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Experimental Research Regarding a New Type of Fine Bubble Generator

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ABSTRACT

In this paper the authors present the draft of a stand for testing the fine bubble generator; the novelty of this type of generator is that the holes from the drilled board are processed by electro-erosion and uniformly distributed in a square net. After experimental researches, the pressure loss is established in function of the gas flow rate that passes through the new type of fine bubble generator; images of the gas bubble jet that enters a resting water layer are presented.

INTRODUCTION

The paper contains data and experiments that belong to the domain of study called the gasodynamic of biphasic environments. The fine bubble generators that generate gas bubble jets that enter a resting or flowing water mass belong also to this domain.

The fine bubbles generators (FBG) assure water oxygenation by injecting the air into water. For an efficient oxygenation, a uniform dispersion of the air in the whole water mass from a basin or tank must be guaranteed. This thing can be accomplished using some FBG placed in a special net on the bottom of the tank.

At the present, the dispersion of air into water is made using porous diffusers constructed by ceramic materials, synthesised glass, plastic materials; these diffusers do not achieve a uniform and accurate dispersion of the air and have great pressure losses.

The authors conceived and manufactured a new type of FBG, for which the air dispersion element consists of a disk provided with a number of holes, arranged in a square net with a step of 10 mm. The holes were practiced by electro-erosion with an electrode of diameter 0.5 mm; microscope measurements showed that the hole diameters situate in the range of 0.489 – 0.528 mm .

Due to the fact that the electro-erosion machine works in xoy coordinates, the hole diameters and the hole net architecture can be easily modified.

The smaller is the diameter of the hole, the smaller will be the radius of the air bubble that exits it; as consequence, an electrode of diameter de 0,2 mm will be used for the following researches.



GAS BUBBLE GENERATION.

Depending on the gas flow rate introduced in the FBG, three bubble formation systems can be distinguished [1]:

- a) – the quasistatic system;
- b) - the dynamic system;
- c) - the turbulent system.

Every system corresponds to a particular frequency range of gas bubbles formation; the transition from one system to the other depends on the gas flow rate, the physical properties of the liquid and the hole dimension.

For the quasistatic system, the air input is very small, lower than the value of 1cm³/s [1]. The frequency of bubbles forming is under 100 bubbles per minute and is proportional to the gas flow rate.

The quasistatic system is separated from the dynamic system by the critical gas flow rate given by the relation [1] :

$$\dot{V}_{cr} = \pi \left(\frac{16}{3g^2} \right)^{\frac{1}{6}} \left(\frac{\sigma \cdot r_0}{\rho_{H_2O}} \right)^{\frac{5}{6}} \quad (1)$$

where: g – gravitational acceleration;

σ - superficial tension coefficient;

r₀ – hole radius.

FBG contains a drilled disk with a single hole, subsequently replaced by a nine hole disk with a medium radius of 0.258 mm ; for ρ = 103 kg/m³, g = 9.81 m/s² σ_{H₂O} = 8 · 10⁻² N/m, it is obtained for an one hole FBG:

$$\dot{V}_{cr,1} = 3.14 \left(\frac{16}{3 \cdot 9.81^2} \right)^{\frac{1}{6}} \left(\frac{8 \cdot 10^{-2} \cdot 0.258 \cdot 10^{-3}}{10^3} \right)^{\frac{5}{6}} = 0.745 \cdot 10^{-6} \text{ m}^3/\text{s} \quad (2)$$

$$\dot{V}_{cr,1} = 0.745 \cdot 10^{-3} \text{ dm}^3/\text{s} = 0.745 \text{ cm}^3/\text{s} = 2.682 \text{ dm}^3/\text{h} \quad (3)$$

Respectively for FBG with nine holes:

$$\dot{V}_{cr,9} = 9 \cdot \dot{V}_{cr,1} = 9 \cdot 2,682 = 24,1 \text{ dm}^3/\text{h} \quad (4)$$

As rotameters calibrated for the air in the range of flow rates 144 – 2200 dm³ / h were used in the experimental plant, this means that the bubbles generating system was dynamic, and when the flow rate increased, it has become turbulent ($\dot{V} \gg \dot{V}_{cr}$).

The characteristic of the turbulent system is the « coalescence » of the bubbles at the hole level; when increasing the air flow rate in the hole, an air jet will exit, and this jet will subsequently disintegrate in an assembly of small air bubbles.

THE DESCRIPTION OF THE TEST STAND FOR THE FBG

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

- maximal discharge pressure: $p = 8 \text{ bar}$;
- aspired flow rate: $\dot{V} = 200 \text{ dm}^3/\text{min}$;
- work temperature : $t = -10 \text{ }^\circ\text{C} - 100 \text{ }^\circ\text{C}$;
- power of the electric engine: $P = 1.1 \text{ kW}$;
- rotating speed: $n = 2850 \text{ rpm}$;
- tank volume : $V = 24 \text{ dm}^3$.

