Research Regarding a New Type of Fine Bubble Generator

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In the paper the authors present the constructive solution for a new type of fine bubble generator; the value of the critical flow rate is established, the results of the measurements made on the fine bubble generator for lower air flow rates and flow rates larger than the critical one are presented. The pressure loss at the air transport through the fine bubble generator is established.

Keywords: fine bubbles generator, electro-erosion processing

Water aeration technologies have developed, through the time, from surface mechanical aerators to fine bubbles aerators; aeration technologies apply both to resting liquids and to flowing liquids with very small velocities ($w < 0.1$ m/s).

The aeration technology follows both insurance of the oxygen necessary to the evolution of a biological process, if existent, and homogenization by mixing of the liquids containing different particles in suspension.

The mass transfer phenomenon from the oxygen contained in the bubbles to the water in the tanks or basins is used in the following cases:

- aeration of the residual waters from the purification stations;
- aeration of the waters from fountains, pools, piscines, basins for fish breeding;
- aeration of euthrophysed lakes.

The aeration installations work with air and in the most of cases the O_2 transfer to the water is looked; as consequence, in some papers they are called oxygenation installations.

Fine bubble generators (FBG) made from ceramic material, syntherised glass, plastic materials are used in order to generate the air dispersion into water.

These FBG can produce fine gas bubbles but the bubble distribution is uncontrollable; at the surface of the drilled disk can appear zones with no gas bubble in the liquid; any uniformity of the air getting out of the FBG is assured.

According to the air bubble dimension that intrude in the water mass from a tank or basin, the bubble generators are divided in :

a. fine bubbles generators with diameter $d_b < 1$ mm;

b. medium bubbles generators with diameter $d_b = 1 \div 3$ mm;

c. large bubbles generators with diameter $d_b = 3 \div 120$ mm.

The bubble dimensions depend on the air output nozzle diameters, on the air flow and the air pressure from the distribution net.

The fine bubbles are obtained by the injection of an air flow through a porous medium (medium that contains small holes).

The constructive solution of a new type of fine bubble generator

For an efficient oxygenation of waters, it is necessary to guarantee an uniform dispersion of the air in the whole water mass from a tank or basin; the air bubbles uniformly spread must insure the necessary of oxygen needed by the respective biological process.

This can be done with the help of the fine bubble generators (FBG), placed on the bottom of the tank or basin, ensuring an uniform distribution of the air.

The authors conceived and built a FBG, presented in figure 1.

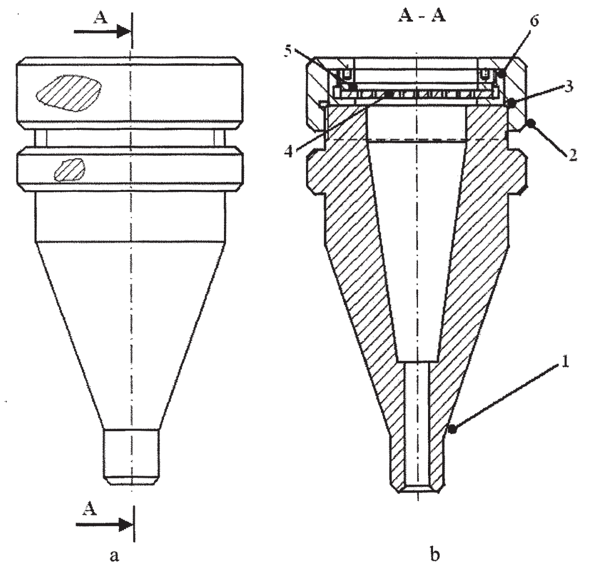

Fig. 1. The fine bubble generator a – front view; b – cross-section

The compressed air enters in the truncated cone body 1, and reaches the drilled disk, 4; the disk has ∅ 0.3 mm or ∅ 0.5 mm holes and is fixed in the case, 3, by the safety ring, 5, tightened by the regulating nut, 6. The case, 3, is tightened on the truncated cone body, 1, by the nut, 2.

