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Influence of Fresh Water on Microbubble Generation in an Airlift Column Applied to Aquaculture: Extraction Capacity

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Abstract

Bubble flows consist a liquid phase and a gaseous phase dispersed as bubbles. They occur in nature and in many industrial applications, such as oil transportation in pipelines and steam generators for power generation. Due to large difference in density between gas and liquid, the flottability force causes bubbles to rise, which in turn can generate overall motion and agitation in liquid. This use of gravity as a flow driver, which is specific to disperse phase systems, is used in process engineering (bubble columns and gasosiphon) to sparingly promote mixing and exchange between gas and liquid. In many applications, bubbles are used to agitate a liquid in order to promote mixing and transfers. This work is devoted to study of hydrodynamics of a bubble column. Experimentally, we have determined properties fluctuations of velocities inside the aquarium of rising homogeneous bubbles for different bubble sizes and vacuum rates. The interfacial area between gas and liquid phase is a crucial factor for mass transfer in bubble columns. The molecular exchange between a given volume of gas and water can be enhanced by formation of smaller bubbles, leading to a larger gas-liquid interface. This work presents the various physical phenomena that apply to bubbles, as well as associated dimensionless numbers. A state art of Micro-Bubble Generators (MBG) is then presented, presenting systems using various phenomena such as cavitation, electrolysis, or shear.

Keywords

Vacuum Airlift Column, MIBC, Casein, Turbidity, Surfactant, Coalescence

1. Introduction

Microbubble generation systems have been increasingly developed in recent years. This technology has seen a great expansion of its applications. Its fields of application are, among others, water purification and filtration [1] [2], oxygenation, decarbonation, ozonation systems [3] [4], water cleaning systems from aquaculture [5] [6]. This diversity of areas of use, has seen increasing development in recent years, this is due to privileged properties of microbubbles for removal of suspended solids [7]. In our study, the generator is installed in an airlift column. This system allows cleaning water by removing, thanks to microbubbles, the particles present in flotation [8]. This work is divided into two parts, a theoretical study and an experimental study. The theoretical part consists of a bibliographic research of approach to find products that could answer our problem, but also creation of microbubbles in fresh water and how to improve it. As for practical part, the objectives are, to determine the size of bubbles in fresh water, to study and decrease coalescence on several meters, to improve flotation and skimming in the system [9] [10].

Following the difficulties encountered to satisfy initial objectives of experimental part, new objectives were set, the determination of the most effective surfactant for the removal of suspended solids (SS) through qualitative and quantitative tests, tests on column and aquarium with inert materials (colloidal clay) and finally determination of size of microbubbles and its coalescence on a fixed height using a fast camera.

2. Methods and Materials

2.1. Experiments for Determination of Bubble Size and Coalescence

These tests were performed with a Dalson camera and different lenses. The software used was Camexpert and Labview to program camera settings. The objective was to find the size of bubbles created from a diffuser with and without surfactant. From beginning, several problems were encountered, and therefore, several lenses were tested to try to overcome these obstacles. The ideal method of measurement consists in illuminating a single plane, perpendicular to camera, in the tank. The sharpness is adjusted on this plane with a ruler and then once bubbling is underway size of the sharp bubbles could be known by extrapolating measurement in pixels thanks to dimensions of ruler [11]. Moreover, even if such a system could have been set up, a problem would have arisen with bubbling density, because to be in same conditions as in the column a high flow of air would have to be introduced and it would have created a bubbling surely too dense for measurement of size and coalescence on the illuminated plane [12]. A general illumination was set up, with problems that this introduces. We had to determine the depth of field distance in front of camera in which we see clearly without changing settings of lens to know if the error induced by a bad determination of bubble-lens distance could be harmful. These measurements were made using a micrometer winch that allowed for slight variations in distance from camera to the tank. Depths of field of more than 10 cm were found.

This test was carried out with fixed lens settings, the static camera on winch and a mobile ruler inside tank. For image processing and measurement of distances we used image J software. The distances were measured in relation to face of tank closest to camera. All images remained sharp. Three measurements were made per image for better accuracy.

