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Influence of the Water Nature on the Two-phase Flow in an Air-lift Column

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Authors' contributions

This work was carried out in collaboration among all authors. Author DB designed the study, wrote the protocol and performed the experiments. Authors DB, AMN and NL performed the data analysis and wrote the first draft of the manuscript. Authors DB, TJ and BD managed the literature searches and revised the manuscript. Author JYC supervised the work. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this study is to determine the phase indicator functions of a two-phase flow in an air-lift vacuum column. The outcome of this study is to master the hydrodynamics in a vertical column when determining the size, the velocities of the bubbles and the void rate then the gas-liquid interphase. The functions are the vacuum rate, the interface speed and bubble size, the flow rate and the speed of the liquid phase. The vacuum lift air column that is the subject of this study is based on the principle of air lift and flotation, all under vacuum. In its operation, the column combines hydraulic pumping, solute transfer and particle phase separation functions, which has the particularity of minimizing energy costs. The process of air-lift columns under the vacuum is still at the development stage and the experimental study of its hydrodynamics is one of the determining axes in the course of the exploration with a assessment to optimizing its design and functioning. The experiments were carried out on a vertical column composed of two concentric plexiglas tubes connected to a water recirculation tank and to a vacuum pump. For all experiments performed, demineralized water and salt water are used and the flow rate is measured using a flow meter. The

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experimental analysis is done using two-phase instrumentation consisting of a bi-probe and the use of experimental techniques has enabled a better understanding of the hydrodynamics of the two-phase flow.

Keywords: Bubble size; speed; vacuum rate; water quality; flow.

1. INTRODUCTION

The study of the generation and behavior of bubbles within them requires to take into account the conditions of pressure prevailing in the column of the air injection and of the nature of the liquid used [1]. The objective is to control the hydrodynamics, the mixture of the bubbles and the vacuum rate so as not to damage the micro-algae in contact with the wall and also to control the salinity and it is useful in aquaculture. Regarding the influence of salinity on the two-phase behavior of the liquid, even if observations regularly emerge as the difference in the sizes of the bubbles, no satisfactory explanation has yet emerged. The research work entitled "prediction of micro-bubble dissolution characteristics in water and seawater" [2], experimentally confirms the commonly observed results concerning the size of the lower bubbles in sea water compared to salt water, but does not explain the reason, and just mentions the probable influence of the change in surface tension or ionic effects. The complete source found is the thesis work [3] on the local analysis of the transfer of matter associated with the formation of bubbles generated by different types of orifices. It clearly synthesizes in its bibliographic part many aspects of the problem of the formation of bubbles by air injection. Practically this work carried out to improve the culture of micro-algae and for example micro-algae grow well in salt water.

2. METARIALS AND METHODS

Previous studies [4] conducted on the effectiveness of an air lift, have highlighted different two-phase behaviors between freshwater and seawater. In order to know the source of these differences, the most striking of which are reside in differences in bubble size and coalescence capacity, column experiments of small volume (about 30 L) were carried out. The diameter of this column corresponds to that of the inner column of the air lift studied and presented to the INSA [5]. This column corresponds to a new experimental setup, these first studies make it possible to define the possible applications and the limits of the test bench. The advantage of the column lies in these dimensions which make it more handleable and allows easier study of various waters than in an air-lift assembly.

2.1 The Protocol

In the perspective of a complete study on the column, it is interesting to characterize the following solutions:

- Distilled or fresh water, at room temperature (about 25°C), cold (about 10°C or 15°C), hot (about 35°C);
- Seawater with various salinity: 5%, 15%, 25%, 35%;
- High salinity water 150%;
- Sea water;
- Rearing water;
- Fresh water in the presence of surfactant;
- Fresh water in the presence of cooking salt 35%.

In the following configurations: for different flow rates, at different heights of the optical probe, in pressure and in vacuum, for different diffusers (agglomerated sand, ceramic and free air).

