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Bubble Flow Study of an Air-Lift Vacuum Column: Column Coldep Case

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Abstract The efficacy and potential versatility of the airlift system are well established. However, many questions remain unanswered. This study discusses only one of them which is the hydraulic behavior of the column, the "pump" function. This is to determine the influence of certain parameters such as water salinity, airflow rate, type of injector on the behavior of the gas phase, which will act directly on the behavior of the liquid phase, and thus the hydraulic behavior. We seek to determine parameters where the column fulfills its role with maximum efficiency.

Keywords Vacuum column; vacuum rate; bubble sized, bubble speed

1. Introduction

In recent years, consumption and production in seafood has increased. An estimated 7% annual growth knowing that currently about 50% of alimental fish comes from aquaculture. The aquatic industry has grown and has led much problems and especially for this study, it concerns environmental problems. Aquaculture production is diverse among the countries in the world. China is the largest producer with 70% of production.

And it is in countries like China and Ecuador as aquaculture pollute and alter the littoral rejecting heavily in the water some nitrogenous organic substances [1, 2].

It was therefore necessary to focus on the cleaner aquaculture using systems to treat the waste. Several solutions have emerged:

The treatment of aqueous effluents using microalgae that will absorb nutrients and promote the purification of nitrogen and phosphate in the case of this study [3]. Offshore aquaculture, which proposes to limit the environmental impact of the coastline by moving, cages far enough away from the coast [4]. The airlift makes it possible to raise fish to the space and with a limited amount of water. In this case, the parameters of the pond water [5] can be controlled and varied more easily. In this study case, the injection of oxygen is not enough to extract much CO_2 dissolved in water. This is why ventilation systems are often used. These aeration systems, putting the air in contact with the water, then make it possible to transfer the CO_2 from the water to the air or conversely according to the needs [6].

2. Description of the airlift

The airlift is installed in the Laboratory of Fluid Mechanics and Acoustics of INSA. The column consists of double concentric PVC tubes (Figure 1). The inner tube has a diameter of 160 mm. The outer tube, at its base, has a diameter of 350 mm. The rest of the height has a diameter of 250 mm. Both tubes are extended in a bi-cone. The total height is 4 meters. In addition to the column, the installation consists of a tank with a capacity of

2 m^3.A tank of 200 liters is used to retrieve the filtered foam in the bi-cone. To create the vacuum, a vacuum pump of Busher brand was used consuming between 0.7 and 3 kW/h [7]. The nominal flow rate is 120 m^3/h.
The injected air for the creation of the bubbles comes from the compressed air network of the laboratory [8].
The bi-cone has been designed to facilitate the recovery of foam at the top of the column. It stagnates and settles between the two cones forming the cone. Loaded with impurities, the foam is recovered by gravity in the 20 liters tank. The bi-cone is used to manage the water at the top of the column. The increase in the diameter reduces the risk of water plugging and the risk of water being sucked by the vacuum pipe. The injection of air can be done with three different injectors. Two passages located at the bottom of the column allow the insertion of two injectors directly into the inner tube of the column. This passage concerns two types of injector: the "open tube" injector (it is only an open pipe without diffuser) and the porous injector (for the creation of fine bubbles). The last injector, the microporous injector, is contained in the injection chamber located at the bottom of the column at the level of the suction tube of the water.

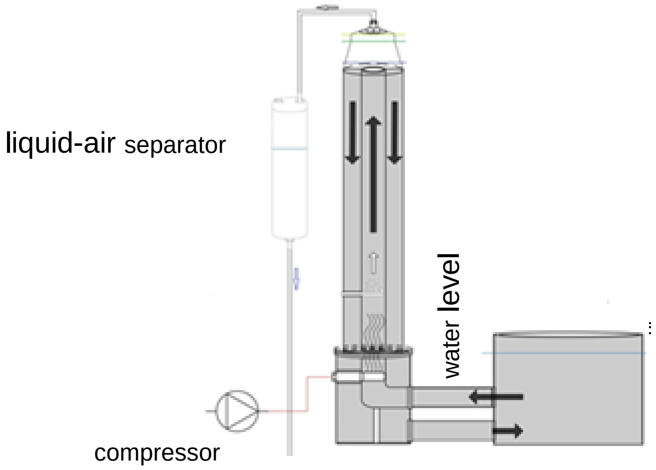


Figure 1: Airlift depression column: Coldep

3. Analysis of the results obtained

3.1. Water flow

Figure 2 shows the evolution, in fresh water, the water flow depending on airflow to each injector.