In Table 1 all data were collected. At a distance of 22 cm, still remaining sharp, the pixel measurement is multiplied by 4. With such an error one cannot be sure of size of measured bubbles. In view of results obtained in measurement of depth of field and magnification measurements were not continued. The study of results under real conditions of machine with surfactants was more important. The effects on size of bubbles are no longer looked at the final result (the amount of SS collected) is objective now.

2.2. Experiments with Surfactants

These experiments collect work done with surfactants presented in "surface tension" part of theoretical block. The qualitative study has been realized on an aquarium Figure 2 and quantitative one on a column Figure 1. The aquarium has as dimensions 40 × 20 × 25 cm, with 4 transparent walls and a black base to be able to appreciate bubbles Figure 2. The column was made of plexiglass, we could only study bubbling at the top of column with a transparent plexiglass bicone Figure 1.

2.3. Qualitative Studies

These experiments were conducted in aquarium with different diffusers. The air pressure at inlet was 2 bar with a flow rate of 1 l/min and 8 liters of water in aquarium. The characteristics to be looked at and compared were bubble size, coalescence, amount of foaming and bubble duration [13].

Test 1: Metal diffuser in fresh water without surfactant.

Bubbles are visible to eye and larger than one millimeter in size. Foaming is non-existent, bubbles burst as soon as they reach surface, Figure 3. We notice that higher air flow rate, more coalescence there is [14]. At low flow rates, the collision of bubbles is limited and therefore coalescence.

Test 2: Ceramic diffuser (large pores) in fresh water without surfactant.

Table 1. Dosages summary and toxicity percentages

	Initial dose	Optimal dose	Toxicity LD50	Toxicity pourcentage	Toxicity pourcentage
Tween 20	0.157 ml/l	0.007 ml/l	18 ml/kg hamster 216 mg/l flish	0.87% hamster 79.6% flish	0.035 hamster 3.55% flish
MIBC	0.025 ml/l	0.014 ml/l	2.08 g/kg rat 359 mg	0.96% rat 5.6% flish	0.54 % rat 3.13% flish
Casein	1 mg/l	1 mg/l	1000 g/kg rat		

