© 2014 IJIRT | Volume 1 Issue 10 | ISSN: 2349-6002

Hydrodynamic study of an electroflotation column operating in continuous mode

I. Ksentini, K.Hmidi, N.Hajlaoui, L. Ben Mansour
Applied fluid mechanics, process Engineering and Environment Laboratory
Sciences Faculty of Sfax, B.P.1171, 3000 - Tunisia

***Abstract*— In this work, we propose to study the bubble hydrodynamic in an electroflotation column operating in continuous mode. The effect of current density, applied at the electrodes, and liquid phase flow variation on both bubble diameter and bubble rise velocity were studied. The technique adopted to calculate the bubble characteristics is video recording followed by image processing. Modelling the Reynolds number was done in order to predict and discuss the different bubble flow regimes. Defining laminar and turbulent regime of bubbles allowed us the prediction of optimal operating conditions of pomace olive oil wastewater treatment by electroflotation. The treatment consists in optimizing the suspended solid rate reduction which was done successfully.**

***Index Terms-* Electroflotation; Hydrodynamic; bubble flow; current density; treatment.**

I. INTRODUCTION

Gas-liquid reactors are widely used in industrial processes such as food processing, wastewater treatment, lubricants, cosmetics and many other fine chemicals [1]. The performance of such reactors depends largely on bubble hydrodynamic [2]. Bubble columns which are a type of gas-liquid reactor can be considered as one of useful and interesting new process. These columns are the center of various aspects such as mass transfer, heat exchange and hydrodynamic [3].

In fact, electroflotation is the electrochemical version of traditional dissolved air flotation able to float tiny bubbles of hydrogen and oxygen gases to the surface due to water electrolysis according to these reactions [4]:

* Anode reaction: water oxidation

$$H_2 0 \rightarrow \frac{1}{2}\ O_2 + 2H^+ + 2e^- \qquad (1)$$

* Cathode reaction: water reduction

$$2\ H_2 0 + 2e^- \rightarrow \mathrm{H}_2 + 2\ OH^- \qquad (2)$$

Recent researches focused on the separation efficiency of the electroflotation column used largely as wastewater treatment process [5-6]. In fact, many factors interact in this process. Current density applied at the electrodes is among factors which has a significant effect on the separation efficiency. This was confirmed in the study of Ksentini et al. [7] in which they used insoluble electrodes to treat cardboard wastewater. Ben Mansour et al. [8] also showed the significant effect of current density on the process [8]. Indeed, the current density influences directly the number and the size of bubbles and it is proportional to the mass of these bubbles [9-10]. Pino et al. and many other studies related the bubble behavior which affects the hydrodynamic regime of bubbles to the separation process [11-13]. In fact, when the electroflotation is used as a process for eliminating suspended solids contained in wastewaters, only bubbly laminar regime can lead to high separation rate [14]. Studying the bubble hydrodynamic involves particularly a better comprehension of bubble shape, bubble rise velocity and Reynolds number. Unfortunately, not enough works were done to observe the effect of liquid phase flow variation on the bubble behavior. Electroflotation column working in continuous mode is rarely found in literature. In this context, we propose to study the effect of current density applied at the electrodes of the electroflotation column and liquid phase flow variation on bubble hydrodynamic. The co-current configuration is studied in this context. The method of video recording followed by image processing was employed in order to determine bubble diameters and bubbles rise velocities. Reynolds number was then modelled and regressions were obtained linking the process operating parameters with the results obtained. A concrete use of obtained results is the determination of optimal operating conditions of pomace olive oil wastewater treatment by electroflotation. The treatment consists in optimizing the suspended solid rate reduction which requires a laminar bubbly regime.