The essential element of a FBG is the hole disk, 4, which needs to satisfy the following conditions:

a. to be resistant at the action of the liquid with which enters in contact (residual waters, waters with special *p*H);

b. to allow the air uniform distribution with small pressure losses ;

c. to be easily cut (processed);

d. to have a high mechanical resistance, sufficient to resist at the weight of a water column of $4 \div 5$ m.

From the specialty literature [1, 2], for F.B.G. produced till now, two general conditions have appeared.

The first condition (fig. 2):

(1)

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$$\frac{s}{d_0} > 3 \qquad (1)$$

where:

s is the width of the plane disk;

d_0 – the hole diameter

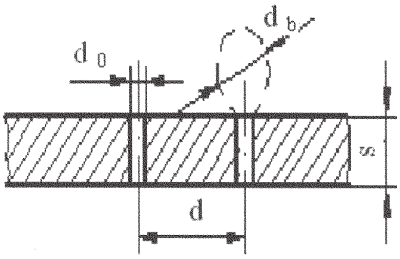

Fig. 2. Hole spacing in the FBG disk

The second condition:

$$\frac{d}{d_0} > 2 \qquad (2)$$

where: *d* represents the distance between two adjacent holes.

Usually, the diameter of the formed bubble (d_b) is:

$$d_b \approx 2\, d_0 \qquad (3)$$

As consequence, to obtain fine or very fine bubbles, the hole diameter must be the smallest possible (d_0 < 1 mm), and the holes repartition on the board must be uniform. These two conditions can be realized with the help of non-conventional technologies [3]:

- processing by electro-erosion;
- electrochemical processing;
- laser processing;
- electron beam processing etc.

The experiments performed using a laser plant were not satisfactory so that the disk drilling was made by electro-erosion; by this process, the uniformity of the hole contour is guaranteed, the precision of the cut plant can reach 0.005 mm [3].

To cut the holes in the FBG disk, an electro-erosion cutting machine of AG 55 L type was used.

This process insures an uniformity of the air injection hole diameters and, in the same time, an uniform distribution (intended by the designer) of these holes. This process controls the aeration phenomenon of tanks or liquid basins.

Using the electro-erosion processing machine, a hole net with an ∅ 0.5 mm electrode (fig. 3) was made, in an aluminum plate of width *s* = 2 mm; the net pitch is of 10 mm.

Measurements were performed on the 9 holes denoted 1,2, ...,9, using an universal microscope „ZEISS" with an accuracy of 0.001 mm for linear dimensions and 1' for angular dimensions; the results of the measurements are presented in table 1 .

It can be seen from table that a satisfactory processing accuracy of the holes is obtained; it is obvious that the hole network architecture induces a certain geometry of the fine bubble flow.

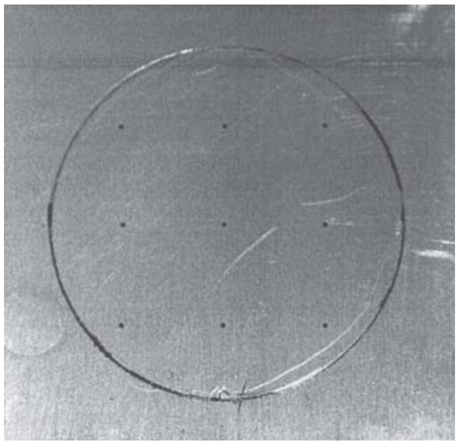

Fig. 3. Hole network processed by electro-erosion

Establishment of the critical flow rate

According to the gas flow rate ($\dot{V}$) the bubble generation systems are classified into three categories [1, 4] :

A – the cvasistatic system ($\dot{V} < \dot{V}_{cr}$);

B - the dynamic system ($\dot{V} \geq \dot{V}_{cr}$)

C – the turbulent system ($\dot{V} >> \dot{V}_{cr}$)