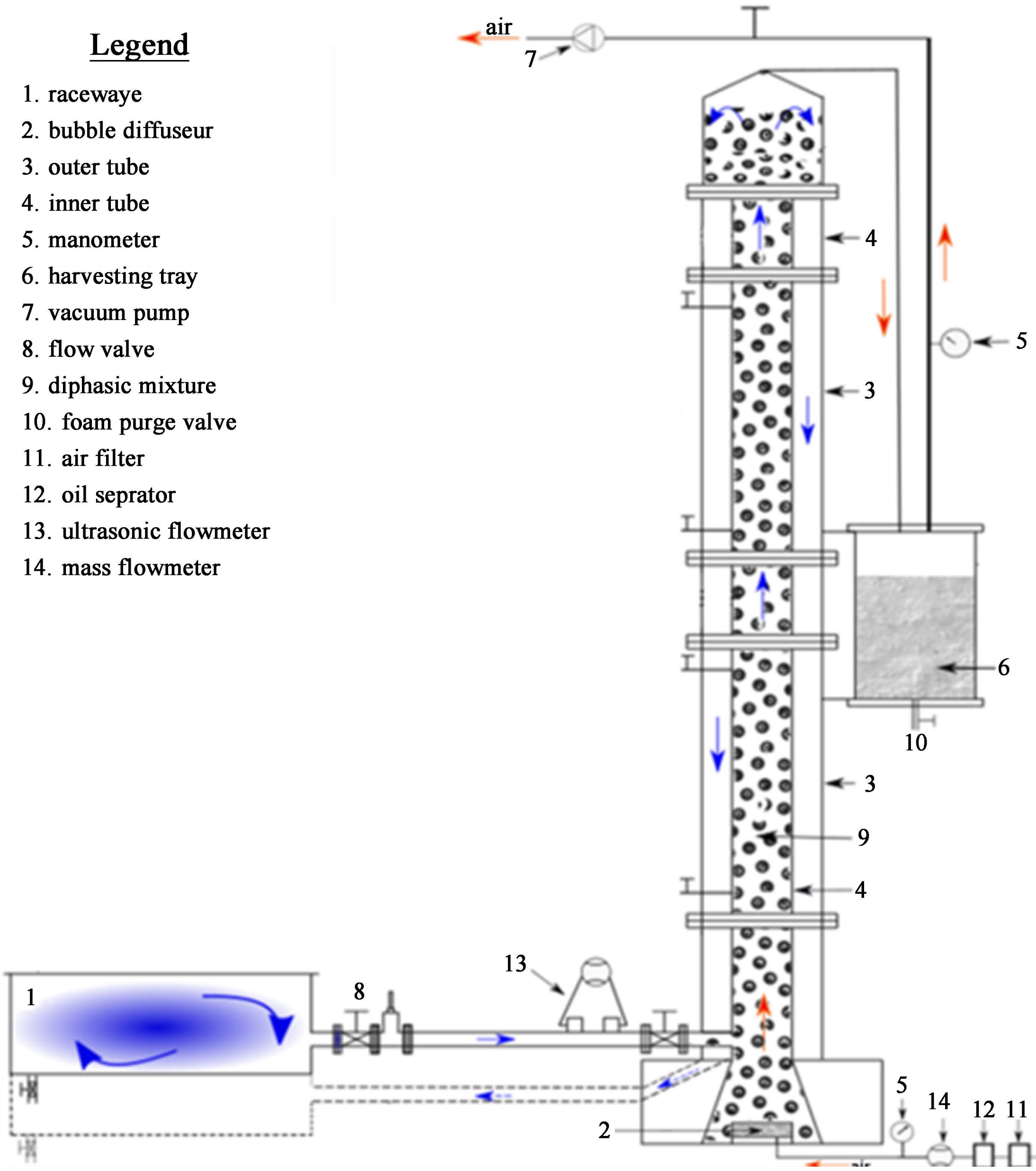

Figure 1. Coldep vacuum column.

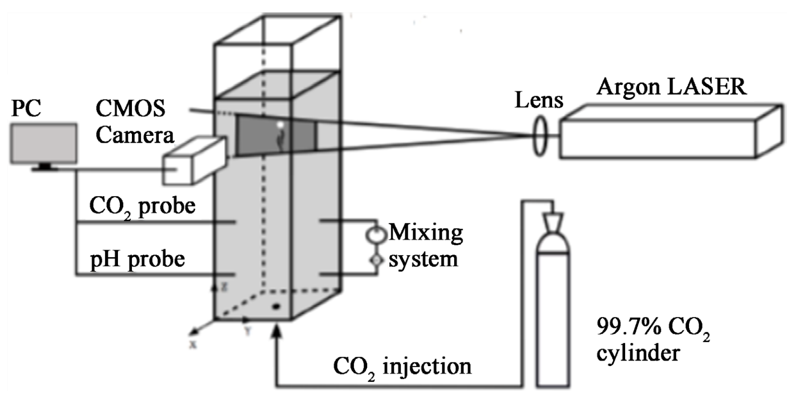

Figure 2. Test bed (aquarium).

Figure 3. Column in operation without clay.

Similar results with metal diffuser. The coalescence does not decrease by reducing flow rate, the cause is probably pore size of diffuser.

Test 3: Ceramic diffuser (small pores) in fresh water without surfactant.

Same bubbling characteristics as for metallic diffuser. It can be concluded that variation of material in diffuser does not influence size and coalescence to naked eye. On other hand, a variation of pore size is important for creation of small bubbles.

Test 4: Dissolved air generator in fresh water without surfactant.

The bubbles have a micrometric size, difficult to appreciate with naked eye. The coalescence is unappreciable. The bubbles rise at a very low speed, and in a few minutes whole water is filled with bubbles. On other hand, behavior of bubbles on surface is similar to previous tests very light foaming, practically non-existent.

With qualitative tests in fresh water without surfactant, it can be concluded that type of diffuser is very important for bubble size and that bubble size and air flow rate are very important for coalescence. It should be noted that no generator was able to create foam on surface. The next test will be done with metal diffuser and addition of surfactants in indicated doses. Tween 20 and MIBC were purchased from Sigma Aldrich, Aura-Pure was supplied by Latvian company Aura via based in Riga and soluble casein was supplied by French company Laffort.