The compressor is endowed with a manometer (3) and a pressure reducer (4) that assure the desired working pressure.

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

- one pipe through the valves (15) supplies the FBG;
- one pipe through the valves (16) and (17) evacuates the excess of air delivered by the compressor.

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

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).

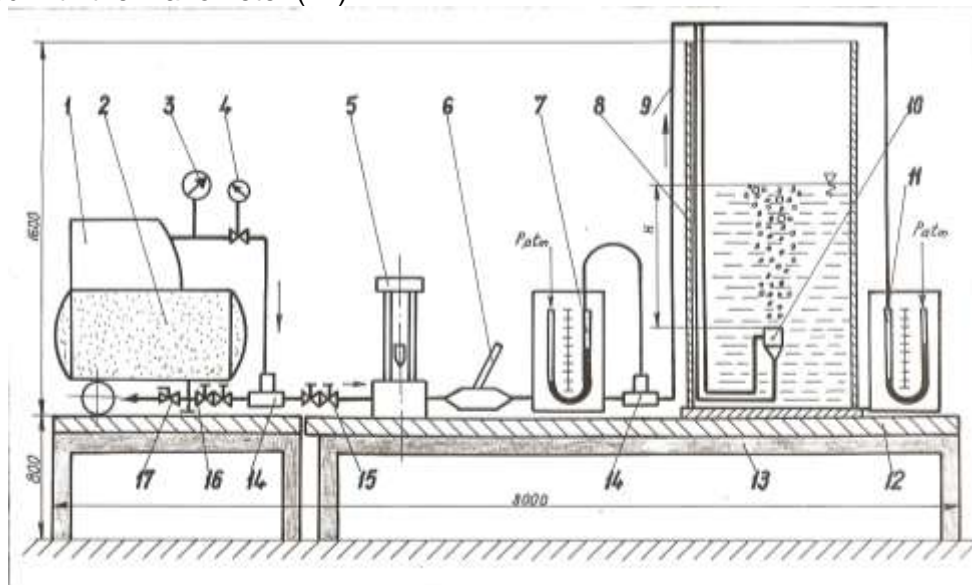


Figure 1. Sketch of the FBG experimental stand

- 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, 18 - graduated scale.

A picture of the test stand for FBG is presented in figure 2; this stand was constructed in the laboratory of the Chair of Thermotechnics, Thermic Machines and Frigorific

Installations, from the POLITEHNICA University of Bucharest.



Figure 2. General view of the test stand for the FBG.

The compressor, the rotameters, the manometers, the plexiglas tank full of water, $H=0.5$ m can be remarked in figure 2.

Only one FBG was introduced in the tank; two FBG are presented in the picture, the right one is not real, because formed by reflection.

The disk with nine holes was introduced inside the FBG; the bubble column that appears for a flow rate of $300\text{dm}^3/\text{h}$ and a pressure of $600\text{ mm H}_2\text{O}$ can be remarked in the picture.

3. THE TEST METHOD.

At the beginning, the tank was filled with water, such that over the drilled disk existed a water layer of height $H = 500\text{ mm H}_2\text{O}$ (figure 2).

Subsequently, the researches took place in the following two steps:

I – At the first step, FBG contained a disk with a single central hole with a diameter of 0.517 mm (figure 3).

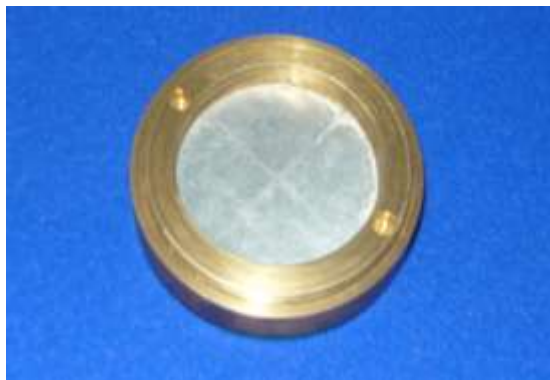


Figure 3. Disk with one hole.



Figure 4. The case containing the disk is introduced in the FBG.



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The disk was fixed in a case that was introduced inside the fine bubble generator; the case is fixed with a nut, which is screw cut in the body of the generator (figure 4).

Subsequently, the air compressor was brought into service, the FBG was fed and after the FBG was introduced in the water tank; in this way the penetration of the water under the drilled disk was stopped. The existence of the water under the drilled disk affects the results of the measurements.