II. MATERIALS AND METHODS

A. Materials

1) Electroflotation column and used equipment

The lab scale electroflotation column equipped with insoluble electrodes and the equipment used for the determination of bubble characteristics is shown in the schematic diagram (Fig.1)

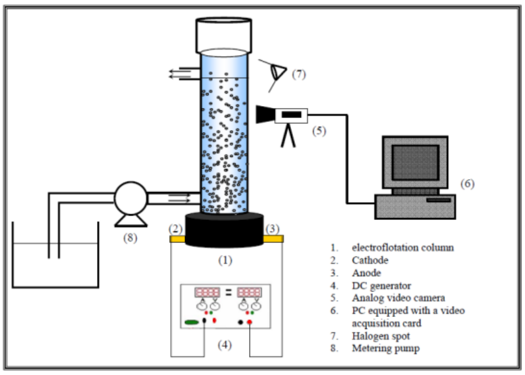

Fig. 1. Electroflotation column in co-current configuration

The electroflotation column is made of cylindrical glass vessel of 9.5 cm internal diameter and a height of 1 m. It is equipped by titanium coated with ruthenium oxide anode and stainless steel cathode. These two superposed electrodes are supplied by a generator of DC current which makes possible

the variation of current density in the electrodes. The column is related to a metering pump (type ProMinent - Gamma/L) in order to vary the liquid phase flow.
The equipments used for the determination of the bubble characteristics by image analysis are an analog video camera, an acquisition card from Pinnacle systems, a PC equipped with appropriate image analysis software (Photoshop CS4 and Virtual Dub 1.8), and a triple 60 watt power halogen spots. Both co-current and countercurrent configurations could be done.

2) Pomace olive oil wastewater:

The effluent is a mixture of wastewater coming from the olein unit and the machine washing unit of a pomace olive oil refinery. Its physicochemical characterization is given in table 1:

TABLE 1: Physicochemical characterization of the effluent

SS *[mg/l]*	*6440*
Fat Content *[mg/l]*	*713*
COD [mgO_2/l]	*12300*
BOD_5 [mgO_2/l]	*150*

B. Methods

The method of calculating the average bubble diameter at different operating conditions consists of recording the bubble flow, then extracting different images from the video file. A wire of a known diameter (0.149 mm) is used as the calibration factor. For getting a sufficiently representative bubble size, 60 bubbles were at least measured. [15]
In order to have a better image quality, the bubbles were illuminated with diffuse back light [16]. Additional image treatment was done using appropriated software equipped with powerful shape filter. Bubble is then clear and the measurement of its characteristics is at that moment possible (Fig 2).

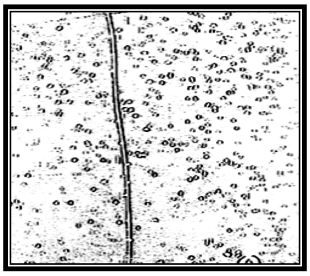

Fig. 2 Image treated for the determination of bubble size

Bubbles rise velocities were calculated using the equation below:

$$U_B = \frac{H}{t} \qquad (3)$$

where H is the bubble course in a laps time t. In fact, series of single bubbles were identified and recorded in their ascension. Then, images were treated and superposed in order to calculate the bubble rise velocity. The same wire of known diameter was also used (Fig 3).

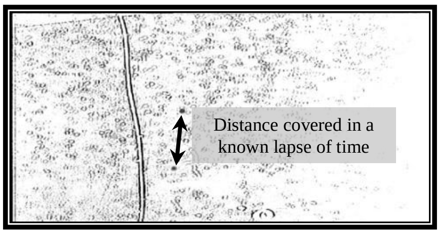

Fig. 3 Images treated and superposed in order to determine the bubble rise velocity

III. RESULTS AND DISCUSSION

A. Effect of current density and liquid phase flow rate on bubble characteristics

Experiments were carried out using tap water (1atm, 20°C) in order to check the effect of current density**,** applied at the column electrodes**,** and the liquid phase flow rate (Q) on both bubble diameter and its rise velocity. The results are shown in the figures 4 and 5:

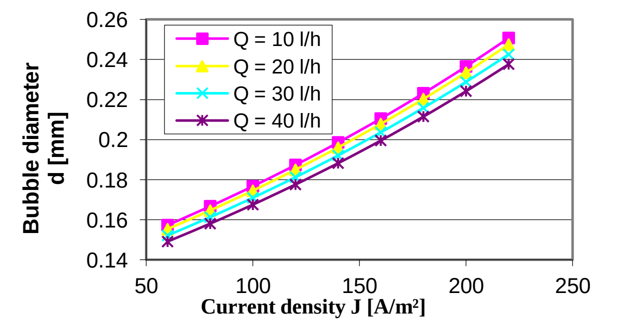

Fig. 4 Effect of current density and liquid phase flow rate on bubble diameter

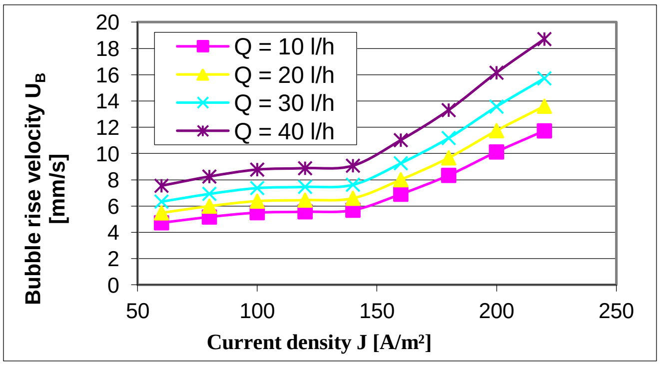

Fig. 5 Effect of current density and liquid phase flow rate on bubble rise velocity

We noticed that:

- increasing current density for a given liquid phase flow rate affect**s** significantly bubble size and bubble velocity. In fact, its leads to larger bubbles which have faster rise velocity due to the dominance of buoyancy force. This is well explained by the fact that bubble flow is increasing. This is compatible with Saxena et al. work [17].

- increasing liquid phase flow rate does not affect significantly bubble size; in fact it leads to a small increase of bubble size. On the other hand, it leads to faster bubble due to the co-current liquid phase movement.

B. Effect of current density and liquid phase flow rate on bubble flow Reynolds number

In case of bubble flow, it is known that transition from laminar to turbulent regime can be achieved by the calculation of Reynolds number. The value Re = 1 delimits this zone [18].

$$Re = \frac{\rho_L \times U_B \times d_B}{\mu_L} \quad (4)$$

Where :

ρ_L : The liquid phase density [Kg.m^{-3}]
μ_L: The liquid phase viscosity [Kg.m^{-1}s^{-1}]
d_B: The bubble diameter [m]
U_B: The bubble rise velocity [m.s^{-1}]

The result is shown in the figure 6 below:

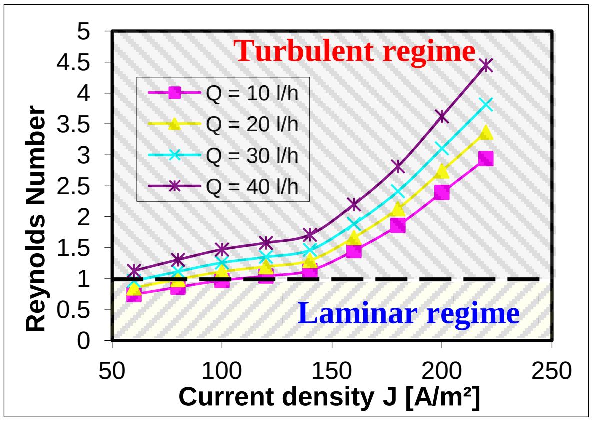

Fig. 6 Effect of current density and liquid phase flow rate on bubble flow Reynolds number

We note that:

- For a given current density, increasing the liquid phase flow leads to obtaining turbulent regime. At 40 l/h (equal to a residence time t_r = 10.5 minutes) and even for a small current density, turbulent regime is only observed.
- For a given liquid phase flow rate, increasing current density leads also to obtaining turbulent regime. Previous work [9]showed that in batch mode (no liquid phase circulation), the transition from laminar to turbulent regime is approximately in 140 A/m², this transition is rapidly moved to low current density when increasing liquid phase flow.

C. Modelling

An appropriate software (DATAFIT V.8.1) was used to elaborate regressions linking the results obtained with the operating parameters. Models are summarized in table 2:

TABLE 2: Regression equations predicting bubble flow Reynolds number, bubble diameter and its rise velocity

	Models	
Bubble diameter	$d = 3.45.10^{-2} \times J^{0.38} \times Q^{-3.69.10^{-2}}$	(5)
Bubble rise velocity	$U_B = 0.44 \times J^{0.86} \times Q^{0.35}$	(6)
Reynolds number	$Re = 5.33.10^{-4} \times J^{1.44} \times Q^{0.31}$	(7)

In which:
d [mm]: bubble diameter
U_B [mm/s]: bubble rise velocity
J [A/m²]: current density
Q [l/h]: liquid phase flow

These equations, and more precisely relative to bubble flow Reynolds number, are important and crucial to predict the optimal operating condition for treating industrial effluent by electroflotation.