Test 5: Fresh water with 0.025 ml/l MIBC.

A total of 0.2 ml was introduced into 8 liters of aquarium water. The product mixes easily in water, there is no need for agitation. At low air flow rates there is no apparent effect on bubbles. At high flow rates there is an immediate foaming. The size of bubbles does not change compared to test 1, but coalescence is significantly reduced. The foam is very persistent Figure 4 and there are bubbles suspended in whole water. If air supply is cut off, foam remains for 10 seconds until it disappears completely. If dose is increased characteristics remain the same.

Test 6: Soft water with 3 ml/l of Aura-Pure.

As soon as product is introduced, water becomes whitish with a remarkable smell. At low flow rates there is no foaming and no significant remark on size or coalescence. At high flow rates characteristics are same as without product, no visible effects except coloring of water [15].

Test 7: Fresh water with 0.16 ml/l Tween 20.

Amounts of 1.25 ml were introduced into 8 liters of water. The mixing is complicated due to difference in density of water and Tween 20 **Figure 5**, manual stirring is necessary for homogenization. The effects are same as with introduction of MIBC. However, foaming is much more abundant and persistent. The foam does not disappear; generator must be stopped to avoid overflowing aquarium after 5 minutes. The foam remains for more than an hour until it disappears completely [16].

Test 8: Fresh water with 1 mg/l casein.

A dilution of casein was made for a better homogenization of product because it is very difficult to dilute in water. The dilution is made by 0.5 g of casein in 0.5 liters of boiling water. The mixture is stirred for at least 15 minutes. There is no apparent effect on size or coalescence **Figure 6**; however, slight foam with large bubbles is formed on surface [17]. It does not persist after air intake is stopped. The dosage was increased to see if there was any effect on size, but only visible result was a more abundant foaming.

The dissolved air generator was tested under same conditions giving the same

Figure 4. Column in extraction phase after addition of MIBC.

Figure 5. Column in extraction phase after addition of Tween 20.

Figure 6. Column in extraction phase after addition of casein.

characteristics as in fresh water, but with advantages of surfactants. That is to say we had smaller bubbles, reduced coalescence and in addition a foaming characteristic of surfactants. Nevertheless foaming had same characteristics with all generators used. The conclusions that can be drawn from use of surfactants are varied. Firstly, it can be excluded that test results with Aura-Pure are not satisfactory. The other three surfactants have adequate properties for an extended study in a reduced column. The best results observed are foaming, size and coalescence for Tween 20, followed by MIBC and casein with only a slight effect on foaming.

3. Results and Discussion

3.1. Quantitative Studies and Results

For these experiments, column was used. The objective of these studies was to validate observations made in qualitative part, while trying to have best performance with least amount of product [18]. For this purpose, the product chosen was ultraventilated green clay powder, which would simulate suspended solids (SS). The clay was from the brand Argiletz laboratories and had a size of approximately 20 μm. The parameters of experiments were:

Fresh tap water: 70 liters;

Ultraventilated green clay: 7 grams (0.1 g/l);

Diffuser air flow: 3 l/min;

Incoming air pressure: 2 bar.

The course of experiments follows same routine. First water is stabilized in bicone. Then clay is added, stirring until homogenization. Then desired amount of surfactant is introduced and column is rotated. When the system starts to foam we increase the air flow to start the extraction. Once a certain time or quantity of foam is reached in collector, the machine is stopped and extracted foam is emptied and recollected.

For this reason, two tests were performed, first one, to determine amount of surfactant needed for ideal foaming and good harvest, and then a second one where we introduce amount found beforehand and we perform an extraction on a fixed time. This second test had for objective to be able to compare different surfactants with similar conditions of study. The surfactant chosen will be one with the best results in toxicity, price, biodegradability and TSS collection power. Three tests were carried out, namely.