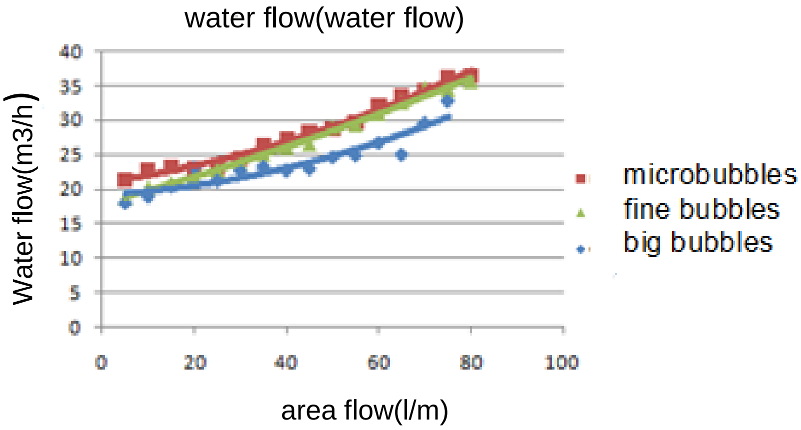


Figure 2: Water flow according to the airflow in fresh water for the 3 injectors

In freshwater, according to the literature, water flows increase with the flow of air, whatever the type of injector [9]. The water flows in fine and microbubbles are similar because in fresh water, the bubbles coalesce and form bubbles of the same diameter. Thus, the flow of water driven by the bubbles will be the same. However, open water flow (large bubbles) is lower than that in the case of fines and microbubbles. However, the larger the bubbles, the lower the transfer. It is therefore not coherent that the flow rate in open tube is lower than in fines or microbubbles. The probable explanation comes from the fact that the big bubbles are injected by the side of the tube. They therefore remain "stuck" to the wall, which could increase friction and thus limit the flow of the trained water. The two following figures represent the evolution of the water flow as a function of the salinity for the fine and microporous injectors. Due to lack of time, open-tube water flow rates for both salty and salty water were not studied.

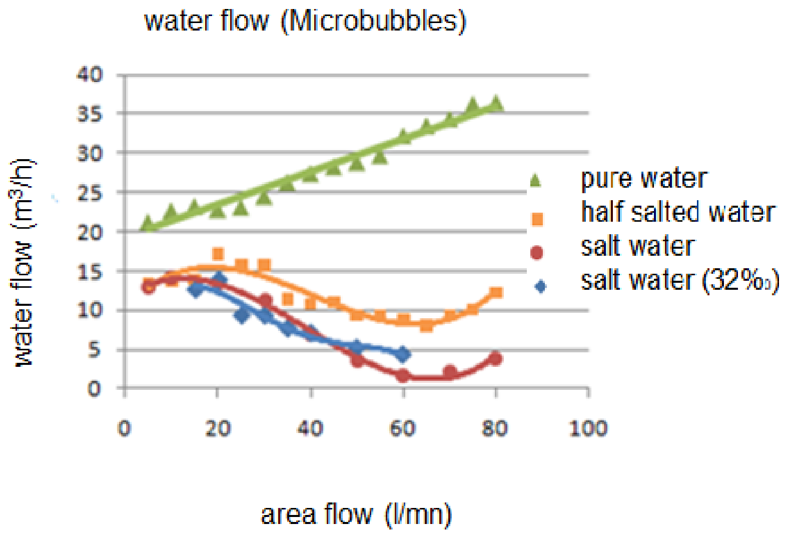


Figure 3: Water Flow versus Microbubble Air Flow

In microbubbles, the flow of water decreases with salinity as shown in Figure 3. This is consistent with what we had seen before. This is due to the phenomenon of "against Air-Lift". This phenomenon consists of a reversal of the fluid flow direction. It appears sequentially. Indeed, in the presence of this phenomenon, there is an alternation between "normal" circulation and reversed circulation. This phenomenon is all the more important as the bubbles are small. Now, the more the water is salty, the less the bubbles will tend to coalesce; they will therefore remain small. It can be noted that the water flow tends to increase up to 20 L / min of air, then decreases drastically up to about 60 L/min and finally increases beyond. In fresh water, the flow is more important because coalescing bubbles. This is in agreement with the literature. The water flow measured in salt water is consistent with what was found in previous tests (blue line in Figure 2)