2.2 Characterization of Salt Water

To homogenize the salt solution, the column works under vacuum overnight at an air flow rate of 15L / min. However, the dissolution time and the agitation within the column do not allow a homogeneous solution to be obtained. The transparent bottom flange allows a deposit of salt to be observed at the bottom of the column, under the injector. Thus, the measurements were carried out for a salinity of 27.8 g / l. It was nevertheless chosen to carry out these measurements at this salinity, because the addition of salt a few minutes before the acquisitions would have created an even more heterogeneous solution.

3. THE FRESHWATER SOLUTION IN THE PRESENCE OF SURFACTANT

0.3 ml of surfactant was added to 23 l of fresh water. The main idea was to homogenize the solution overnight like seawater reconstitution, but on the first bubbling, the surfactant created a thick foam overflowing from the column. We note that after 24 hours of rest, the foaming is much less strong. This is likely due to the spread of the surfactant throughout the volume. By injecting air too soon after the addition of surfactant from the top of the column, therefore in the region of the free surface, the production of bubbles has been enormously favored [6-8].

4. RESULTS AND DISCUSSION

The particularity of our work compared to others is that we used the different water, and the different% in salt, at different temperatures and pressures. To find out the acquisition time allowing a sufficient number of bubbles to pass to relevant statistical processing, a comparative study is carried out. In Fig. 1, the particle sizes are calculated from measurements taken over 60, 120, 200, 300 seconds for demineralized water under vacuum at an air flow rate of 4.08L / min. The ordinate represents the number of bubbles of diameter included in the class given on the abscissa, and normalized by the number of bubbles present in the class of maximum size. It can be seen that the results of the treatment are very similar, which suggests that it is possible to acquire measurements of fairly short duration. This conclusion is at least valid in bubble flow regime. For higher flow rates, the minimum acceptable time is likely to increase. A similar approach had been carried out for slug churn, but artifacts due to the acquisition itself such as the drift of the probes zero, degrade the readability of the results. These artifacts are, besides the simple fact of being able to accelerate the calendar of manipulations, are another reason for choosing short acquisition times.

The convergence depends on the air flow injected into the air lift column [9], in order to obtain satisfactory results, the measurements in demineralized and salt water under vacuum are carried out for an acquisition time of 300s (see Fig. 1). The number of bubbles intercepted by the probe in a mixture of pressurized salt water is low and in this case, the acquisition time is doubled: 600s. The following Fig. 2 represents the dispersion of the results obtained for the rising speed of the bubbles according to different calculation methods proposed by the software in the case of an air flow in demineralized water.

From a flow rate of 4 l / min, the dispersion between the value of a speed for the same acquisition is around 33% (see Fig. 2). The data collected for the following measurements are those given by the cross-correlation method. Because if this graph shows that for data processing, there is no better or more precise method than another, the intercorrelation method offers, by an intercorrelation coefficient greater than 0.7, a validity index of measurement.

4.1 Flow-pressure Coupling

In depression, the points obtained are a function of a coupling between the flow rate and the pressure which vary respectively from 0 to 18 L / min and from - 0.5 to - 0.43 bars. Each point is a separate state. The valve of the buffer tank was not regulated during the manipulations, whereas this would have made it possible to stabilize the depression within the column and to treat the evolution of the results for increasing flow rates in a more coherent manner.

A decrease in depression and an increase in flow rate qualitatively influence in the same way by a general increase in pressure within the column in Fig. 3. The variation in flow rate and depression is almost monotonous in the case of demineralized water and salt water. Only the flow of 7 l / min for the two waters corresponds to a higher depression than for the lower flows and the linearity is no longer respected. Thus, the evolution of the data (ascent speed, diameter, void rate) according to the flow gives erroneous information, but makes it possible to define consistent trend curves. Care must be taken when processing the values obtained for the flow rate of 7 l / min.

4.2 Data Processing

The Diameter of the Bubbles: For demineralized water under vacuum, a large increase in the diameter of the bubbles is observed when the flow of injected air increases. For 15 L / min, the average diameter is 9.3 mm while the average diameter of the bubbles for the other three measurements seems to be capped at 4 mm for a flow rate of 15l / min Fig. 4. A change of scale makes it better understand the differences between pressurized and vacuumed salt water and pressurized demineralized water.