- **Test 1**: Methyl-Iso-Butyl-Carbinol (MIBC)

The estimated dose of MIBC was 0.025 ml/l, on a total of 70 l, 1.55 ml will be introduced. Steps of 0.5 ml will be made. Before addition of surfactant a collection (0) is made in column tank and an extraction from collector without surfactant. After introduction of 0.5 ml effects on bubble size and foam formation at top of column are visible. Another 0.5 ml is introduced for a total of 1 ml (0.014 ml/l). Foaming, size and coalescence conditions seem to improve. The results seem acceptable, extracted water is quite loaded with clay. A last collection is made from the collector with a total quantity of 2 ml.

- **Test 2:** Tween 20

After the first try, the estimated dose of Tween 20 was 0.16 ml/l, on a total of 70 liters 11.2 ml are introduced. Steps of 0.5 ml will be made. At 0.5 ml first harvest is done. At 1 ml effects are already very remarkable, it is not necessary to go further. It should be noted that a quantity smaller than 0.5 ml could be considered

- **Test 3:** Casein

But to move on to trial 3, the estimated dose of casein was 1 mg/l, on a total of 70 liters 70 mg will be introduced. We test with solution that we had kept from first tests. The results are not satisfactory, nothing happens after addition of 200 mg. The casein loses its foaming effects after several days in aqueous mixture. A new dilution of 1 mg/ml is made. At 70 mg the effects are already visible. A long reaction time is needed

3.2. Observation

The quantities of product needed are generally smaller than what was found in bibliography. Only casein needs same amount, but it can be dissolved without addition of NaOH. The general impressions are positive. The best results with naked eye were with casein. Its bubbling was not very abundant and bubbles do not reduce its size but its ability to collect TSS in interface is remarkable. As for MIBC, coalescence is very reduced, as well as size of bubbles, on other hand foam formed, even if very fine, does not color and has difficulty in collecting TSS at the interface. Finally, Tween 20 creates a very abundant and fine foam, even too abundant. The ability to capture TSS is average.

In this second round of experiments a collection at goal of 5 minutes of extraction will be performed with the following three tests.

- **Test 1**: MIBC

We proceed as before. We will collect from the collector with a quantity of 1 ml (7) and then from the tank (8).

- **Test 2**: Tween 20

For Tween 20 we start with 0.5 ml. We collect from the collector (9) and then from tank (10)

- **Test 3:** Casein

We proceed as before. We try with old casein, but we have same results. It has degraded and a huge quantity is needed to make it foam in column. We collect from collector with a quantity of 350 mg and then from tank. A new dilution is made to add 70 mg. A harvest from collector is made with a quantity of 70 mg and then from tank. Casein has a greater capacity to capture TSS than others [19]. The possible cause of this is that proteins produced create a network at air-water interface, and, perhaps, a physico-chemical affinity with clay also improves capture. Too much foaming is not beneficial for proper functioning of column. A last test was carried out in which casein and MIBC were combined. The results are very satisfactory because two elements combined very well. The characteristics of two elements were obtained, small bubbles and a fine foam but which captures very well SS at interface of bubbles. A collection was made, perceived turbidity seemed darker than all others. The casein-MIBC mixture was most effective in collecting TSS. Doses of latter experiment weree same as in experiments measured 1 and 2, with a similar collection time (5 minutes). Finally same experiment was attempted with Tween 20 with acceptable results but slightly less satisfactory than previous mixture. It should be noted that harvests from tests with Tween 20 tend to form micelles that are very difficult to dissolve, and therefore determination of long-term turbidity is more complicated. In **Table 2**, data for each sample is collected, with type of surfactant used, its dose and whether it was taken from pool or from harvest. It can be noticed that with smaller concentrations than expected good results are obtained. If toxic effects are reviewed, very small percentages are found, which together with biodegradability of studied products, make it possible to have no more concerns about contamination of water.

Comparative photos of various samples:

In first image appear samples 0, 1 and 9 **Figure 7**, which have almost no difference; 7 remains a little darker, but it is casein 13 that gains in turbidity. In second one, which was taken upside down to avoid shadow generated by cap, slight difference is noticeable between casein with MIBC and casein alone. The casein with tween 20 remains behind. Tests for determination of turbidity could be done with an Endress + Hausser turbidimeter. These values will give an idea of amount of light that gets through our sample. The values in **Table 3** support conclusions reached in previous paragraph. The cleaning of column in fresh water is practically null; addition of casein multiplies by 14 cleaning capacity of column and collects almost a 40% of TSS; with addition of MIBC cleaning is not 14 times superior, but 18 times, and half of particles in suspension were removed with extraction of 2 liters of foam collection time was between 20 and 30 minutes, about 2 liters required to achieve the turbidity measurement **Figure 8**.