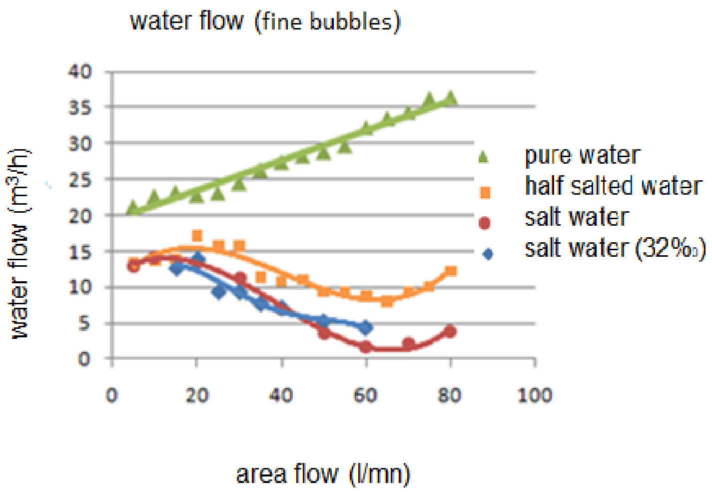


Figure 4: Water flow as a function of airflow in fine bubbles

In fine bubbles, the flow of water increases with the flow of air, whatever the salinity of the water (figure 4). However, this flow is greater in fresh water because the bubbles are larger. On the other hand, the flow of water in half-salty and salty water seems identical, whereas it should be more important in half salted water than in salt water, as it has been demonstrated before. By observing, the diameter of the bubbles in fine bubbles (Figure 14 which represents the evolution of the diameter of the bubbles), we note that the diameter in salt water and half-salted water is very close. Thus, from a certain salinity, the diameter of the bubbles evolves only very little. This explains the fact that the flow of water is also similar.

3.2. Vacuum Rate

Here are the graphs representing the vacuum rate as a function of the airflow, for different parameters (salinity, injector). The rate noted "high-low int" in the following graphs corresponds to the average vacuum rate in the inner tube over the entire height of the column.

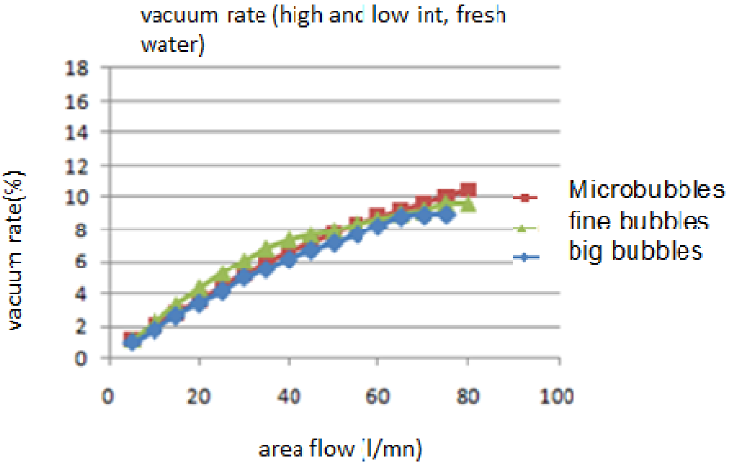


Figure 5: Vacuum Rates versus Fresh Air Flow

In fresh water (Figure 5), the vacuum rate increases with the airflow. This is reliable with the literature and with previous tests. What is more interesting is that the vacuum rate is equivalent regardless of the type of injector. Indeed, in fresh water, the bubbles coalesce easily and quickly. Whatever the injector, the bubbles will therefore have the same diameter. This means that in fresh water, it is not necessary, from a hydraulic point of view, to put porous injectors that induce losses (and therefore higher energy costs).