Air flows below 14L / min, the average diameters are distorted (Fig. 5). At low flow, fewer bubbles are created and the share of parasitic bubbles due to a crack in the diffuser is large and modifies the average value of the bubbles perceived by the probe. Too few points were made for flow rates greater than 15 l / min in order to conclude when the evolution of the average diameter of the bubbles. Finally, it is the particle size study which makes it possible to determine the most represented diameter which gives a conclusion without the parasitic effect of the cracked bubbler.

The bubble diameter most represented in demineralized water under vacuum is smaller than the average diameter indicated by the previous graph: it is of the order of 4.7 mm at 12l / min Fig. 6. The increase in the flow of injected air under pressure in demineralized water corresponds to a slight increase in the average diameter of the bubbles and close to 3 mm at 15 l / min. In salt water, the most represented average diameter decreases as the flow rate increases. According to this graph, coalescence does not take place in a saline environment since the diameter of bubbles decreases.

These two different trends are accentuated by vacuum injection, that is to say that in demineralized water, the diameter of the bubbles is greater at a given flow rate under vacuum than under pressure. Whereas for salt water, the depression decreases the average diameter of the bubbles compared to the pressurization for a given flow. This would mean that in demineralized water, the depression favors the coalescence of the bubbles and that in salt water, the depression maintains the non-coalescence of these and however, the probe does not allow to acquire the data necessary for such a hypothesis.