The critic flow rate for working fluids water/air and holes 0.1…..2 mm is calculated by using the relation [5]:

$$\dot{V}_{cr} = \pi \left(\frac{16}{3g^2} \right)^{\frac{1}{6}} \left(\frac{\sigma \cdot r_0}{\rho_{H2O}} \right)^{\frac{5}{6}} \qquad (4)$$

where:

g – gravitational acceleration , g = 9.81 m / s²

σ - superficial tension coefficient, for water σ= 8 10^{-2} N / m

ρ_{H2O} = 10³ kg/m³

r_0 – the hole radius [m]

It is obtained that:

$$\dot{V}_{cr} = 3{,}14 \left(\frac{16}{3 \cdot 9{,}81^2} \right)^{\frac{1}{6}} \left(\frac{8 \cdot 10^{-2}}{10^3} \right)^{\frac{5}{6}} \cdot r_0^{\frac{5}{6}} = 0{,}745 \cdot 10^{-3} r_0^{\frac{5}{6}} \ \mathrm{m^3/s} \qquad (5)$$

For r_o = 0.25 x 10^{-3} m it is obtained that:

$$\dot{V}_{cr} = 0{,}745 \cdot 10^{-3} \left(0{,}25 \cdot 10^{-3} \right)^{\frac{5}{6}} = 0{,}744 \cdot 10^{-6} \ \mathrm{m^3/s} = 2{,}678 \ \mathrm{dm^3/h} \qquad (6)$$

Considering the fact that nine holes exist in the drilled disk, the gas flow rate through the rotameter will be of:

$\dot{V}_r$ =9 x 2.678 = 24.102 dm³/h

By consequence, the experimental research will use two rotameters with the following measuring ranges:

$\dot{V}_r$ = 10 - 90 dm³ / h, range corresponding to the cvasistatic and dynamic systems;

$\dot{V}_r$.= 200 – 2000 dm³ / h range corresponding to the turbulency system.

Table 1

DIAMETERS OF THE DISK HOLES

No. hole	1	2	3	4	5	6	7	8	9	Average
d_0 [mm]	0.528	0.540	0.508	0.489	0.516	0.525	0.507	0.511	0.529	0.517

It is already known [1] that Davidson & Schuler made researches about FBG with r_0 = 0.334 mm; they chose for the dynamical system a flow of 0.5 – 2.5 cm^3 / s, (for one hole) which for nine holes becomes a flow of 16.2 – 81 dm^3 / h.

These data confirm that the measuring range of the air flow rate passing through the rotameter is similar with the one used by other researchers [1, 5-8] .

The description of the experimental stand for the FBG

The fine bubble generator is mounted inside an experimental stand installed in the laboratory of the Thermotechnics, Thermic Machines and Frigorific Installations Dept. from the “Politehnica” University of Bucharest.

To avoid the vibration transmission from the compressor to the FBG, the stand is constituted by two independent modules (fig.4). The stand contains a compressor (1) produced under license by NUAIR (Robassomero, Italy), with the following parameters:

-maximal discharge pressure: p = 8 bar;

- aspired flow: $\dot{V}$ = 200 dm^3/ min ;

- working temperature : t = -10 - 100 ^{0}C;

- power of the electric engine : P = 1.1 kW ;

- rotating speed: n = 2850 rpm;

- tank volume: V = 24 dm^3.

The compressor is provided with a manometer (3) and a pressure reducer (4) that delivers the work pressure needed.

To guarantee the desired flow for the FBG two compressed air pipes were made:

-one pipe through the valves (15) supplies the FBG;

-one pipe through the valves (16) and (17) evacuates the excess of the air delivered by the compressor.

The air flow introduced in the FBG is measured by the rotameter (5), chosen depending on the value range of air flows.

When entering the FBG, the air temperature is measured with the thermometer (6) and the pressure with the manometer (7); the pressure inside the FBG, before the drilled disk, is measured with the manometer (11).