Here are some turbidity values for known fluids. The units are in NTU, which is equivalent to FNU because 1 FNU = 1 NTU. The only difference between two

Table 2. Data for each sample, with type of surfactant used.

Sample	Surfactant	Dose	Total	Origin
0				Pool
1				Collector
2	MIBC	0.014 mg/l	1 ml	Collector
3	MIBC	0.028 mg/l	2 ml	Collector
4	Tween 20	0.007 mg/l	0.5 ml	Collector
5	Tween 20	0.014 mg/l	1 ml	Collector
6	Casein	1 mg/l	70 mg	Collector
7	MIBC	0.014 mg/l	1 ml	Collector
8	MIBC	0.014 mg/l	1 ml	Pool
9	Tween 20	0.007 mg/l	0.5 ml	Collector
10	Tween 20	0.007 mg/l	0.5 ml	Pool
11	Casein	5 mg/l	350 mg	Pool
12	Casein	5 mg/l	350 mg	Collector
13	Casein	1 mg/l	70 mg	Collector
14	Casein	1 mg/l	70 mg	Pool
15	Casein + MIBC	1 mg/l + 0.014 ml/l	70 mg + 1 ml	Collector
16	Casein + Tween 20	1 mg/l + 0.007 ml/l	70 mg + 0.5 ml	Collector

Figure 7. Qualitative study collections.

Table 3. Turbidity values.

	FNU
Eau pure	0.101
Eau + 7 g (P)	18.7
Eau + 7 g (C)	24.3
Eau + 7 g + cas	340
Eau + 7 g + Cas (Nettoyé)	11.4
Eau + 7 g + Cas + MIBC	450
Eau + 7g + Cas + MIBC (N°)	9.5

units is wavelength of light emitted to study turbidity. In case of FNU, infrared light is used and for NTU, visible light.

For tests with surfactants, it can be said that the ability to extract TSS from casein is superior to that of other products. Moreover, fact that it is a protein of natural origin, added to its price, makes it best of tested products. In second position we can notice MIBC, followed by the Tween 20. Both have remarkable characteristics of foaming and coalescence reduction, but in global case they do not collect as much TSS.

4. Velocity Field Measurements

A grid was used for measurements. Five measurements were made on width in 4 different heights. Then each velocity was integrated on small areas of 40 × 30 mm to deduce flow in each frame and finally added to find total flow.

The results in first tests in middle of tank are very similar Figure 9, Figure 10 inbound and outbound speed 11, 12. We notice a high velocity outside raceway. On other hand, inside the raceway velocity is practically zero. Indeed, during experiments with clay, sedimentation was found in inner part of tank.

The representations of outgoing and incoming velocity fields can be seen in Figure 13 and Figure 14. In first figure we see velocity field from above. With axis that goes from 0 to 105 of height, one from 0 to 200 of width beginning from exterior and last speeds. Figure 14 keeps same axes but flow comes towards outside. In incoming side velocities are slightly higher but shape of flow

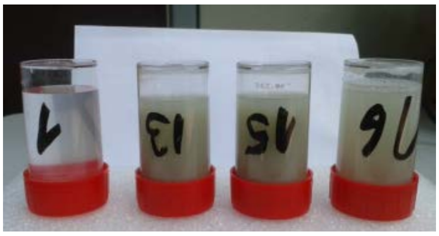

Figure 8. Quantitative study harvests.