D. Treatment of pomace olive oil wastewater by electroflotation in continuous mode

The pomace olive oil wastewater treatment objective is focused in the reduction of suspended solids rate contained in such effluent. So, electroflotation process will not be efficient if turbulent regime is adopted. In fact, in such regime, agitation will be created and therefore disadvantages the treatment efficiency. On the other hand, laminar regime with very small Reynolds numbers will impose great treatment duration to achieve a good treatment result which is considered as a waste of time and money. That is why; the optimal operating condition corresponds to a bubble Reynolds number equal to 1 when electroflotation is used to eliminate suspended solids.

Therefore, we tried to resolve equation 7 in order to obtain Re = 1. Two possibilities exist: fixing the liquid phase flow and calculating the corresponding current density, or the opposite. Actually, experiments were done in both cases: Fixed liquid phase at 10 l/h (t_r = 42 min) or fixed current density on 90 A/m²).

Table 3 gives the results of the bubble Reynolds number model resolution.

TABLE 3: Resolving Reynolds number model

Q = 10 l/h	$J = \left(\frac{Re}{5.33.10^{-4} \times Q^{0.31}}\right)^{0.694}$	➔ J = 113.89 A/m²
J = 90 A/m²	$Q = \left(\frac{Re}{5.33.10^{-4} \times J^{1.44}}\right)^{3.226}$	➔ Q = 30.28 l/h

In order to verify the validity of these models and the efficiency of the adopted process, treatment of this wastewater was done respecting the matrix of experiments shown in table4:

TABLE 4: Matrix of experiments and results of treatments

Experiment	Operating conditions		Suspended solid after treatment	Suspended solid abatement rate (%)
01	Q = 10 l/h	J = 113.89 A/m²	161	97.5
02	Q = 10 l/h	J = 140 A/m²	1532.7	76.2
03	J = 90 A/m²	Q = 30,28 l/h	180.3	97.2
04	J = 90 A/m²	Q = 40 l/h	1803.2	72

We noted that:

- ✓ In experiment 01 and 03, which are supposed at Re = 1, a very good treatment efficiency is observed. This validates the calculated models.
- ✓ In experiment 02 and 04, we treated wastewater in turbulent regime, that's why the suspended solid abatement rate decreased.

A complete physicochemical characterization of treated effluent (experiment 01) was done (Table.5). It shows the efficiency of the electroflotation process in the treatment of wastewaters.

TABLE 5: Physicochemical characterization of treated effluent

Parameters	*Before treatment*	*After treatment*	*Abatement rate (%)*
Suspended Solids *[mg/l]*	*6440*	*161*	*97.5*
Fat Content [*mg/l*]	*713*	*13*	*98.1*
COD [mgO_2/l]	*12300*	*730*	*94.1*
BOD_5 [mgO_2/l]	*150*	*108*	*28*

IV. CONCLUSION

An electroflotation column was used in order to study the hydrodynamic of bubbles in continuous mode. The method of video recording and image processing was adopted to evaluate the bubble characteristics. We have noticed that for a given flow rate, increasing current density leads to obtaining larger bubbles which have faster rise velocity. On the other side, for a given current density, increasing liquid phase flow rate does not affect significantly bubble diameter but largely increases their rise velocity.

An analysis of regimes within the column was also established by calculating bubble flow Reynolds numbers. We have noticed that both current density and liquid phase flow rate have significant effect on the transition from laminar to turbulent bubble flow. Models predicting the variation of Reynolds numbers were established and used successfully in order to predict the optimal operating condition to treat a real industrial wastewaters coming from the pomace olive oil refinery. The treatment was focused on the abatement of suspended solids rate contained in this effluent. This rate exceeded 97 % which validates models and shows the efficiency of the electroflotation process.

