INCREASING THE PERFORMANCE OF OXYGENATION INSTALLATIONS

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Abstract. The paper aims to demonstrate that fine bubble generators manufactured by spark erosion are more efficient than generators endowed with porous diffusers. Pressure losses experimentally established are presented and energy consumption needed for water oxygenation is calculated. In the tank with water we place a fixed fine bubble generator. Using the geometrical similarity, we oxygenate the water from another tank using a mobile fine bubble generator, by this marking out the benefits of the mobile fine bubble generators.

Keywords: oxygen meter, fine bubble generator, oxygen dissolved in water.

1. INTRODUCTION

The transfer of oxygen towards water that occurs in aquariums and fish farms, as well as in used waters, represents an important problem in the implementation of aeration technologies.

If fine bubble aeration [1] is used, important energy savings are obtained, of 20 ÷ 50 % of the energy needed for aeration [2].

A percentage of 67% of the energy consumption of the cleaning plant is represented by the energy consumption of the waste water treatment process [1, 2].

The energy consumption can be decreased by using fine bubble generators (FBG) with small pressure losses; in the same time, the efficiency of the oxygen transfer towards water has to be high and the compressed air consumption has to be reduced.

Air pressure at the fine bubble generator input is a very important parameter used in the selection and monitoring of fine bubble generators, independently of their shape or material from which they are manufactured. Its monitoring is needed during the functioning of the aeration plant because it indicates if the fine bubble generator is working correctly by the fact that each choking of the FBG nozzles automatically leads to an increase of the air pressure at the input.

The nozzle dimensions are highly important parameters that characterize a FBG, because they directly influence its work pressure. The work pressure of a FBG is in fact the pressure of air found under the nozzle plate.

The first part of the paper presents two constructive solutions:
- Version I: FBG endowed with porous diffusers;
- Version II: FBG with plates that feature nozzles manufactured by spark erosion.

Pressure losses and energy consumption in the case of an aeration process will be specified for both versions.

The second part of the paper presents an aeration system with mobile fine bubble generators is more efficient than one using the fixed ones, because the air bubbles have a larger trajectory during their way through the water; the contact between the air bubble and the water increases.

Following the theoretical and experimental researches conducted in the laboratory of Thermotechnics, Engines, Thermal and Refrigeration Equipment from UPB it was found that the increase of oxygenation installations performance can occur in two ways:
- a) Replacement of porous ceramic diffusers with fine bubble generators (FBG) with very low pressure losses;
- b) Using the mobile FBG that reduce water oxygenation time compared with fixed FBG.

2. FINE BUBBLE GENERATORS WHERE THE POROUS PLATE IS MANUFACTURED FROM CERAMIC MATERIALS

The shape of porous diffusers can be circular, rectangular etc.; the diameter of circular diffusers can be of Ø50, Ø100 or Ø150 [2]. The manufacturing process can lead to various porosity values,
the pore diameter being in the range of $4 \div 500 \mu m$. Figure 1 presents a photograph of an Ø150 mm porous diffuser.

![Fig. 1. Aspect of Ø150 ceramic porous diffuser.](image)

For this type of FBG, pressure losses remain high enough compared to the values specified in the technical documentation provided by renowned manufacturers DIFFUSER EXPRESS [4], TRAILLGAZ [5]. Figure 2 presents the variation of the pressure loss ($\Delta p$) in the case of a Ø150 FBG in function of the flow rate of the air that passes through the FBG.

Three different lots of ceramic porous diffusers with different volumetric porosity were tested [2] – Figure 2.

![Fig. 2. Variation of pressure loss in function of the air flow rate.](image)

It can be noticed from figure 2 that a pressure loss of $1.0 \div 1.2 \, \text{H}_2\text{O}$ occurs for $V = 600 \, \text{l/h}$.

The medium value of the pressure loss is of $\Delta p_1 = 1.1 \, \text{mH}_2\text{O} = 1100 \, \text{mmH}_2\text{O} = 11213 \, \text{N/m}^2$. This pressure loss refers specifically to the FBG and does not include the losses in the compressed air supply network.

3. FINE BUBBLE GENERATORS WHERE THE POROUS PLATE IS BUILT FROM METAL PLATES PERFORATED BY SPARK EROSION

A high performance FBG must have a pressure loss as reduced as possible and to emit bubbles uniformly on its whole surface [6, 7].

Figure 3 presents a new type of FBG where the porous plate is built from an aluminum plate with Ø0.5 mm nozzles manufactured by spark erosion.

The nozzles size establishes the size of the gas bubble [8].