Experimental results

The research regarding the new type of F.B.G. will be made in several steps:

- in the first step, the water was not yet introduced in the tank (8); measurements about the air circulation from the compressor to the FBG were made; these results will be used later.

- in the second step, the water will be introduced in the tank (8) such that over the hole disk of the FBG the water level will have a H=0.5 m height.

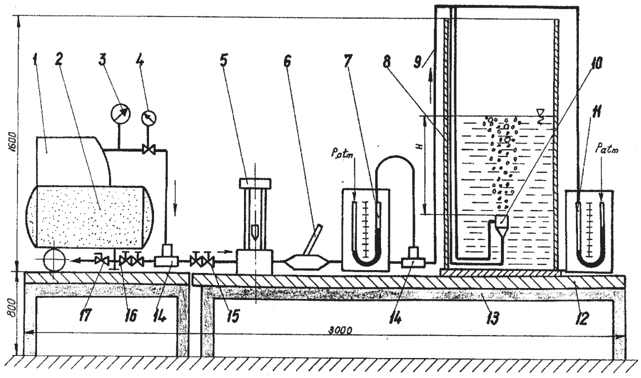

Fig. 4. Sketch of the FBG experimental stand
1- air compressor; 2- compressed air tank; 3- manometer; 4- pressure reducer; 5- rotameter; 6-thermometer; 7- manometer; 8- water tank; 9- compressed air pipe; 10- FBG; 11 manometer; 12- stand base board; 13- metallic holders; 14 – tee piece; 15 – adjustment valves of the air flow to the FBG; 16 – adjustment valves of the air flow evacuated outside; 17- closing valve

- in the third step, the water level in the tank will be modified and the oxygenation efficiency will be established.

Some measurements of the air flow rate and pressure from the compressor to the FBG were performed in the first step; the results are noted in table 2:

$\dot{V}_r$ [dm^3/h] – air flow rate measured with the rotameter (5) (fig.4);

t [^{o}C] – air temperature when entering the tank, measured with the thermometer (6);

Δh_1 [mmH_2O] – static air pressure at the entrance at the tank, measured with the manometer (7);

Δh_2 [mmH_2O] – static air pressure before the drilled disk of FBG measured with the manometer (11);

w_t – theoretic air velocity through a hole;

Δh – the pressure drop measured for a FBG from syntherised glass [6].

It can be remarked from the figure 4 that the gasodynamic resistances between the measuring points of the manometers 7 and 11 are negligible and then $\Delta h_1 \approx \Delta h_2$; two manometers were mounted in order to verify the exactitude of the measurements.

The theoretical flow velocity of the air through a hole was computed with respect to the real air flow rate through the rotameter:

$$w_r = \frac{\frac{\dot{V}_r}{9}}{\frac{\pi d_0^2}{4}} = \frac{\dot{V}_r}{7{,}065\, d_0^2} = \frac{\dot{V}_r \cdot 10^{-3}}{\frac{3600}{7{,}065(0{,}517 \cdot 10^{-3})^2}} = \frac{\dot{V}_r}{6{,}798} \text{ m/s} \quad (7)$$

relation in which $\dot{V}_r$ is introduced in dm^3/h.

Table 2
MEASURED AND CALCULATED VALUES

Measured values	$\dot{V}_r$ [l/h]	Δh_1 [mmH_2O]	Δh_2 [mmH_2O]	w_t [m/s]	Δh [mmH_2O]
1.Rotameters for flows: $\dot{V} = 10 \div 90$ dm^3/h	10	2.0	2.0	1.47	
	30	2.5	2.5	4.41	
	50	3.0	3.0	7.36	200
	70	4.0	4.0	10.30	
	90	5.0	5.0	13.25	250
2. Rotameters for flows: $\dot{V} = 200 \div 2000 dm^3$/h	200	24.0	23	29.45	300
	400	90	89	58.91	
	600	170	168	88.36	
	800	290	287	117.82	
	1000	420	417	147.27	
	1200	580	577	176.73	
	1400	780	775	206.18	
	1600	990	985	235.64	