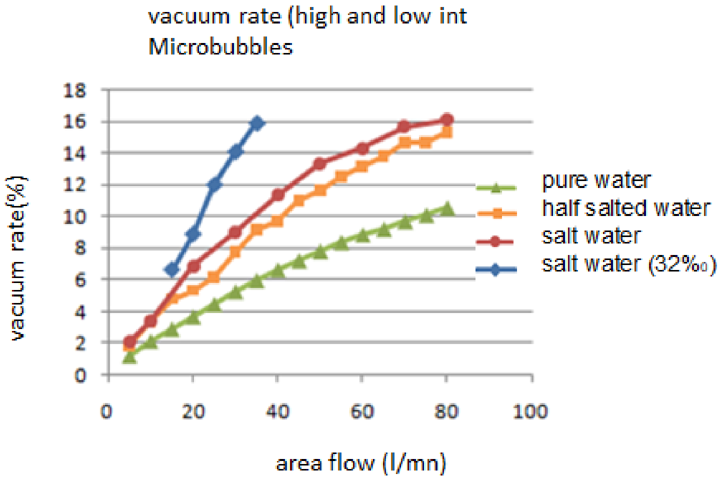


Figure 6: Vacuum Rate vs. Microbubble Air Flow

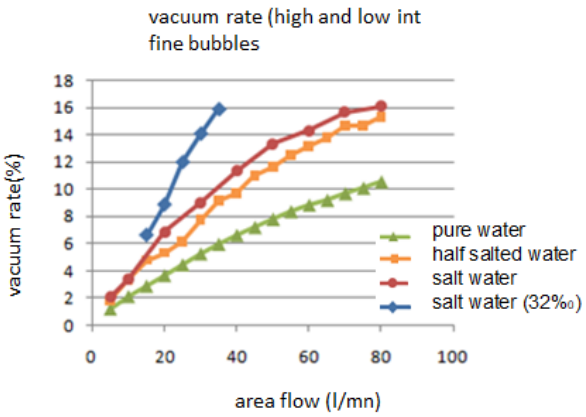


Figure 7: - Vacuum Rate vs. Fine Bubble Airflow

It is noted that, whether fines or microbubbles, the rate of vacuum in mid-salt water and the rate of vacuum in salt water are very close. Indeed, the diameter of bubbles evolves only very slowly with salinity. Thus, the void rate will be close. The connection between bubble diameter and vacuum ratio is very simple. A small diameter bubble rises at a lower speed than a larger diameter bubble. Thus, it will remain longer in the column which, at a given air flow, will result in having a higher vacuum rate. The void rates found in previous tests (blue curve in Figures 6 and 7) are visibly higher than the void rates calculated in this study. This comes from a handling error in previous tests. Indeed, the pressure tap at the top of the column was in the air. There was therefore a "layer" of air between the water level and the pressure point. However, this layer of air was not taken into account when calculating the vacuum rate from the pressure measurements. However, this one had a tendency to increase the rate of vacuum perceived by the manometer. This vacuum rate therefore seems higher than it really is. To solve this problem, care was taken to place the pressure in the water. It is now proposed to observe the variation of the void ratio as a function of the height. The rate of vacuum present in the outer tube is also calculated. This void rate is due to the bubbles that are not evacuated by the top of the column and therefore down in the outer tube.

The graph below corresponds to the vacuum rate calculated in the case of fine bubbles in salt water. However, the conclusions made from it will be valid for all other cases. The curve "Rate high-low int" corresponds to the average vacuum rate throughout the height of the inner tube. In the same way, the curve "Rate up-down ext" corresponds to the average rate of vacuum throughout the height of the outer tube. The "mid-low int vacuum rate" corresponds to the average void ratio in the lower half of the inner tube. In contrast, the "High-middle int void rate" corresponds to the average void ratio in the upper half of the inner tube.

