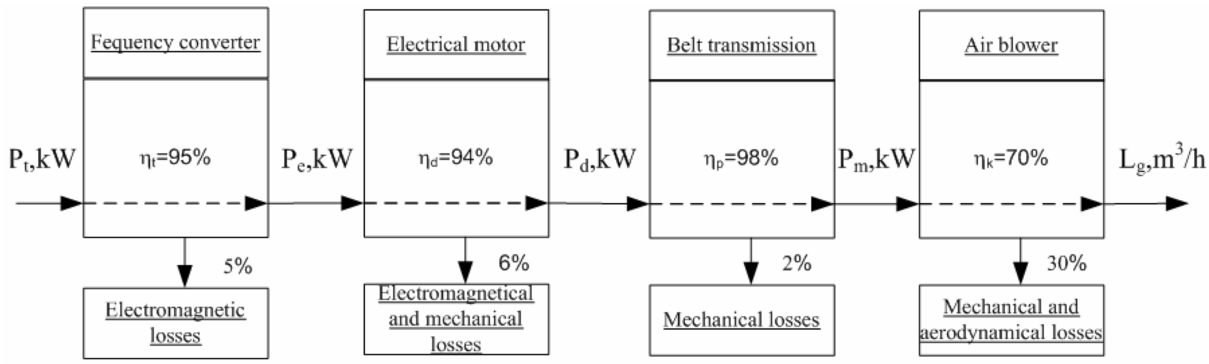

Fig. 3. **Power balance of wastewater aeration system**

As it is presented in Fig. 3, energy transfer and transformation take place in several devices, and each device has its own efficiency η. The aeration unit electrical power consumption P_t can be calculated knowing the necessary mechanical power on the air blower shaft, and the efficiencies of all devices between electrical grid and air blower shaft. The formula to compute electrical power is as follows:

$$P_t = \frac{P_m}{\eta_f \cdot \eta_d \cdot \eta_p} = \frac{P_m}{\prod_{i=1}^{k} \eta_i} , \quad (3)$$

where P_k – air blower power;
η_f – frequency converter efficiency;
η_d – electrical motor efficiency;
η_p – transmission efficiency.

Using the data from Fig. 3, we can calculate the overall efficiency of power transmission and transformation from electric grid to the air blower shaft $\eta = \eta_f \cdot \eta_d \cdot \eta_p = 0.95 \cdot 0.94 \cdot 0.98 = 0.875$.

Air pressure to be provided by air blower must be bigger than counter-pressure of wastewater in the depth h. The calculation provided in this article takes in account that if the wastewater aeration diffuser submerging depth $h = 4$ m, the air pressure provided by the air blower must be at least $p_1 = 400$ mbar. At the same time in this depth the air blower must provide the air supply intensity $L_{g1} = 2466$ m^3/h. From the air blowers catalogue, the mechanical power necessary to supply the mentioned amount of air under the pressure of 400 mbar is $P_{k1} = 34.1$ kW. At the same time, as we calculated previously, if the wastewater aeration diffuser submerging depth $h = 6$ m, the air supply intensity $L_{g2} = 1565$ m^3/h, and pressure $p_2 = 600$ mbar. Now we can calculate the electrical power necessary to drive the air blower for the aeration tank with the wastewater aeration diffuser submerging depth $h = 6$ m. The formula describing interconnection between the Roots twin rotor type air blower power, air supply intensity and the necessary pressure was used:

$$P_{k2} = \frac{P_{k1} \cdot L_{g2} \cdot p_1}{L_{g1} \cdot p_2} \quad . \tag{4}$$

Using appropriate numbers, we can find out that $P_{k2} = (34.1 \cdot 1565 \cdot 6)/(2466 \cdot 4) = 32.4$ kW – necessary power to drive the air blower, if $h = 6$ m.

Taking in account the losses during the energy transformation and transfer from electrical grid to the air blower shaft, the necessary electrical power for both simulated models – when h = 4 m and h = 6 m, was calculated. Accordingly $P_{t1} = P_{k1}/0.875 = 38.97$ kW, and $P_{t2} = P_{k2}/0.875 = 37.09$ kW. The power difference is $\Delta P = P_{t1} - P_{t2} = 1.88$ kW, showing that with the increase of the wastewater aeration diffuser submerging depth h from 4 meters to 6 meters there is a decrease of the necessary electrical power. Decrease of the power consumption from the grid has also economical consequences – as the air blower is working 24 hours a day, this summarizes in 8760 hours annually. If the power supply decreases by 1.88 kW, the economy of electrical energy is $\Delta A_t = \Delta P \cdot t_g = 1.88 \cdot 8760 = 16469$ kWh annually. The current tariff to be paid in Latvia for electrical energy is 0.0334 Ls/kWh, and annual economy from the increase of the wastewater aeration diffuser submerging depth h from 4 meters to 6 meters is $E_g = 16469 \cdot 0.0334 = 550$ Ls.

Conclusions

1. Analysis of the factors influencing air oxygen utilization efficiency η proves that the wastewater aeration diffuser submerging depth h is the most influential. Calculations show that by increase of the wastewater aeration diffuser submerging depth h from 4 meters to 6 meters (capacity of the aeration tank and the oxygen dissolving ratio kept constant) allows to decrease the air blower capacity more than 1.5 times.
2. Electrical energy savings, when the wastewater aeration diffuser submerging depth h increases from 4 meters to 6 meters, are at least 3.2%.
3. Reduced number of disk diffusers can be a much more important source of financial investments savings, because it is proportional to the wastewater aeration diffuser submerging depth h increase ratio.

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