International Journal of
Emerging Research in Management &Technology
ISSN: 2278-9359 (Volume-6, Issue-2)

Research Article | **February 2017**

Theoretical and Experimental Researches about the Pressure Loss of a New Type of Fine Bubble Generator

Mihaela Constantin*, Nicolae Băran, Rareș Păun, Giovani Roza
Department of Thermotechnics, Engines, Thermic and Refrigeration Equipment, “Politehnica” University of Bucharest, Romania

Abstract—

In this paper we theoretically calculate the pressure loss that appears when the compressed air circulates from the input of the fine bubble generator to the output of the air bubble in the water layer. We expose the sketch of the experimental plant and the sketch of a new fine bubble generator type. For this type, the nozzle plate is engaged in a rotational motion, that leading to the reduction of the water oxygenation time. At the end of this paper we expose the results of the experimental researches and we compare them with the theoretical results established in the paper and with the ones already existing in the specialty literature.

Keywords—Fine bubble generators, water oxygenation, nozzle plate, experimental researches, pressure loss

I. INTRODUCTION

The oxygen transfer in used waters represents an important issue in the purge technology; using the fine bubble aeration, the amount of the input air is optimised, leading to important energy savings. The fine air bubbles are obtained using the fine bubble generators (FBG) made from ceramic materials; these types of generators are known in the specialty literature [1] as ceramic porous diffusers.

Using porous diffusers has the following disadvantages:
-the emission of the air bubbles is done through air bubbles of unequal diameters;
-the air bubbles have an irregular appearance, only on some parts of the surface of the porous diffusers;
-the porous diffusers have large pressure losses [1].

In the last years, the researches concerning water oxygenation were oriented towards obtaining fine bubble generators having the air injection nozzles in water with a diameter d<1 mm. FBG that have the perforated plate obtained by an unconventional technological process (electro erosion) were constructed; by this process an uniform distribution of the nozzles on the surface of the plate and an equal diameter of the nozzles are assured. Constructive solutions of the FBG obtained by electro erosion and their performances are presented in papers [2][3]. The dimension and size of the nozzles are parameters of critical importance of the FBG, because they directly influence the air input pressure of the FBG. The input air pressure of the FBG is a very important parameter in selecting, evaluating and monitoring of the fine bubble generators, independently of the shape and material from which they are made. Hence monitoring this parameter during the working time of the aeration plant is necessary, because it shows the working status of the fine bubble generator; every choke or obstruction of the FBG nozzles leads automatically to an increase of the input air pressure.

II. THE DESCRIPTION OF THE EXPERIMENTAL PLANT

Figure 1 presents the general sketch of the plant for waters oxygenation.

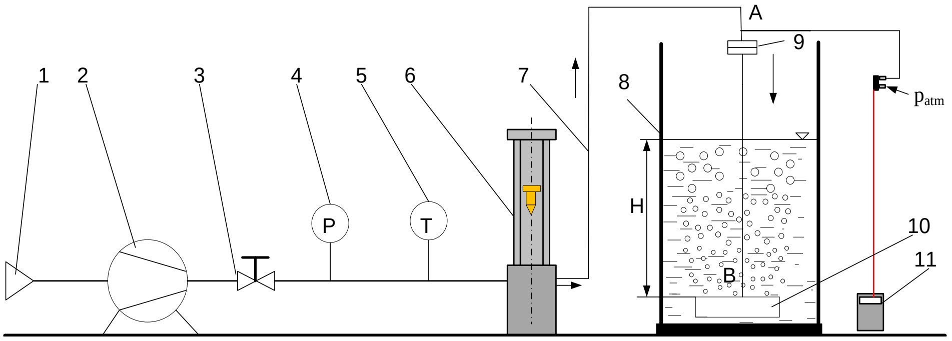

Fig. 1 Sketch of the experimental plant
1-air filter; 2-electrocompressor with compressed air reservoir; 3-pressure reducer; 4-manometer; 5-thermometer; 6-rotameter; 7-compressed air feeding pipe of the FBG; 8-water tank; 9-mobile sealing; 10-FBG; 11- digital manometer.