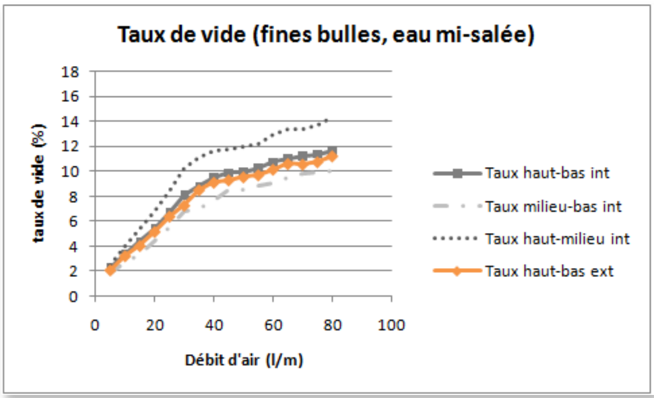


Figure 8: Void rate in mid-salt water and fine bubbles

It can be noted that the void ratio changes significantly according to the height at which one is placed in the column Figure 8. It is clearly visible that the top of the column void ratio (corresponds to the curve "high-middle int rate") is greater than the average void fraction (corresponding to curve "high-low rate int"). Similarly, the rate at the bottom of the column is lower than the overall average. This is easily explained. The more bubbles rise, more depression increases (or the more pressure will be low) and thus the volume of bubbles increases.

The evolution and value of the vacuum ratio in the outer tube is a very interesting result. Initially, we wanted to know it in order to understand and anticipate the phenomenon of "against Air-Lift". It was anticipated that the vacuum rates in the outer and inner tubes would approach only in the event that the counter-Air-Lift phenomenon appeared. However, we note that these two void rates are very close regardless of the parameters (salinity, injector). This result may seem surprising in fresh water because it was supposed that the bubbles, larger in fresh water, would be almost all evacuated by the top of the column. The expected external vacuum rate was therefore very low. Now, in fact, a certain number of bubbles descend through the outer tube. This number is less important than in the case of salt water or half salt but since the diameter is larger, the volume is not negligible. To evaluate this diameter, photos were taken. This diameter, evaluated qualitatively at 3 mm in the case of fresh water, does not depend on the type of injector but only on the salinity of the water. Pictures were also taken in the case of semi-salty and salty water. However, the number and size of the bubbles are, respectively, so large and small that it has proved impossible to determine their diameter.
The average difference between the vacuum level "outer" and the void fraction "inside" is about 0.5%.This gap is logically low or almost zero when encountered against the Airlift (in the case of salt water and microbubbles mainly). The main difference between measurements with and without Airlift comes from the dispersion of the measurements (Figure 9).

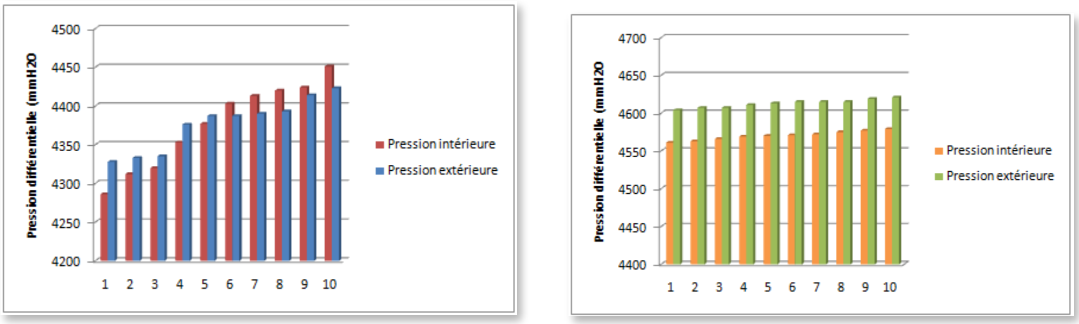


Figure 9: Dispersion of measurements in salt water (left) and in fresh water (right), for an airflow of 50 L / min in the case of microbubbles

The abscissa corresponds to the 10 readings that are made for each series of measurements. It is by averaging these 10 readings that the vacuum rate is calculated. In fresh water (Figure 9b, on the right); the measured pressure is more constant than in salt water (Figure 9a, on the left). In addition, the external differential pressure measured in fresh water is always higher than the internal differential pressure. A higher differential pressure corresponds to a lower vacuum ratio [10]. This is not the case in salt water. It is clearly seen that the highest pressure is sometimes the external pressure, sometimes the internal pressure. However, the external pressure is relatively more constant than the internal pressure. These large dispersions demonstrate the existence of a phenomenon of counter airlift.