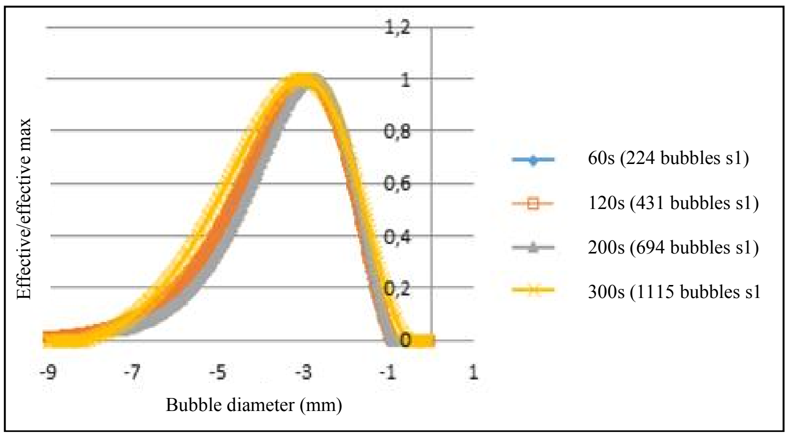

Fig. 1. Convergence of measurements

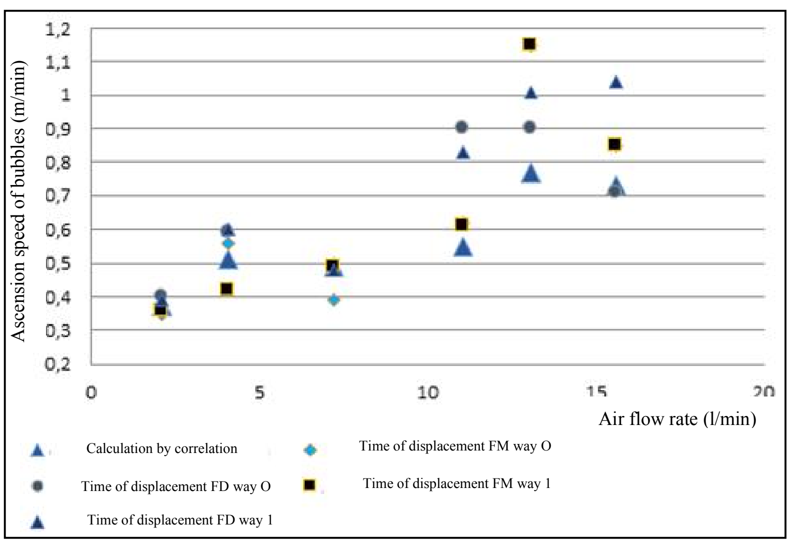

Fig. 2. Bubble speed as a function of different calculation mode

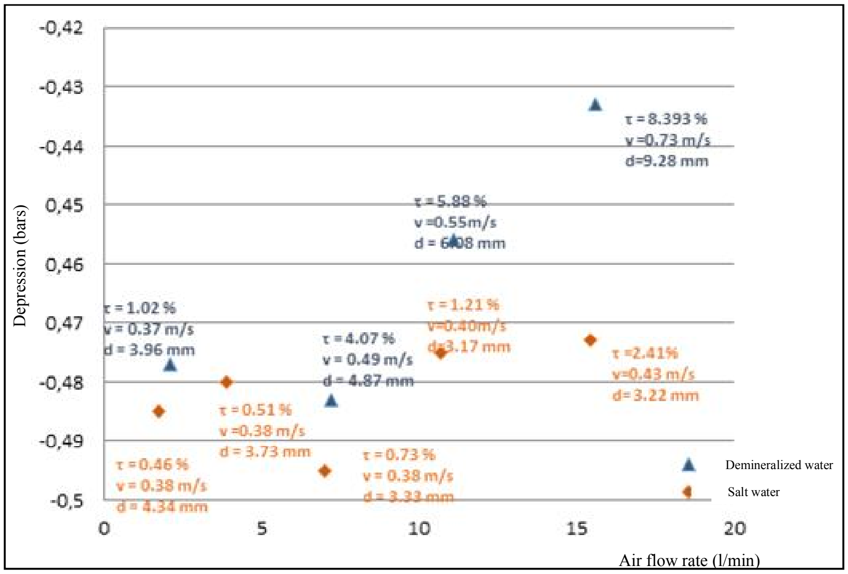

Fig. 3. Pressure variation as a function of flow

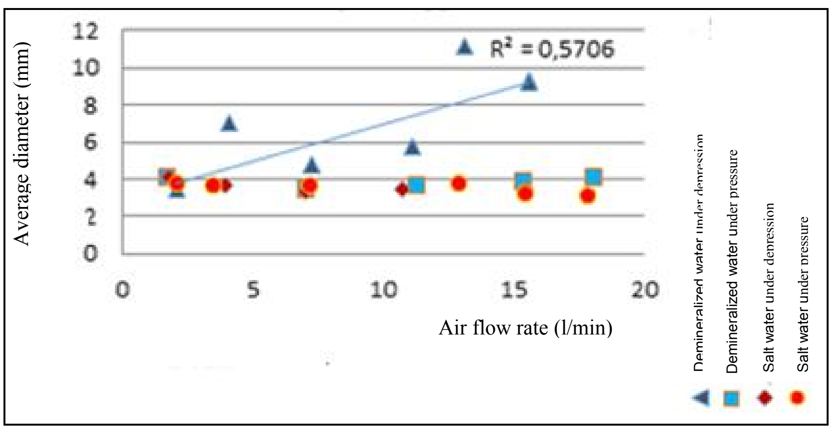

Fig. 4. Average diameters as a function of various water

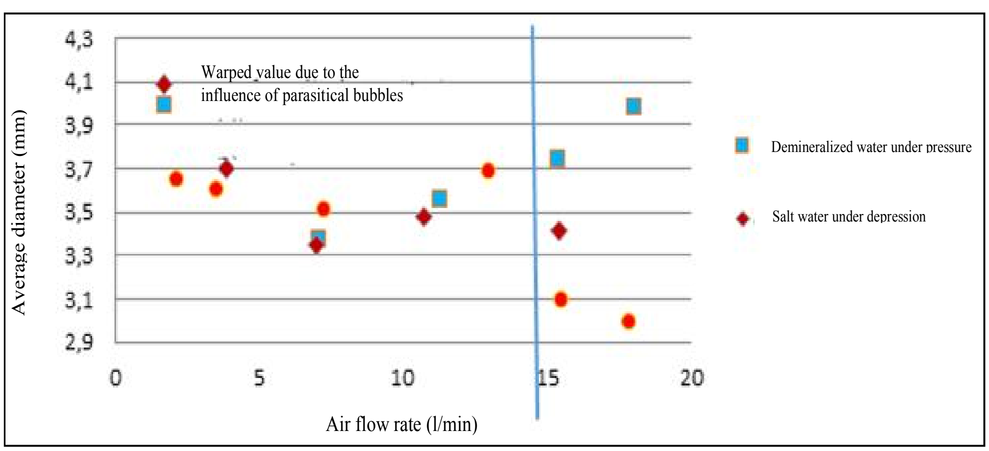

Fig. 5. Bubble diameters for different types of water

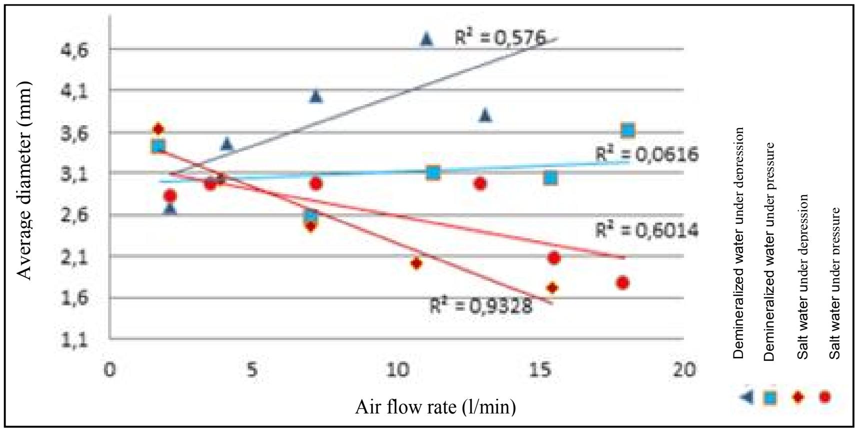

Fig. 6. Particle size study for different flow rates

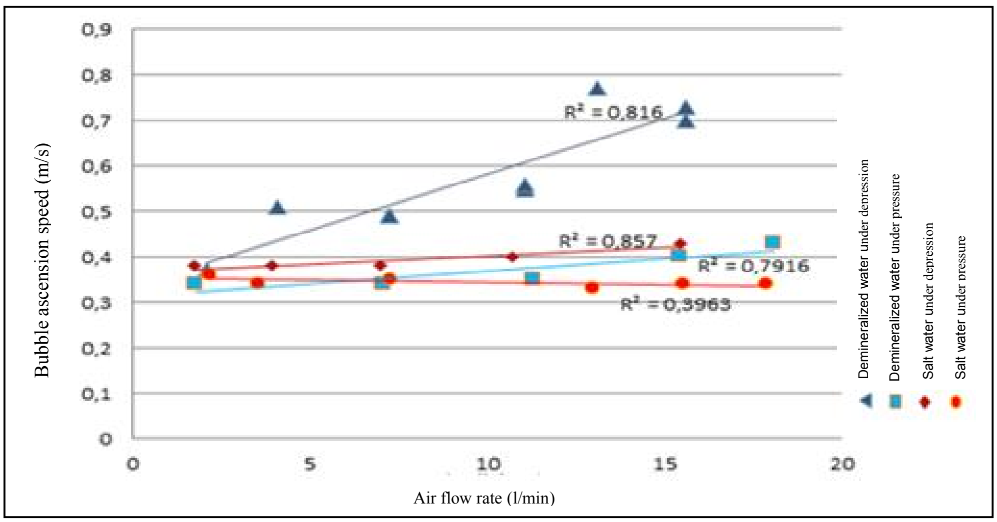

Fig. 7. Bubble velocity for different air flow rates

4.3 Ascent Speed

The rate of ascent of the bubbles increases with increasing air flow for demineralized water and salt water under vacuum, but decreases slightly for salt water under pressure. This is explained by the correlation of the speed of the bubbles with respect to their diameter. A bubble of larger diameter has a higher speed. These trends in the evolution of the diameter and rise of the bubbles are similar for demineralized water, but which is not the case for salt water. This divergence of salt water can be explained by the fact that microbubbles are not taken into account in the calculation of velocities [10].