The air compressed by the compressor (2) is directed through the rota meter (6) to the FBG (9). The pressure and the air flow are maintained constant using the pressure reducer (3).

The air flow rate towards the FBG is measured using the rota meter (6), and the input air pressure of the FBG (point A) using the digital manometer (11).

In figure 2 we present the sketch of a new FBG type.

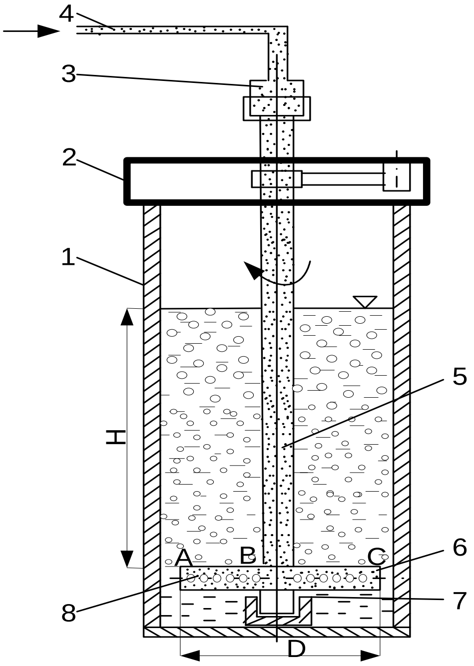

Fig. 1 Sketch of the FBG
1-water tank; 2-platform for the actuating mechanism of the FBG rod; 3-mobile sealing; 4-compressed air feeding pipe; 5-FBG rod; 6-nozzle box; 7-axial bearing; 8- Ø0.5mm nozzles

This FBG type is provided with a mobile sealing (3) that allows a rotational motion of the nozzle plate.

The mobile sealing (3) (fig. 2) is composed of two parts:

- a fixed part, solidary with the pipe (4) and a mobile part solidary with the rod (5) and the nozzle plate (6). The rod (5) and the plate (6) are driven in rotational motion by an electrical motor placed inside the platform (2). During the rotational motion, the air exits in the opposite direction to the rotational motion through the nozzles from zone AB, respectively BC.

Using this solution, the water oxygenation time is reduced to half compared with the FBG for which the nozzle plate is fixed.

III. THEORETICAL DETERMINATION OF THE PRESSURE LOSS WHEN THE AIR CIRCULATES THROUGH THE FINE BUBBLE GENERATOR

The pressure losses related to the FBG are composed of:

a) a linear pressure loss (ξ_l) of the air from the the FBG input (point A) till point B (fig.1) ;

b) a local pressure loss at the sudden variation of the flow section in point B (ξ_1) ;

c) a local pressure loss at 90^{o} direction change of the air flow towards the nozzles (ξ_2);

d) a local pressure loss when the air circulates through the nozzles (ξ_3).

a) for the straight sector AB of the pipe (fig.1.) the air admits a flow regime characterized by the Reynolds number [4]:

$$\mathrm{Re} = \frac{w \cdot d}{\upsilon} \tag{1}$$

where :

d-the diameter of the pipe; d=0.02 m;

υ -kinematic viscosity of the air ; $\upsilon = 16.6 \cdot 10^{-6} \ m^2/s$;

w- the medium flow speed of the air through the pipe.