The following remarks were made during the tests:

- the manometer displayed an overpressure of 520 mm H₂O;
- the hydrostatic load was of 500 mm H₂O.

However, the air bubbles did not appear from the FBG; the following problem appeared: which is the condition that must be fulfilled in order that FBG emit air bubbles?

The answer at this problem was established as follows:

The superficial tension force between gas and liquid (air – water) that stops the exit of the bubble from the hole is given by the following relation:

$$F = \sigma \cdot l = \sigma \cdot 2\pi \cdot r_0 \quad (5)$$

in which : σ – superficial tension coefficient;

l – length of the watered contour;

r_0 – hole radius

The pressure created on the gas, by the superficial tension, will be equal to:

$$p_{ts} = \frac{F}{S} = \frac{\sigma \cdot 2\pi \cdot r_0}{\pi \cdot r_0^2} = \frac{2\sigma}{r_0} \quad (6)$$

The medium radius of the nine holes of the FBG is of 0.2585 mm , $\sigma = 8 \cdot 10^{-2}$ N/m

$$p_{ts} = \frac{2 \cdot 8 \cdot 10^{-2}}{0.2585 \cdot 10^{-3}} = 620 \text{ N/m}^2 \quad (7)$$

$$p_{ts} = \rho_{\text{H}_2\text{O}} \cdot g \cdot \Delta h_{ts} \text{ N/m}^2 \quad (8)$$

$$\Delta h_{ts} = \frac{p_{ts}}{\rho_{\text{H}_2\text{O}} \cdot g} = \frac{620}{10^3 \cdot 9.81} = 0.063 \text{ mm H}_2\text{O} \quad (9)$$

or:

$$\Delta h_{ts} = 63 \text{ mm H}_2\text{O} \quad (10)$$

Therefore the overpressure of the gas in front of the hole disk must satisfy the following condition:

$$\Delta h_1 > \Delta h_{ts} + H \quad (11)$$

or:

$$\Delta h_1 - H > 63 \text{ mmH}_2\text{O} \quad (12)$$

in which: Δh_1 - is the indication of the manometer (7), (figure 1)

H – is the hydrostatic load (fig.1)

This condition is verified both in tables 1 and 2, where on the first row the difference $\Delta h_1 - H$ is of 65 mm H₂O , respectively 68 mm H₂O .

In the first step, the pressure drop on the FBG that contained the one hole disk was measured in the flow rate range $\dot{V} = 144 - 228 \text{ dm}^3 / \text{h}$ and $\Delta h_1 = 568 - 1000 \text{ mm H}_2\text{O}$.

II - In the 2nd step, the nine-hole disk was introduced inside the FBG, the medium diameter of the holes being of 0.517 mm (figure 5).



Figure 5. Case containing a nine-hole disk

Figure 6. Case fixed inside the FBG.

In figure 6, it can be remarked how the case will be fixed with a bronze nut.

Keeping count that a nine-hole disk was used, the rotameter needed to be changed as the flow rate varied in the range of 200 – 646 l/h. The instruments scale limited the measurement range.

4. THE RESULTS OF THE EXPERIMENTAL RESEARCH

* The results of the measurements made in the first step, when FBG had the one hole disk 0.517 are presented in the table 1.

Table 1. The values of the magnitudes measured at the first step, for $H = 500 \text{ mm H}_2\text{O}$

\dot{V} [dm ³ / h]	144	180	210	228
Δh_1 [mm H ₂ O]	568	728	895	1000
$\Delta h_1 - H$ [mm H ₂ O]	68	228	395	500

The graphs presented in the picture 7 were constructed based on the data from the table 1.

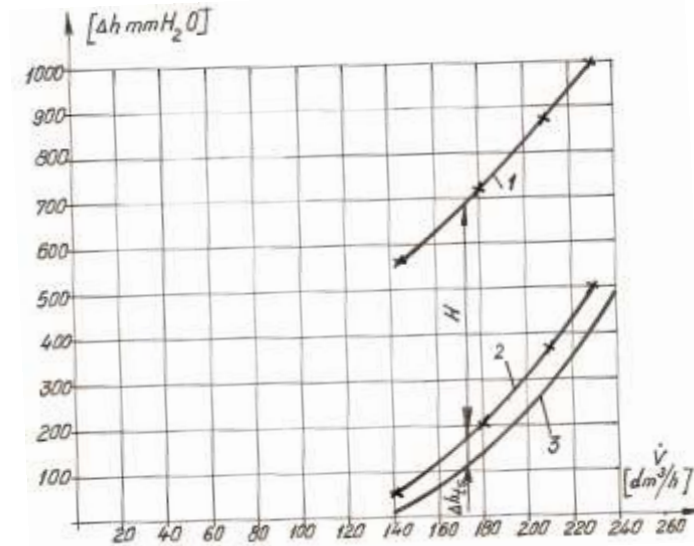


Figure 7. The graphic representation of the functions:
 1 - $\Delta h_1 = f(\dot{V})$; 2 - $\Delta h_1 - H = f(\dot{V})$, 3- $\Delta h_{GBF} = f(\dot{V})$

For $H = 500 \text{ mmH}_2\text{O}$, at the moment when the manometer displays a value of $563 \text{ mmH}_2\text{O}$, the first air bubbles begin to appear. (figure 8, a).



a.



b.