3.3. Optical probe measurements

By the use of the optical probe, the diameter of the bubbles can be determined depending on the conditions of parameters (injector, salinity, air flow). In addition, the probe provides bubble velocity and void rate inside the column. This vacuum rate is however very punctual an it is only valid for a given position. As previously stated, the probe is placed in six different positions: at the top, at the center of the tube, at the wall of the tube and then in between. We then redo the same positions at the bottom. Thus, it will be possible to perform a weighted average to calculate the average void ratio in the column. It will then be possible to compare the vacuum ratio values with the values found by the pressure sensors.

3.4. Vacuum rate

Figure 10 presents the vacuum rate measured for each position of the probe, in fine bubbles in half salted water. These curves are directly plotted from the measurements made by the optical probe. There are therefore 6 curves, one for each position of the probe. Only one graph is displayed here, because the conclusion that will be made on this one is transposable to others.

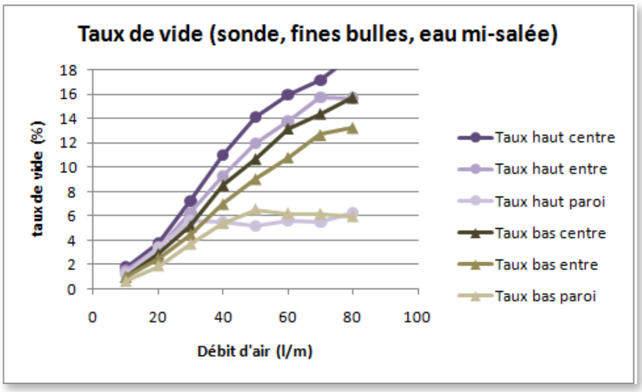


Figure 10: Vacuum rates measured by the probe in half-salted water for fine bubbles

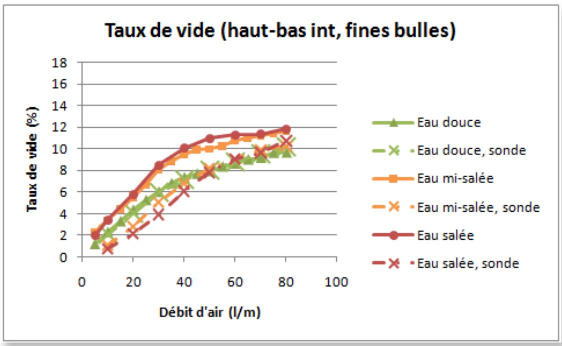
As seen in Figure 10, the void rate is higher at the top than that at the bottom. Moreover, from these measurements, it is possible to observe the evolution of the void rate along the section of the tube. It is observed clearly that the higher the void rate around the center of the tube. This result is also true, as it will be seen later, for the diameters and the velocities of the bubbles. Thus, the majority of bubbles, and especially the larger ones, tend to be in the center of the tube. We also note that the vacuum rate varies more strongly depending on the radial position than the height. It is also observed that the gap between the curves increases with the air flow. At low flow, the flow is more homogeneous. At a higher rate, the differences are accentuated the different.

By analyzing these differences in greater depth, it is noted that whatever the parameters are, there is a constant proportionality between the measurements in the center, in the middle and on the wall. We could therefore estimate the measure in all positions by knowing only one. These ratios of proportionality have been calculated. These ratios are different depending on whether the void ratio, the diameter or the speed are mentioned. Thus, for example, in the case of the vacuum ratio:

$\alpha\_middle = 0.87 * \alpha\_center$

$\alpha\_wall = 0.48 * \alpha\_center$

This can be very useful for reducing the handling time. It's enough to have one value and find the others. We can now compare the average vacuum ratio found with the probe to the vacuum ratio calculated from the pressure measurements. Figure 11 and Figure 12 present vacuum rate versus fine bubble airflow and vacuum rate versus microbubble air flow respectively.