The calculus expression of the volumetric flow rate is [5]:

$$\dot{V} = w \cdot A \quad m^3/s \tag{2}$$

$$w = \frac{\dot{V}}{\frac{\pi \cdot d^2}{4}} = \frac{4 \cdot \dot{V}}{\pi \cdot d^2} \tag{3}$$

where :

$\dot{V}$ -the air flow that circulates through the FBG ; $\dot{V} = 600 \ \ dm^3 / h$

d-the inner diamater of the pipe [m]; d=0.02 m.

$$w = \frac{4 \cdot 600 \cdot 10^{-3}}{3600} \cdot \frac{1}{\pi \cdot (0.02)^2} = 0.53 \ \ m/s \tag{4}$$

$$\mathrm{Re} = \frac{w \cdot d}{\upsilon} = \frac{0.53 \cdot 0.02}{16.6 \cdot 10^{-6}} = 662 \tag{5}$$

From the specialty literature, for a laminar flow regime, the coefficient of linear pressure loss is determined using the relation [5]:

$$\lambda = \frac{64}{\mathrm{Re}} = \frac{64}{662} = 0.096 \tag{6}$$

The calculus relation of the linear pressure loss [6]:

$$\Delta p_l = \lambda \frac{l}{d} \rho \frac{w^2}{2} \left[N / m^2 \right] \tag{7}$$

where: l-length of the pipe; l=2 m;
ρ-air density [kg/m^3];
w- air flow speed [m/s].

The air density is determined from the thermal equation of state [5]:

$$\rho = \frac{p}{RT} \ [kg / m^3] \tag{8}$$

$$p = p_{atm} + p_H + p_{ts} \, ;$$

$$p_{atm} = 101325 \ \ N / m^2 \, ;$$

p_H -hydrostatic load; p_H=500 mmH$_2$O;
p_{ts} -pressure due to the surface tension; from [2] p_{ts} =63 mmH$_2$O;
R-the air constant; R=287 J/kgK
T-the air temperature; $T = t_c^o + 273.15K$

$$\rho = \frac{101325 + 9.81 \cdot (500 + 63)}{287 \cdot (24 + 273.15)} = 1.25 \ \ kg / m^3 \tag{9}$$

$$\Delta p_l = 0.096 \cdot \frac{2}{0.02} \cdot 1.25 \cdot \frac{0.53^2}{2} = 1.76 N / m^2 \tag{10}$$

$$\Delta p_l = \rho_{_{H_2O}} \cdot g \cdot \Delta h_l \ \ [N / m^2] \tag{11}$$

$$\Delta h_l = \frac{\Delta p_l}{g} = \frac{1.76}{9.81} = 0.18 \ mmCA \tag{12}$$

b) The air arrives through the pipe AB (fig.1) with the inner diameter of 20 mm and at the input of the perforated plate, admits a sudden enlargement of its transversal section; by consequence, the local pressure loss is established by the relation [7]:

$$\Delta p_1 = \xi_1 \cdot \rho \cdot \frac{w^2}{2} \tag{13}$$

$$\xi_i = \left(1 - \frac{A_0}{A_1} \right)^2 \tag{14}$$

where:
A$_0$-the surface of the pipe section;
A$_1$-the surface of the rectangular section of the FBG;

$$A_0 = \frac{\pi \cdot d^2}{4} = \frac{\pi}{4} \cdot (0.02)^2 = \pi \cdot 10^{-4} \ \ m^2 \tag{15}$$

$$A_1 = 80 \cdot 40 = 3200 \ \ mm^2 = 32 \cdot 10^{-4} \ \ m^2 \tag{16}$$

$$\xi_i = \left(1 - \frac{\pi \cdot 10^{-4}}{32 \cdot 10^{-4}} \right)^2 = 0.81 \tag{17}$$

$$\Delta p_1 = 0.81 \cdot 1.25 \cdot \frac{0.53^2}{2} = 0.14 \quad N/m^2 \tag{18}$$

$$\Delta h_1 = \frac{\Delta p_1}{g} = \frac{0.14}{9.81} = 0.0142 \quad mmCA \tag{19}$$

c) The pressure losses that appear when the air flow direction changes 90°, namely from point B to the nozzles input are determined in the following way:

This direction change is assimilated with a mechanical elbow of 90° with smooth walls, for which is chosen from [7] a value of $\xi = 1.5$ for the coefficient of local pressure loss. The local pressure loss will be of:

$$\Delta p_2 = \xi \cdot \rho \cdot \frac{w^2}{2} = 1.5 \cdot 1.25 \cdot \frac{0.53^2}{2} = 0.265 \quad N/m^2 \tag{20}$$

$$\Delta h_2 = \frac{\Delta p_2}{g} = \frac{0.265}{9.81} = 0.027 \quad mmH_2O \tag{21}$$

d) The local pressure loss at the air circulation through the perforated nozzle is determined in the following way: the perforated plate (9) a G.B.F. contains n=37 nozzles having the diameter d=0.5 mm placed on a straight line, equally placed one from the other, at the distance: t=20·d = 20·0.5 = 10 mm, avoiding this way the interference of the bubble columns. To calculate the pressure loss when the air circulates through a nozzle, the nozzle is assimilated with a cylindrical jet with sharp edges, observing the condition [7]:

$$l \geq 3 \cdot d \tag{22}$$

where:
l-the lenght of the cylindric jet;
d-the diameter of the jet.

In this case the perforated plate has a thickness of 2 mm; therefore 2>3·0.5; 2>1.5 mm. For this type of jet, in the specialty literature [7] are given:
-the speed coefficient: φ=0.82;
-the resistance coefficient: ξ=0.5.

The local pressure loss that appears when the air circulates through a nozzle is calculated using the relation :

$$\Delta p_3 = \xi_3 \cdot \rho \cdot \frac{w^2}{2} \tag{23}$$

The air flow rate that feeds the FBG is of $\dot{V} = 600 \quad dm^3/h$; the theoretical air flow speed through a nozzle will be of :

$$w_t = \frac{\dot{V}}{A} = \frac{\dot{V}}{n \cdot \frac{\pi \cdot d^2}{4}} = \frac{600 \cdot 10^{-3}}{3600} \cdot \frac{4}{37 \cdot \pi \cdot \left(0.5 \cdot 10^{-3}\right)^2} = 22.86 \quad m/s \tag{24}$$

The real flow rate will be of:

$$w_r = \varphi \cdot w_t = 0.82 \cdot 22.86 = 18.74 \quad m/s \tag{25}$$

By consequence:

$$\Delta p_3 = 0.5 \cdot 1.25 \cdot \frac{18.74^2}{2} = 109.74 \quad N/m^2 \tag{26}$$

$$\Delta p_3 = \rho_{H_2O} \cdot g \cdot \Delta h_3 \quad [N/m^2] \tag{27}$$

$$\Delta h_3 = \frac{\Delta p_3}{g} = \frac{109.74}{9.81} = 11.187 \quad mmH_2O \tag{28}$$

The total presure loss of the FBG, expressed in mmH_2O will be of:

$$\Delta h_t = \Delta h_l + \Delta h_1 + \Delta h_2 + \Delta h_3 = 0.18 + 0.014 + 0.027 + 11.187 = 11.40 \ mmH_2O \tag{29}$$

This value, theoretically calculated, will be compared with the results experimentally obtained.

IV. EXPERIMENTAL RESEARCHES REGARDING THE PRESSURE LOSSES AT A NEW TYPE OF FINE BUBBLE GENERATOR

In a dynamical regime, the air circulates through the pipe A-B (fig.1), penetrates through the nozzles and enters the water from the tank. The air pressure at the FBG input must overcome the hydrostatic load, the surface tension and the pressure losses:

$$p_1 = \rho_{H_2O} \cdot g \cdot H + \frac{2\sigma}{r_0} + \Delta p \quad [N/m^2] \tag{30}$$

The value of Δp can be dduced from this relation, if p_1 is known.

$$\Delta p = p_1 - \rho_{H_2O} \cdot g \cdot H - \frac{2\sigma}{r_0} \ [N/m^2] \tag{31}$$