This type of FBG was put to tests using an experimental plant built in the laboratories of POLITEHNICA University of Bucharest. Other types of FBG with nozzles manufactured by spark erosion are presented in [9, 10].

Figure 4 presents the principle scheme of the plant used for water oxygenation.

![Fig. 3. Section through a rectangular shape FBG: 1 – holder; 2 – compressed air supply pipe; 3 – FBG body; 4 – screw for fastening the plate to the body; 5 – nozzle plate.](image)

During dynamic conditions, air flows through the A-B pipe (Fig. 4), inflows the FBG body and enters through the nozzles in the water from the tank. The air pressure at the input of the FBG body has to surmount hydrostatic load, surface tension and pressure losses [11]:

$$ p_1 = \rho_{\text{H}_2\text{O}} \cdot g \cdot H + \frac{2\pi}{r_0} + \Delta p_{\text{II}} \, [\text{N/m}^2] \quad (1) $$

If $p_1$ is known, using this relation one can find the value of $\Delta p$:

$$ \Delta p_{\text{II}} = p_1 - \rho_{\text{H}_2\text{O}} \cdot g \cdot H + \frac{2\pi}{r_0} \, [\text{N/m}^2] \quad (2) $$
Experimental measurements led to the following data:

\[ p_1 = 583.44 \text{ mmH}_2\text{O} = 5723.5 \text{ N/m}^2 \]

In the equations above, \( H \) is the height of the water layer above the FBG; \( H = 0.5 \text{ m} \); \( r_o \) – inner radius of a nozzle; \( r_o = 0.25 \cdot 10^{-3} \text{ m} \); \( \sigma \) – surface tension coefficient of water; \( \sigma = 73 \cdot 10^{-3} \text{ N/m} \).

By replacing in (1), one obtains:

\[ \Delta p_{II} = 5723.5 - 1000 \cdot 9.81 \cdot 0.5 - \left( \frac{2 \cdot 73 \cdot 10^{-3}}{0.25 \cdot 10^{-3}} \right) = 244.35 \text{ N/m}^2 \]

This value is lower than the one calculated from the version I (\( \Delta p_{II} < \Delta p_I \)).

Between the two versions there is a difference:

\[ \Delta p = \Delta p_I - \Delta p_{II} = 11213 - 244.35 = 10968.65 \text{ N/m}^2 \]

The energy consumed in an aeration process (\( E \)) is computed using the following relation [2]:

\[ E = V \cdot \Delta p \cdot \tau \text{ [J]} \]

where: \( V \) is the volumetric air flow rate [m$^3$/s]; \( \Delta p \) – pressure loss [N/m$^2$]; \( \tau \) – working time of the plant [h].

\[ \Delta E = 600 \cdot 10^{-3} \cdot 10968.65 \cdot 1 = 6581.19 \text{ [J/h]} \]

During one year, with the functioning of a single GBF is obtained annual energy savings:

\[ \Delta E = \frac{6581.19 \cdot 24 \cdot 365}{3.6 \cdot 10^6} = 16.114 \text{ [kWh/year]} \]

Obviously in wastewater treatment plants, the number of F.B.G. is in the range of thousands, so there is a significant energy saving.

4. THE EXPERIMENTAL SETUP FOR TESTING THE FUNCTIONING OF MOBILE FINE BUBBLE GENERATORS

In order to establish a relationship between the functioning of fixed and mobile FBGs, namely to make a comparison between them, we used a similitude of dimensions and time scales [6].

Thus, the tank where the fixed FBG is introduced has water with a volume of \( V = 0.5 \cdot 0.5 \cdot 0.5 = 0.125 \text{ m}^3 \) (Fig. 5.a). This tank is oxygenated with an fixed FBG for two hours with an air flow \( V = 600 \text{ dm}^3/\text{h} \) and \( H = 500 \text{ mm H}_2\text{O} \).

In this case, the dissolved \( O_2 \) concentration in water increase from \( C_0 = 5.46 \text{ mg/l} \) to \( C_{120} = 8.31 \text{ mg/l} \).

If tank size is increased eight times on the Ox axis is obtain (Fig. 5.b), a volume of \( 8 \cdot 0.125 = 1 \text{ m}^3 \).

If in this tank is mounted one fixed FBG, in order to reach from \( C_0 \) to \( C_{120} \), we need a greater time, theoretically equal to \( 8 \cdot 2h = 16h \).

What happens if in the large tank is inserted a mobile FBG with the same features and aerates using the same flow rate equal to that used in the GBF Fixed?

