Decrease of Energy Consumption in the Case of Water Oxygenation Processes

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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. The advantages of using fine bubble generators endowed with plates with nozzles manufactured by spark erosion are emphasized.

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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 \cite{1} is used, important energy savings are obtained, of 50 % of the energy needed for aeration \cite{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 \cite{1-2}. 

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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 aeration devices are classified in the following categories:
- FBG where the porous plate is manufactured from ceramic materials;
- FBG where the porous plate is built from perforated elastic diaphragms;
- FBG where the porous plate is built from metal plates with nozzles.

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 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.

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 around 300μm. Figure 1 presents a photograph of a Ø150 mm porous diffuser.

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 (Δp) 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] – fig. 2.
It can be noticed from figure 2 that a pressure loss of $1.0 \div 1.2$ H$_2$O occurs for $V = 600 \text{ l/h}$. The medium value of the pressure loss is of $\Delta p=1.1$ mH$_2$O=1100mmH$_2$O. This pressure loss refers specifically to the FBG and does not include the losses in the compressed air supply network.

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

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

(1)

where:
- $\dot{V}$ - volumetric air flow rate [m$^3$/s];
- $\Delta \dot{p}$ - pressure loss [N/m$^2$];
- $\tau$ - working time of the plant [s].

The pressure loss $\Delta \dot{p}$ has two components:

\[ \Delta \dot{p} = \Delta \dot{p}_r + \Delta \dot{p}_{GFB} \ [N/m^2] \]

where:
- $\Delta \dot{p}_r$ - the pressure loss on the compressed air supply network, namely from the compressor output to the FBG input.
- $\Delta \dot{p}_{GFB}$ - the pressure loss that appears during the passage of the air through the FBG.

The computation of $\Delta \dot{p}_r$ is not an objective of this paper.

For the first constructive version we have:

\[ E_t = \dot{V} \cdot \Delta \dot{p}_t \cdot \tau \ [J] \]  

(2)

$\dot{V} = 600 \text{ l/h} = 600 \cdot 10^{-3} \text{ m}^3/\text{h}$

$\Delta \dot{p}_t = 1.1 \text{ mH}_2\text{O} = 11.213 \text{ N/m}^2$

$\tau = 1 \text{ h}$
\[ E_f = 600 \cdot 10^{-3} \cdot 11213 \cdot 1 = 6728.9 \ J \]

The energy consumed in a year, measured in kWh, will be equal to:

\[ E_{\text{ann}} = \frac{6728.9 \cdot 24 \cdot 365}{3.6 \cdot 10^6} = 16.47 \ kWh \]

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 Ø 0.5mm nozzles manufactured by spark erosion. The nozzles size establishes the size of the gas bubble [8].

![Fig. 3. Section through a rectangular shape FBG](image)

1- holder; 2- compressed air supply pipe; 3 – FBG body; 4 – screw for fastening the plate to the body; 5- nozzle plate

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. 4. The scheme of the experimental plant](image)

1-air filter; 2-electrocompressor with compressed air tank; 3-pressure reducer; 4-manometer; 5-thermometer; 6-rotameter; 7-pipe for supplying the FBG with compressed air; 8-water tank; 9-FBG; 10- numeric display manometer
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]:

\[ p_1 = \rho_{h,O} \cdot g \cdot H + \frac{2\sigma}{r_0} + \Delta p \ [N/m^2] \]  (5)

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

\[ \Delta p = p_1 - \rho_{h,O} \cdot g \cdot H - \frac{2\sigma}{r_0} \ [N/m^2] \]  (6)

Experimental measurements led to the following data:

\( p_1 = 583.44 \text{ mmH}_2\text{O} = 5723.5 \text{ N/m}^2 \);

\( H \)-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 (6), one obtains:

\[ \Delta p = 5723.5 - 1000 \cdot 9.81 \cdot 0.5 - \frac{2 \cdot 73 \cdot 10^{-3}}{0.25 \cdot 10^{-3}} = 244.35 \text{ N/m}^2 \]  (7)

\[ \Delta h = \frac{\Delta p}{g} = \frac{244.5}{9.81} = 24.92 \text{ mmH}_2\text{O} \]  (8)

This experimentally established value (\( \Delta p = 24.92 \text{ mmH}_2\text{O} \)) was obtained for an air flow rate of \( \dot{V} = 600 \text{ l/h} \); for the same air flow rate \( \dot{V} = 600 \cdot 10^{-3} \text{ m}^3/\text{h} \) and the same time \( \tau = 1 \text{ h} \), the energy consumed for oxygenation in the second version was equal to:

\[ E_2 = \dot{V} \cdot \Delta p \cdot \tau = 600 \cdot 10^{-3} \cdot 244.35 \cdot 1 = 146.5 \text{ J} \]  (9)

The energy consumed in a year, measured in kWh, will be equal to:

\[ E_{H,\text{an}} = \frac{146.5 \cdot 24 \cdot 365}{3.6 \cdot 10^6} = 0.356 \text{ kWh} \]  (10)

Relations (4) and (10) lead to an annual energy economy of:

\[ \Delta E = E_{H,\text{an}} - E_{H,\text{aw}} = 16.47 - 0.356 = 16.114 \text{ kWh/year} \]  (11)

This economy of energy is obtained in the case of the functioning of a sole FBG. Water cleaning plants feature a great number of FBG; for instance, the following ceramic material FBG are used in the cleaning plant of Green Bay – Wisconsin:

In the aeration basin 6128
In the contact basin 2148
Total 8276
The use of FBGs (in the second version) leads to an annual economy of energy
\[ \Delta E = 16.114 \times 8276 = 133359.46 \text{ kWh/year}, \]
that is not to be neglected.

4. Conclusions

The use of porous diffusers has the following disadvantages. Among them, we can cite that the emitted air bubbles have uneven diameters so the air bubbles appear irregularly, only on certain parts of porous diffusers surface and that the porous diffusers have significant pressure losses.

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; the 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 \[ \Delta E = 16.114 \text{ kWh/year} \]
for each functioning FBG appears.

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.

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

References