NOMENCLATURE

U_B	Bubbles rise velocity	$[L.T^{-1}]$
d_B	Bubble diameter	[L]
J	Current density	$[A\ L^{-2}]$
Re	Reynolds number	[-]
ρ	Density	$[M\ L^{-3}]$
μ	Dynamic viscosity	$[M\ L^{-1}\ T^{-1}]$
Q	Liquid phase flow	$[L^3\ T^{-1}]$
t_r	Residence time	[T]

REFERENCES

[1] G. Yuan, D. Chen, L. Yin, Z. Wang, L. Zhao, J.Y. Wang, 2014, High efficiency chlorine removal from polyvinyl chloride (PVC) pyrolysis with a gas–liquid fluidized bed reactor, Waste Manag. **34**(6) pp.1045-50. doi: 10.1016/j.wasman.2013.08.021

[2] D. Bröder, M. Sommerfeld, 2002, An advanced LIF-PLV system for analyzing the hydrodynamics in a laboratory bubble column at higher void fractions, Experiments in Fluids, December, **33**, (6), pp 826-837

[3] M. Stöhr, J. Schanze, A. Khalili, 2009, Visualization of gas–liquid mass transfer and wake structure of rising bubbles using pH-sensitive PLIF, Experiments in Fluids, , **47**, (1), pp 135-143,

[4] Hosny A Y, 1992, Separation of oil from oil/water emulsions using an electroflotation cell with insoluble electrodes, Filtr Sep J, **29** (5) pp. 419.

[5] Kolesnikov V. A, Varaksin S. O, Ilyin V. I, 1994, An electroflotation method for purifying effluents from ions of metals and organic pollutants and its equipment, Russ Chem Ind, **26**, pp. 38-46

[6] Ben Mansour L. Ksentini, I., Elleuch B, 2007, Treatment of wastewaters of paper industry by coagulation –electroflotation, Desalination, **208**, (1-3), pp. 34-41 DOI:10.1016/j.desal.2006.04.072

[7] Ksentini I., Aouadi M.L., Ben Bacha H., Ben Mansour L, 2010, Solar energy integration in the treatment of industrial effluent by coagulation – electroflotation, Desalination and Water Treatment, **20**, pp. 60-65 DOI:10.5004/dwt.2010.1398

Ben Mansour L., Kolsi K., Ksentini I., 2007, Influence of current density on oxygen transfer in an electroflotation cell, Journal of applied electrochemistry, **37**(8), pp. 887-892

[8] Ksentini I., Kotti M., Ben Mansour L. , 2014, Effect of liquid phase physicochemical characteristics on hydrodynamic of an electroflotation column, Desalination and Water Treatment, **52**, (16-18) DOI:10.1080/19443994.2013.800279

[9] Chen G., 2004, Electrochemical technologies in waste water treatment, Sep. Purif. Technol., **38** pp.11-41

[10] Pino L Z, Yepez M M & Saez A E, 1990, An experimental study of gas holdup in two-phase bubble columns with foaming liquids, Chem Eng Commun, **89** pp. 155.

[11] Ilin V I & Sedashova O N, 1999, An electroflotation method and plant for removing oil products from effluents, Chem Petrol Eng, **35** pp. 480.

[12] Alexandrova L, Nedialkova T & Nishkov I, 1994, Electroflotation of metal ions in waste water, Int J Miner Process, **41** pp. 285.

[13] Ben Mansour L., Kesentini I., 2008, Treatment of effluents from cardboard industry by coagulation-electroflotation, Journal of Hazardous Materials, **153**, (3), pp. 1067-1070

[14] M. Kotti, I. Ksentini, L. Ben Mansour, 2013, Bubble hydrodynamic influence on oxygen transfer rate at presence of cationic and anionic surfactants in electroflotation process, J. Hydrodyn. Ser. B, **25**(5) pp. 747-754 DOI:10.1016/S1001-6058(13)60421-7

[15] Schafer R, Merten C & Eigenberger G, 2002, Bubble size distributions in a bubble column reactor under industrial conditions, Exp Therm Fluid Sci, **26** pp. 595.

[16] Saxena SC, Rao NS, Saxena AC. 1990, Heat-transfer and gas-holdup studies in a bubble column: air–water–glass bead system. Chem Eng Commun, **96** pp. 31–55.

[17] Kendoush A.A., Mohammed T.J., B.A. Abid, M.S. Hameed, 2004, Experimental investigation of the hydrodynamic interaction in bubbly two-phase flow, Chem. Eng. Process **43** pp. 23–33.