To perform the measurements, it proceeds similarly as in the case of fixed FBG, as follows:

The water tank is filled to a height \( h = 0.5 \text{ m} \), the aeration installation starts and aerates the water in the tank by moving FBG between A-B points (Fig. 6). At each end of the tank, FBG is rotated with 180° so that the curve generated by the trajectory of air bubbles to be the same and always against the displacement direction.

Figure 6 presents a general sketch of a mobile FBG.
The height of the water layer is the same (0.5 m) for the fixed FBG and for the mobile FBG. The water volume for the mobile FBG is eight times bigger than for the fixed FBG. As we know the dimensions of the tank, we can begin the designing of the displacement system of the fine bubble generator.

Fig. 5. The sketch of aeration tanks: a – aeration tank for fixed FBG; b – aeration tank for mobile FBG.

Fig. 6. Sketch for the measurement of the concentration of dissolved oxygen for mobile FBGs: 1 – water tank; 2 – A-B: the displacement distance of a mobile FBG; 3 – mobile platform; 4 – electric engine for the displacement of the platform; 5 – mechanical system for the 180° rotation of the FBG at the points A and B; 6 – FBG, with 17 holes, Ø 0.5 mm.

Fig. 7. The displacement system of a mobile FBG (upper view): 1 – mobile platform on wheels; 2 – electric stepping motor; 3 – gear wheels; 4 – platform wheeled axle; 5 – intermediary axle; 6 – elastic coupling; 7 – motor driver; 8 – personal computer; 9 – stepping motor; 10 – rod solidary with the FBG; 11 – gear wheels; 12 – gear belt.
To displace the FBG all along the tank edge we consider a mobile platform. In order to keep the same trajectory of the air bubbles at every end of the tank, we must rotate the fine bubble generator with 180°. Hereby, we will need two electro-mechanical systems, which are exposed in Figure 7 [12]:

- One for the displacement of the mobile platform; such a system is composed by a wheeled mobile platform (1) an electric stepping motor (2) and a transmission system of the rotational motion from the motor axle to the platform wheels, composed by two mating gears (3), one solidary with the platform axle (4) and the other with an intermediary axle (5) and an elastic coupling (6) to reduce the vibrations and positioning errors of the motor, a control driver of the motor (7) and a hardware-software system for the programming of the PC-type driver (8) with an integrated software.

- And a second system for the rotation of the FBG at the two ends of the tank, composed by an electric stepping motor (9), a rod solidier to the FBG (10) through which the compressed air circulates and a transmission system of the rotational movement from the motor shaft to the FBG rod composed by two gears (11), a gear belt (12) and an electronic driver for the control of the motor (7).

These two systems were thought, designed and built to be as light as possible, in order to displace the platform on the edge of the aeration tank with the most reliability and control as possible. Therefore we have chosen electrical stepping motors with professional control drivers. In the next figures we can remark the assembling and the working manner of the equipments but also the wholeness of the designed structure.

The total duration of aeration time is found using the same similarity as in the case of dimensioning of the tank, so that, if for the fixed FBG we have a total oxygenation time of 120 min (2 h), multiplied by the constant of similarity we achieve a total oxygenation time of 960 min (16 h).

Following the experimental researches it was found that to get the same value from \( C_0 \) to \( C_{120} \) are not necessary 16 hours but only four hours.

The results of theoretical and experimental researches in the field of water oxygenation are presented also in other papers [13-18].

5. CONCLUSIONS

1. The use of porous diffusers has the following disadvantages:
   - Emitted air bubbles have uneven diameters;
   - Air bubbles appear irregularly, only on certain parts of porous diffusers surface;
   - The porous diffusers have significant pressure losses.

2. The use of FBG with plates perforated by spark erosion has the following advantages:
   - A uniform distribution of the nozzles on the plate surface, according to the designer’s specifications, is assured;
   - Nozzle diameters being equal, air bubbles with the same shape and diameter are emitted; it is possible to control the air flow;
   - There is no risk of choking the perforated plate;
   - Due to small pressure losses, a significant economy of energy \( \Delta E = 16.114 \text{ kWh} / \text{an} \) for each functioning FBG appears.

3. A benefit of using mobile fine bubble generators in the oxygenation process of the water,
compared to the fixed ones, consists in reducing 4 times the time of reaching a desired concentration of oxygen dissolved in water.

4. The consumption of energy needed for aeration represents about 67% from the total consumption of a cleaning plant. This high percentage explains the scientific researches regarding the obtaining of FBGs with reduced pressure losses.

5. The development of water oxygenation using FBGs with plates perforated by spark erosion helps energy saving and efficient protection of environment.

BIBLIOGRAPHY