Indeed, the data in Fig. 7 are also biased by the size of the probe which does not measure a bubble diameter less than the spacing of its tips, ie 2 mm. We know that the population of very fine bubbles (therefore <2 mm) in seawater is preponderant due to bubbling and non-coalescence.

The interfacial air increases when the air flow increases for demineralized water as well as for salt water, whether it is under pressure or under vacuum (see Fig. 8). This result is consistent in salt water for an increase in air flow, hence when the diameter of the bubbles decreases, the interfacial air for the same flow increases. On the other hand, the salt water flow has more bubbles than the demineralized water flow. These bubbles are not perceived by the probe and falsify the measurements. Because for the same air flow, the surface developed by many microbubbles is larger than that developed by a smaller number of larger bubbles. This means that the actual values of the interfacial air of salt water are probably higher and higher than those of demineralized water.

4.4 The Vacuum Rate

Two methods allow the measurement of the vacuum rate: acquisition by the probe and volumetric measurement between static water and the mixture of air and water.

The vacuum rate increases with the air flow. Depression leads to a higher vacuum rate (Fig. 9). For a given flow rate than pressure, the effect is all the more noticeable on demineralized water. But this is due to the nature of the probe and these limits of perception of bubbles of less than 2 mm.

Vacuum rate by volumetric study: Fig. 10 highlights the difference between the vacuum injection method of air, the vacuum rate is greater than under pressure for a given flow. Only three points were noted by this method for demineralized water, the trend curve obtained can thus be questioned.

Relevance of the Methods for Calculating the Vacuum: For demineralized water, the two methods give similar results. A difference is noted for salt water which has microbubbles which are not perceived by the probe. The angle described between the trend curves characteristic of the two methods for pressurized and vacuumed salt water corresponds to the volume of vacuum occupied by bubbles of diameter less than 2 mm. This vacuum volume