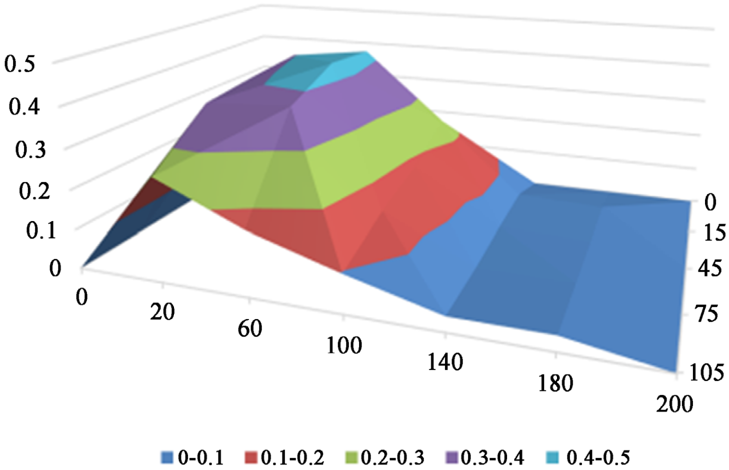

Figure 9. Velocity field on the incoming side.

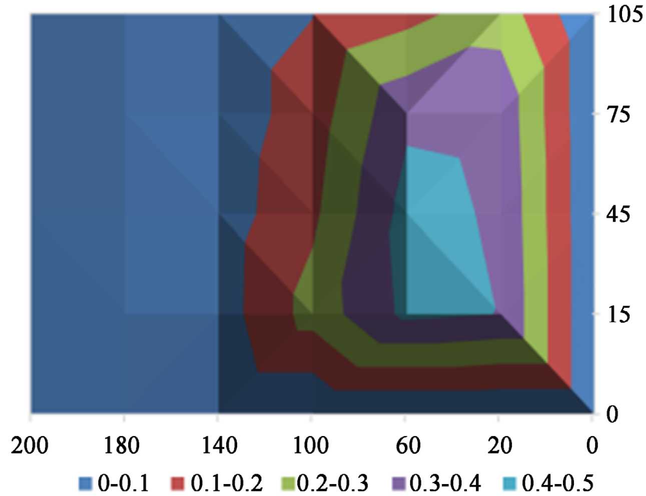

Figure 10. Velocity field on the incoming side.

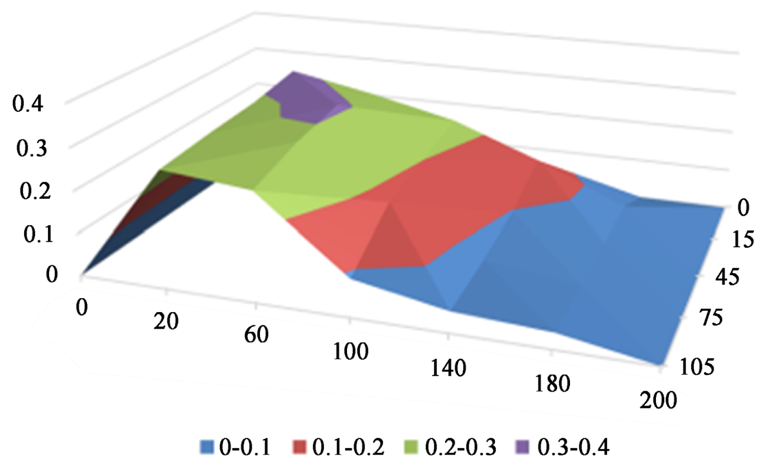

Figure 11. Velocity field on the outgoing side.

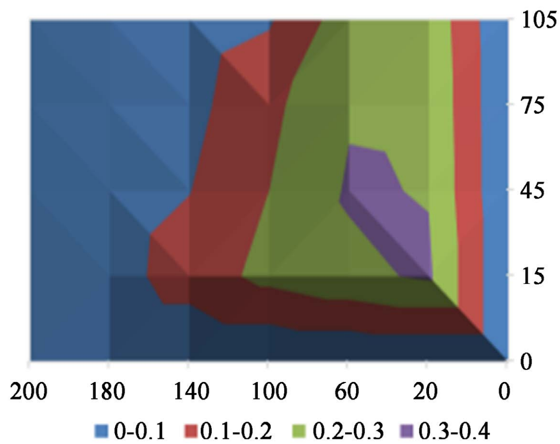

Figure 12. Velocity field on the outgoing side.

remains same. The velocities are measured in m/s. The flow on incoming side is 4.6 l/s and on outgoing side 4.3 l/s, the error is probably due to defects in measurement with reel.