Experimental measurements led to the following data:
$p_1 = 583.44\ \text{mmCA} = 5723.5\ \ N/m^2$
H-the height of the water layer over the FBG; H=0.5 m.
r_0 –the inner ray of a nozzle; $r_0=0.25\cdot 10^{-3}$m
σ – the coefficient of the water surface tension; $\sigma = 73 \cdot 10^{-3}$ N/m
By replacing in the relation (31) we obtain:

$$\Delta p = 5723.5 - 1000 \cdot 9.81 \cdot 0.5 - \frac{2 \cdot 73 \cdot 10^{-3}}{0.25 \cdot 10^{-3}} = 244.35\ \ N/m^2 \tag{32}$$

$$\Delta h = \frac{\Delta p}{g} = \frac{244.5}{9.81} = 24.92 \quad mmH_2O \tag{33}$$

This value experimentally determined ($\Delta h = 24.92$ mmH_2O) is close to the one determined on the theoretical way ($\Delta h_t = 11.40$ mmH_2O).

The pressure loss experimentally determined was obtained for an air flow rate of $\dot{V} = 600\ \ l/h$; it will be compared with data from the specialty literature [1].

For fine bubble generators that have porous diffusers, experimental researches were performed in order to establish the pressure loss that appeared when the air circulated. This way, the pressure losses with respect to the flow rate were determined, for two types of ceramic porous diffusers (DPc) with Ø100 mm diffusers (fig.3) [1].

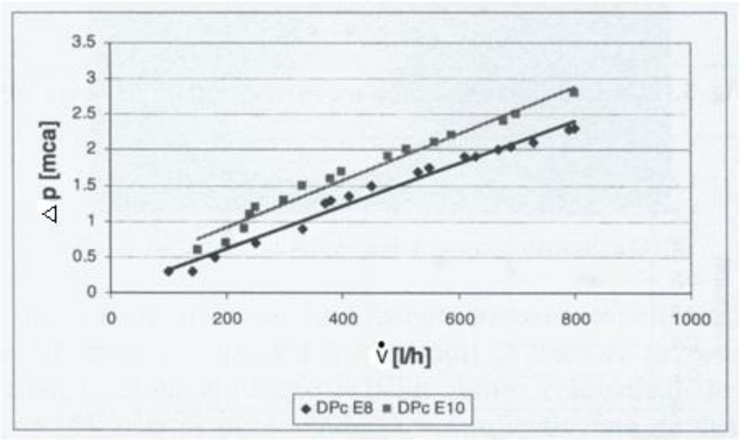

Fig.3. The variation of the pressure loss with respect to the flow rate for the Ø100 mm DPc

It can be remarked from figure 3 that for $\dot{V} = 600\ \ l/h$, the pressure loss through the FBG is of 1.7 ÷ 2.3 mH_2O. For another type of FBG with a diffuser of Ø150mm, three different lots with ceramic porous diffusers with different volumetric porosity (fig.4) were tested.

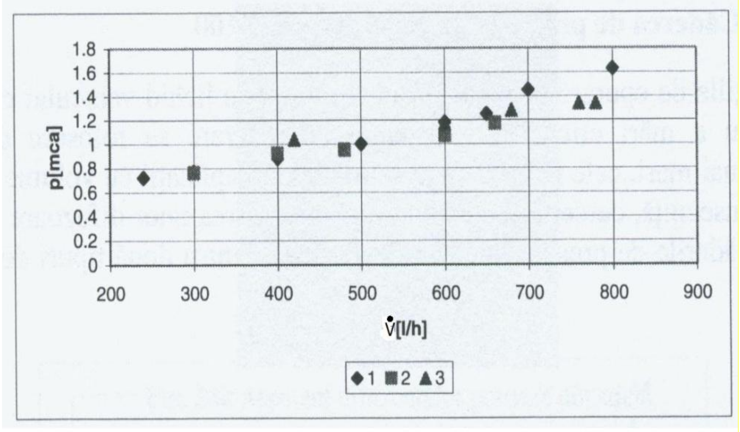

Fig.4. The variation of the pressure drop with respect to the flow rate for Ø150mm DPc

It can be remarked from figure 4 that for $\dot{V} = 600\ \ l/h$ the pressure loss is of 1.1 ÷ 1.2 mH_2O. For FBG with glass porous diffusers, the pressure losses is reduced (fig.5.).