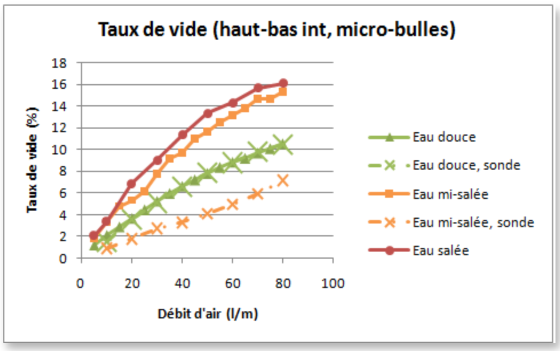


Figure 11: Vacuum Rate vs. Fine Bubble Airflow *Figure 12: Vacuum Rate vs. Microbubble Air Flow*

It can be seen from these two graphs that the weighted average of the vacuum measured by the probe in fresh water is reliable with the vacuum ratio value calculated by the differential pressure. This is a very interesting result because it validates the measurements found by the two measuring instruments. On the other hand, the degree of vacuum calculated by the measurements of the probe in half-salted water (or again for salt water) is very different from that calculated via the measurements of pressure as shown in Figure 11 and Figure 12. This is due to the presence of many bubbles having a diameter less than 2mm. It is clear that the smaller the bubbles are, the greater the difference between the two void rates, which seems obvious because the probe "captures" fewer bubbles [11]. For example, the difference between the half-salt water vacuum rates is greater in the case of microbubbles than in the case of fine bubbles. Indeed, the diameter of the bubbles is smaller in microbubbles than in fine bubbles.

Similarly, in fine bubbles for example, we see that the higher the air flow increases, the more the gap between the rates decreases. Definitely, the more the flow increases and the diameter of the bubbles will be large so the probe will capture more bubbles. We could therefore consider, from this observation, to estimate the proportion of bubbles smaller than 2mm just by analyzing the difference between the two rates.

3.5. Diameter and speed of bubbles

Figure 13 represents the evolution of the bubble diameter as a function of the airflow rate for each position (height and radial) [12]. Here we only mention the case of fine bubbles in salt water but, of course, the conclusions will be valid for the other configurations.

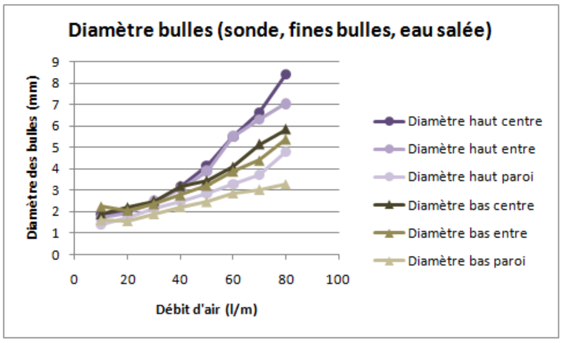


Figure 13: Evolution of bubbles diameter with regard to the position of the probe