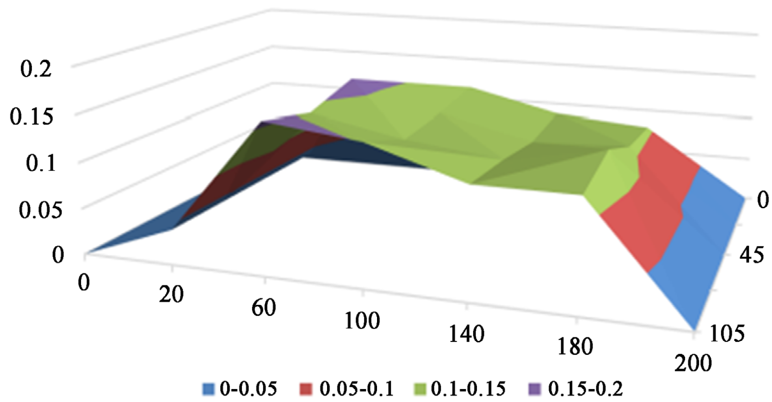

Figure 13. Velocity field between incoming and outgoing side.

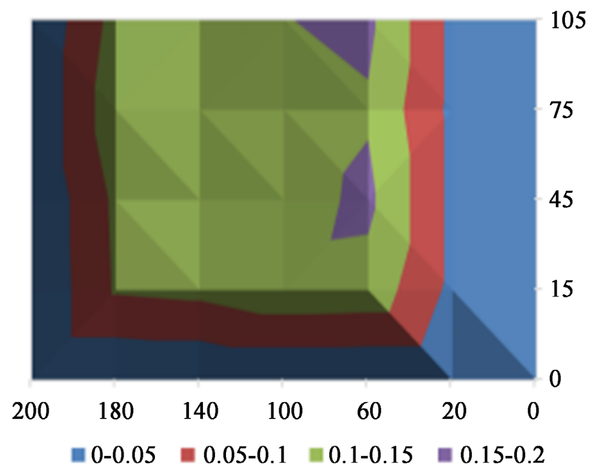

Figure 14. Velocity field between the inlet and outlet side.

In the part between inlet and outlet pipes, we can see a characteristic representation of a laminar flow, zero velocity in contact with walls and rather homogeneous in rest.

The difference between flow in this part of tank and central part will allow us to know real flow in column. This flow rate is general flow rate minus entrainment flow rate. This approximation is rather coarse and it would be necessary to have sensors inside column to check values found. The flow in column will be average of flows found in central part, that is to say 4.45 l/s minus that of intermediate part, 2.7 l/s. This would give a column flow of 1.75 l/s. We have a factor of 2.6 between column velocity and tank velocity. This corresponds to values found by Coldep in large columns.

5. Conclusions

Considering these theoretical and practical studies obtained, it appears clearly that results are satisfactory, in particular for determination of size bubbles and coalescence. The experiments gave us exploitable results but also allowed us to master manipulation of bench and airlift. Moreover, additional results were achieved. These studies allowed us to look at operation of column with inert materials, which makes them more general and repeatable. As for surfactants presented and tested, clear winner in terms of TSS extraction is casein. Besides being a natural product, derived directly from milk, it is biodegradable, with a very low toxicity level and very competitive price. Nevertheless, other products tested showed very acceptable qualities and could be efficient in other cases of study.

The combination of casein and MIBC gives satisfactory results due to complementary action of two agents: MIBC acts as a surfactant that reduces surface tension and contributes to formation of fine bubbles, which clearly increases interfacial area. As for casein, despite fact that its presence contributes to reduce surface tension, it does not seem to act on size of bubbles, on other hand, it intervenes as a foaming agent, which allows it to create and stabilize a thickness of foam at top of column.

The results of solid-liquid separation studies are clear and allow us to conclude that airlift column under vacuum is an efficient and very promising device for removal of turbidity from water. Moreover, casein is a safe material from a toxicity point of view and is widely used as a food additive. Casein and Methyl-Iso Buthyl-Carbinol (MIBC) are inexpensive and available in large quantities. This vacuum column can be used very well in purification chain of turbid water in rural or urban areas for consumption.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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