Figure 8 FBG begins to emit the first air bubbles
 a – isolated bubbles ; b – bubble column.

By increasing the air flow rate, a bubble jet appears (figure 8, b).

** The results of the measurements performed in the 2nd step when the FBG included a nine-hole disk Φ 0.517 are presented in the table 2.

Table 2 .The values of the magnitudes measured at the 2nd step, for $H = 500 \text{ mmH}_2\text{O}$

\dot{V} [dm ³ / h]	200	300	400	500	600	646
Δh_1 [mm H ₂ O]	565	590	646	747	890	947
$\Delta h_1 - H$ [mm H ₂ O]	65	90	146	247	390	447

The graphs presented in the picture 9 were constructed based on the data from the table 2.

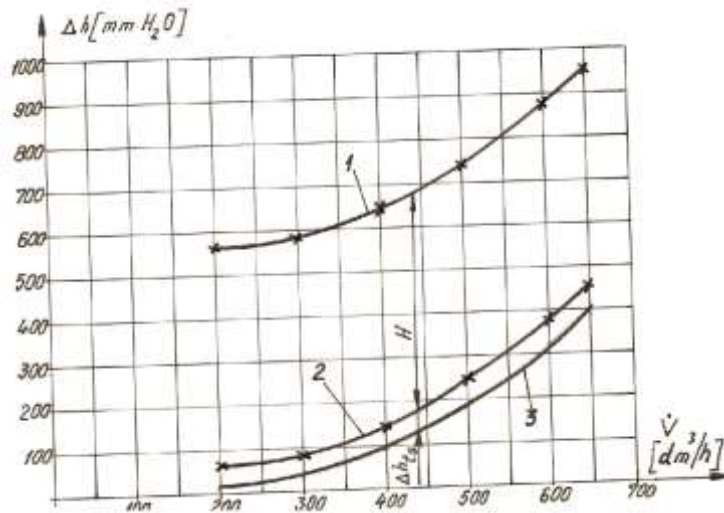


Fig. 9 The graphic representation of the functions:
 1 - $h_1 = f(\dot{V})$; 2 - $\Delta h_1 - H = f(\dot{V})$; 3 - $\Delta h_{GBF} = f(\dot{V})$

In figures 7 and 9 the quantity $\Delta h_1 - H$ consists of the pressure given by the superficial tension Δh_{ts} and the pressure loss (Δh_{GBF}) that appears when the air passes through the FBG; as consequence it can be written:

$$(\Delta h_1 - H) = \Delta h_{ts} + \Delta h_{GBF} \quad (13)$$

If Δh_{ts} is subtracted from $\Delta h_1 - H$, curve 3 that represents the function: $\Delta h_{GBF} = f(\dot{V})$ is obtained.

A bubble hive appearing at a flow rate of $\dot{V} = 180 \text{ dm}^3/\text{h}$ can be remarked in figure 9.



Figure 9. GBF emits a bubble hive



Figure 10. The air bubble generation in the turbulent system.

Increasing the air flow rate to $\dot{V} = 600 \text{ dm}^3/\text{h}$, the turbulent system is reached, the ratio $\frac{\dot{V}}{\dot{V}_{cr}}$ becomes equal to $\frac{600}{24.1} = 24.8$; the bubble column can be seen in figure 10.

CONCLUSIONS:

1. In comparison with the results obtained by the researchers [2][3][4] the new type of FBG presents the following advantages:

- a much smaller pressure drop than for porous diffusers [3]
- an accurate and uniform distribution of the air injection holes, that leads to a growth of the water oxygenation efficiency.

2. The FBG construction is robust, resistant at the action of the pure water (water wells, piscines, etc.) or impure water (treatment stations for residual waters).

3. The subsequent researches must establish the optimal step of the hole net in function of the hole diameter.

Notation list:

r_0 – hole radius;

\dot{V} - volumetric air flow rate;

Δh_1 - air overpressure at the entrance of the water tank;

H - hydrostatic load;

w - air flow velocity;

σ - superficial tension gas-liquid;

ρ – fluid density.

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