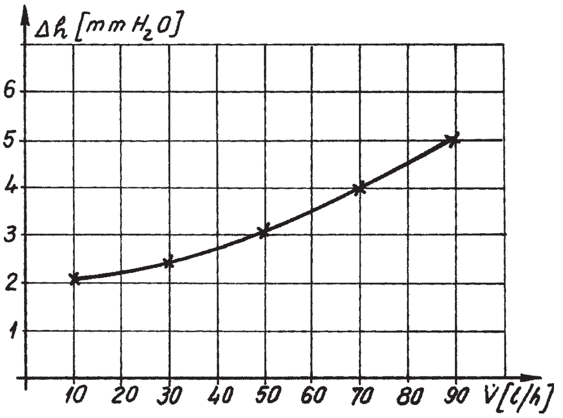

Fig. 5. Graphic representation of the dependence: $\dot{V}_r = f(\Delta h_2)$; the rotameter 1 was used

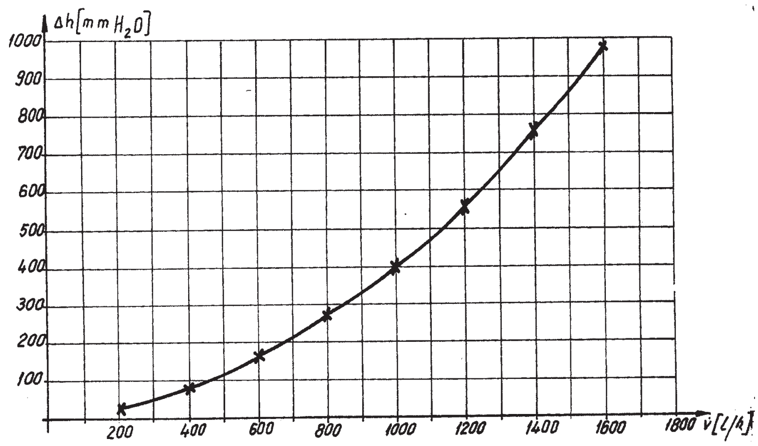

Fig. 6. Graphic representation of the dependence: $\dot{V}_r = f(\Delta h_2)$;the rotameter 2 was used

The values of the calculated velocities in the hypothesis that the flow coefficient of the holes is the same, equal to one, will be used at the second step.

The values of the experimentally determined magnitudes are represented graphically in figures 5 and 6.

It can be seen from figures 5 and 6 that the static pressure from inside the FBG increases as the air flow rate passing through the FBG increases.

It is approximated that the pressure loss at the air transport through the drilled disk is given exactly by Δh_2.

Table 2 shows that the pressure loss at the air transport through the FBG is largely smaller than in a porous diffuser made from syntherised glass ($\Delta h_2 << \Delta h$).

Conclusions

The utilization of a electro-erosion processing plant for the construction of a FBG guarantees the performing of equal dimension holes.

The lay-out of air blasting holes in the FBG can be done in the desired way because the electro-erosion cutting machine uses a computing program in XOY coordinates; the execution of the distance between the holes with a 0.0001 mm precision is guaranteed;

By this processing method (electro-erosion) it is possible to create holes inside a rectangular surface, that can produce a series of plane jets, which will generate bubble screens.

In comparison with the porous diffusers made from syntherised glass or other materials, this new FBG type insures an uniform and precise distribution of the air bubbles and this leads to the growth of the oxygenation efficiency.

The pressure loss at the air transport through this new FBG type is largely reduced than the one of the porous diffusers, and this leads to an economy of the energy used for the air compression.

Notation list

r_0 - hole radius;
V - volumic air flow rate;
Δh_1 - air overpression at the entrance of the tank;
Δh_2 - air overpression before the drilled disk;
H - hydrostatic load;
R - air constant;
p_a - absolute pressure of the air;
w - flow velocity of the air;
σ - superficial tension gas-liquid;
ρ - fluid density.

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