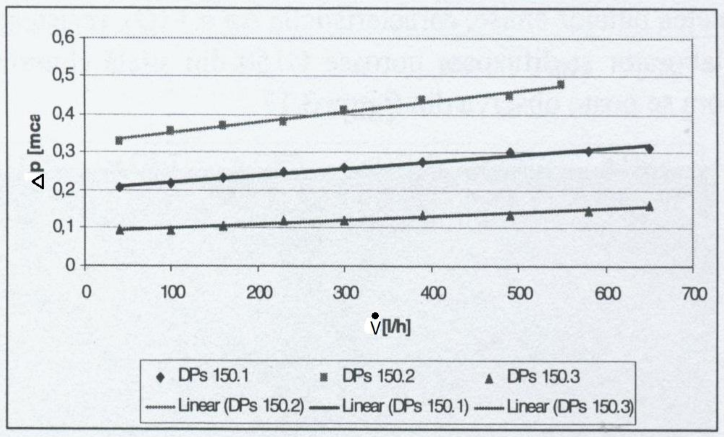

Fig.5.The variation of the pressure drop with respect to the flow rate for Ø150mm DPs

For Ø150mm glass porous diffusers (fig.5.) the pressure loss $\dot{V} = 600\ l/h$ is contained in the range $0.15 \div 0.5$ mH_2O [1]. It can be deduced from figures 3,4,5 that the pressure losses for the FBG with ceramic or glass porous diffusers are greater than for the FBG for which the nozzle plate is manufactured by electroerosion.

V. CONCLUSIONS

1. The idea of manufacturing the FBG by electro erosion is original; FBGs manufactured by electro erosion provide an uniform controlled dispersion of air into water.
2. The theoretically determined pressure loss at the FBG is close to the one experimentally determined.
3. By experimental research it was deduced that the pressure losses at FBG having plates manufactured by electro erosion are lower than for the FBG using „porous diffusers". For the studied case and for the same flow rate 600 l/h from [1] we obtain a pressure loss of:
   -$\Delta p=1.7 \div 2.3$ mH_2O for Ø100mm DPc;
   - H2O for Ø150mm DPc;
   - H2O for Ø150mm DPs.
4. A lower pressure loss leads to a spare of the energy used for the air compression..

REFERENCES

[1] G. Oprina, I. Pincovschi, Gh. Băran, "Hydro-gas-dynamics of aeration systems equipped with bubble generators" (in Romanian), POLITEHNICA PRESS Publishing House, Bucharest 2009.

[2] G. Mateescu, "Hydro-gas-dynamics of fine bubble generators" (in Romanian), PhD Thesis, Faculty of Mechanical Engineering and Mechatronics, POLITEHNICA University of Bucharest, 2011.

[3] Al. Pătulea, "The influence of the functional parameters and of the architecture of the fine bubble generators on the efficiency of the aeration installations,, Faculty of Mechanical Engineering and Mechatronics, PhD. Thesis, POLITEHNICA University of Bucharest 2012.

[4] E. Isbăşoiu, ,"Treatise on fluid mechanics", (in Romanian), AGIR Publishing House Bucharest 2011.

[5] Al. Dobrovicescu, N. Băran et al., Collection „Bases of Technical Thermodynamics" (in Romanian), POLITEHNICA PRESS Publishing House Bucharest 2009.

[6] I. E. Idelcik, "Handbook for the calculation of hydraulic resistances" (in Romanian), Technical Publishing House, Bucharest 1984.

[7] P. G. Kiselev, "Handbook for hydraulic calculations", (in Romanian), Technical Publishing House, Bucharest 1988.