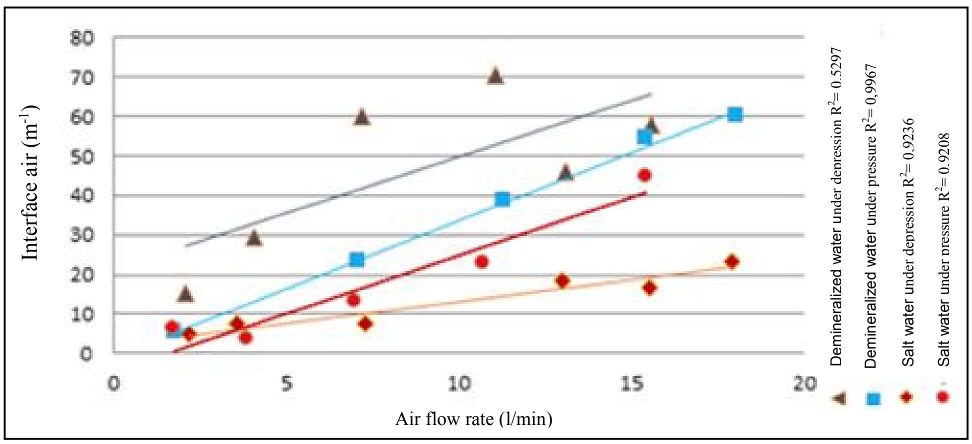

Fig. 8. Variation of interfacial air as a function of air flow

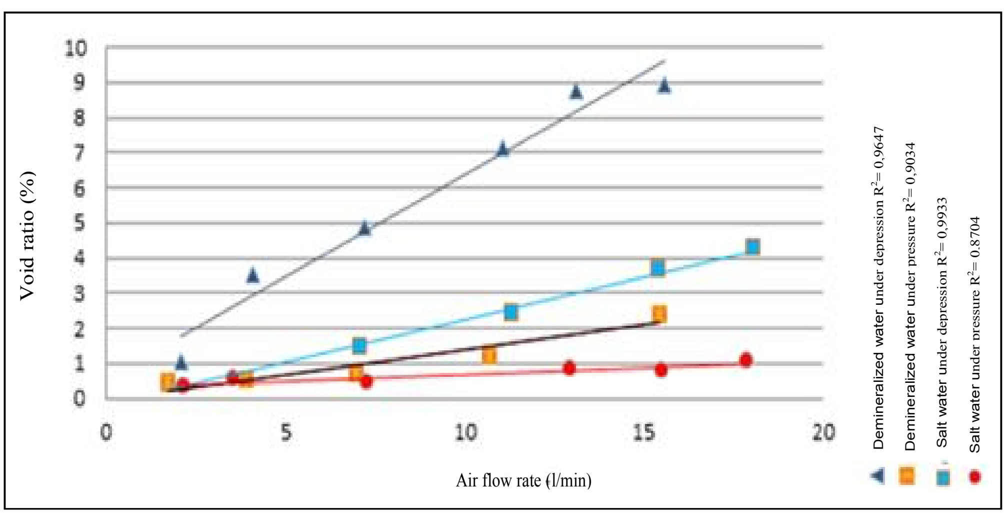

Fig. 9. Effect of vacuum or pressure on the vacuum rate

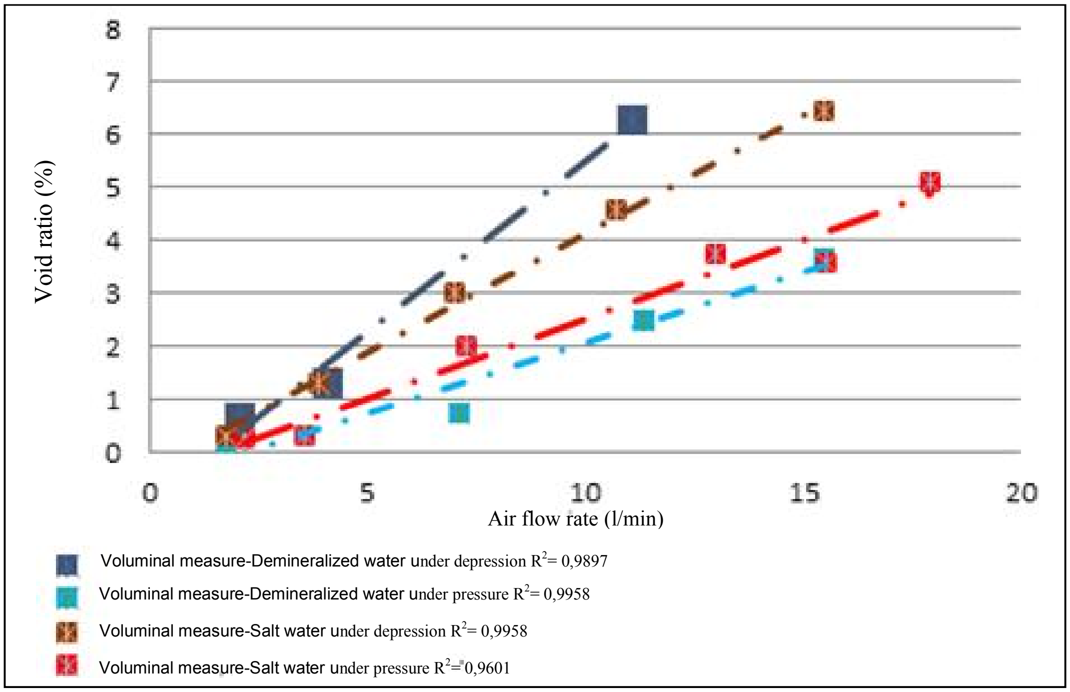

Fig. 10. Evolution of the empty rate depending on the type of water

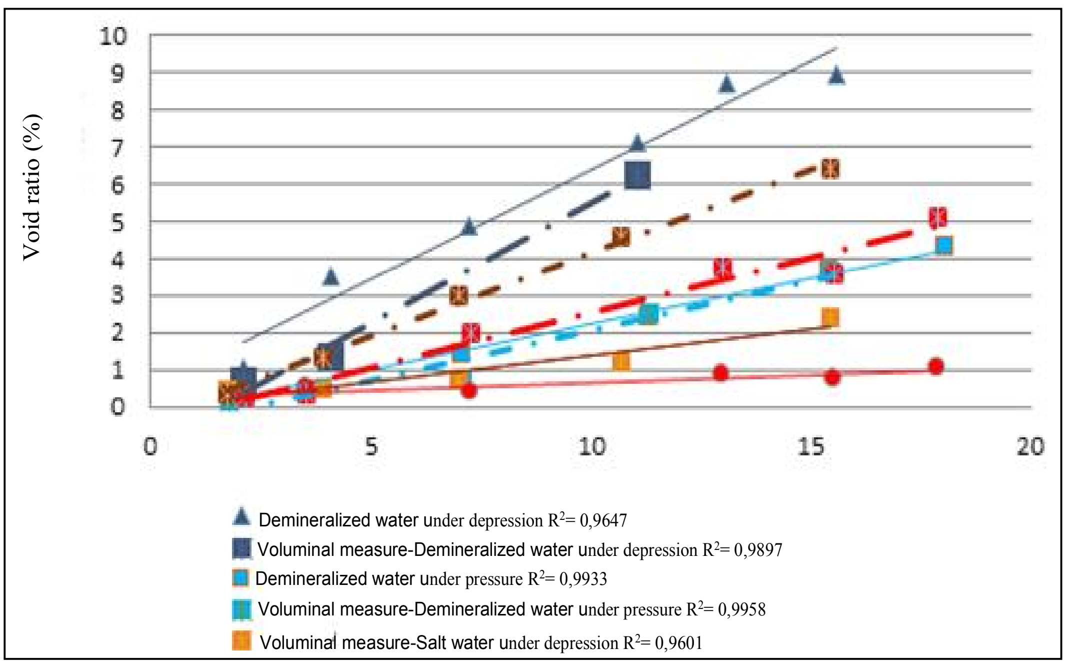

Fig. 11. Calculation of the vacuum rate as a function of the air flow

characteristic of fines and microbubbles is greater under pressure where it presents 79.4% of the total volume, than under depression, where it represents 62.3%. For demineralized water as for salt water, the depression favors the coalescence of the bubbles. This result disagrees with the conclusion obtained by studying the most representative diameters.

However, the conclusion drawn from the study of diameters is unreliable due to the non-perception of fine bubbles by the probe in Fig. 11.

The temperature has a direct effect on the phenomenon of metabolism such as the speed of assimilation, respiration and photosynthesis.

The increase in gas flow leads to an increase in the size and quantity of bubbles as well as their rate of rise.

The size of the bubbles is a parameter which depends on the conditions of injected pressure, inlet flow rate and the diffuser used.

The surface tension of the bubbles is reduced by the salinity, which leads to a decrease in size. In addition, the presence of electrolytes in seawater blocks the coalescence of bubbles and reduces their rate of ascent.

The peculiarity of this work compared to the others is that this work treats at the same time several parameters such as: the influence of the nature of water, the size and the speed of the bubbles, the void rate, the surface tension, the phenomenon of coalescence, temperature and pressure.

The difference is that we have used in our experiment various nature of water, with various air flow at different temperature, of water-surfactant and the probes to determine the pressures at different position of the probe.

5. CONCLUSION

According to the experiments, it follows that the measurements carried out do not inform when the possible influence of the surface tension on the size of the bubbles and their capacity to coalesce. Complementary measurements of fresh water at three distinct temperatures -10, 25 and 40°C within the column were carried out, an experiment which is described in this manuscript would make it possible to verify the hypothesis that the surface tension influences the size bubbles within a solution [11]. In the case where the surface tension really influences the size of the bubbles and their capacity to coalesce, the high value of the surface tension obtained for water saturated with salt offers new perspectives in the applications of the vacuum column lift. It has not been possible from the experiments carried out to demonstrate the role of surface tension on the size of the bubbles and their ability to coalesce. The ambiguity was lifted on the influence of the surface tension on the size of the bubbles, their capacity to coalesce and their speed to rise using several solutions with different air flow and diffusers. The results are satisfactory because there is an increase in the void rate, low speed and diameter of the bubbles favoring the culture of microalgae.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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