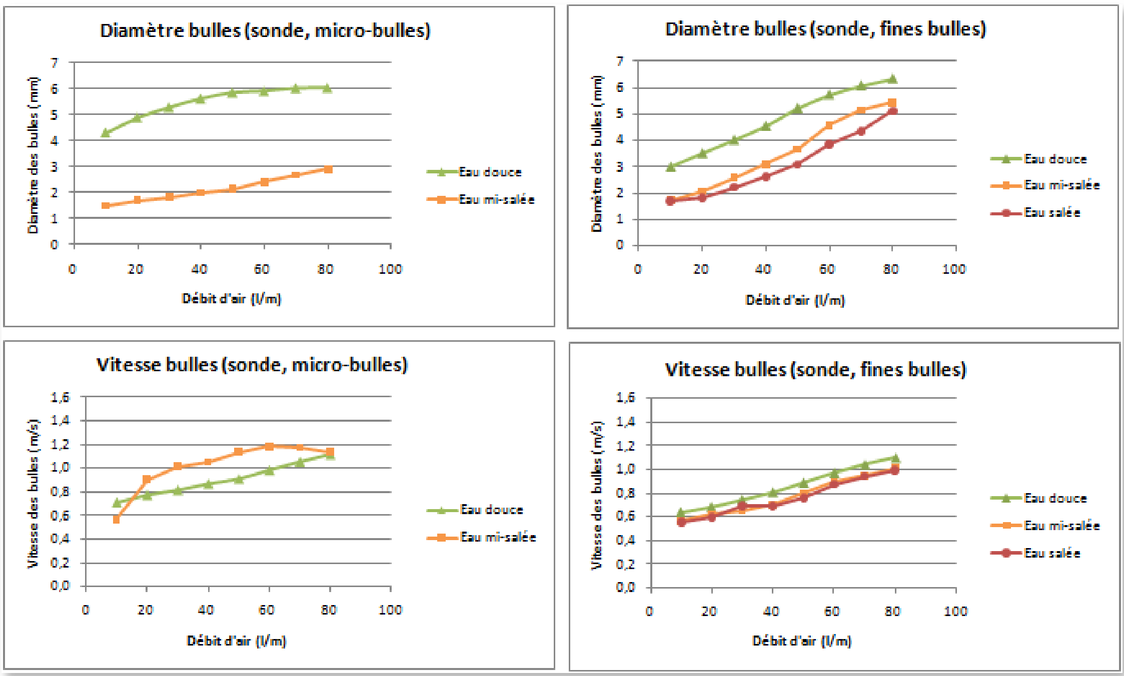


Figure 14: Bubble Diameter and Velocities versus Air Flow for Different Configurations

As it has already been noticed for the vacuum rate, bigger bubbles are around the center at the higher position. It is also noted that the variation of diameter is more pronounced around the wall. This result is transposable in the case of speeds. It is classically about a velocity field in a tube. Nevertheless, the results seem surprising. Indeed, the sensor measures an average diameter less than 2 mm low airflow. However, it was stipulated that 2 mm larger diameter bubbles were not captured by the probe. In fact, the very small diameter bubbles react as solid. They bypass the probe without being sliced. However, it happens that some bubbles are sliced by the probe which can then assess their diameter. Figure 14 presents the diameter and speed of fine bubbles and microbubbles. It was not possible to take measurements of the salt water probe to the microbubbles. This must be due to the fact that there are very few bubbles larger than 2mm in this case, the probe does not capture enough bubbles.

It can be noted that in the case of fine bubbles, diameter and speed are very similar in salt water or half salted. However, the diameter of the bubbles, as well as their speed is more important in fresh water because the bubbles coalesce. For the case of microbubbles, the diameter is also greater in freshwater. However, the speed is lower. Indeed, theory and experience show that the more the bubble is big, the quickly it goes up. This result is therefore to be taken with caution. The Figure 15 compares the velocity of the bubbles with the water velocity they entail.

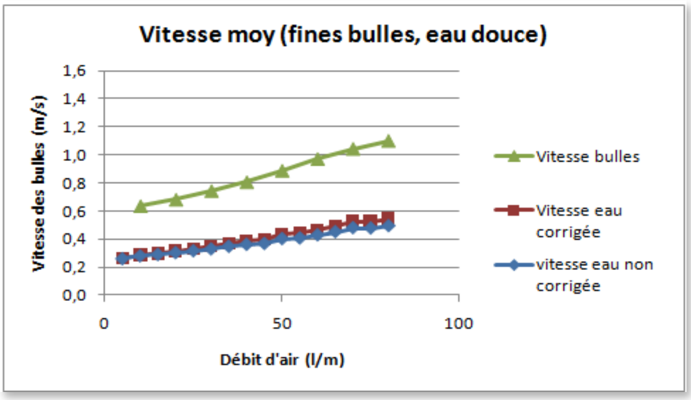


Figure 15: Comparison between bubble velocity and water velocity

As demonstrated in the literature, the speed of the bubbles is greater than the speed of the water, whether corrected or not. The correction takes into account the void ratio when calculating the speed of the water from the flow. Indeed, the water does not fully occupy the section. However, the difference between water speed corrected or not is very small.

4. Conclusion

The airlift is a very innovative system that allows, in a simple, ecological and economical way, to combine three functions manly pumping, mass transfer and skimming foaming. This research work presents the studies carried out on these three functions. Nevertheless, we focused on the hydraulic study of the vacuum column. The influence of various parameters such as airflow, bubble size and salinity, was analyzed in terms of hydraulic behavior. The probe allowed to observe the evolution of the void rate according to the height and the radial position. Thus, the void coefficient changes faster along the radial position than along the height. Similarly, the void fraction in the outer tube is very close to the interior void fraction, and whatever the conditions are.

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