Hydrodynamic study and influence of physicochemical parameters on gas retention in a submerged membrane bioreactor

[1,2]NSOE M.N., [2]KOFA G.P., [3]MARC H., [2]KAYEM G. J., [2]NDI K.S.

[1]Institute of Technology, University of Ngaoundere, P.O. Box 455, Ngaoundere, Cameroon; nsoemenguenestor@yahoo.fr
[2] Water Treatment and Filtration Research (Chem. Eng.) Group, Department of Process Engineering, ENSAI, University of Ngaoundere, P.O. Box 455, Ngaoundere, Cameroon; guikofa@yahoo.fr, ndikoungou@yahoo.fr;gjkayem@yahoo.fr
[3]European Membrane Institute UMR 5635(CNRS-ENSCM-UM) CC047, Place Eugène Bataillon 34095 Montpellier ; marc.heran@umontpellier.fr
Correspondence: nsoemenguenestor@yahoo.fr Tel.: +237 677660466

Abstract

Gas-liquid reactors pose transfer difficulties due to diffusion effects. It is necessary to master the aeration and hydrodynamics of the medium to conduct the reaction well and get a good performance. For this purpose, a study in a submerged membrane bioreactor with a useful volume of 30L, consisting of a microfiltration membrane with an average pore size of 0.14 mm having an effective surface area of 0.2 m2 and a PVC cylindrical air diffuser of radius 4 cm has been studied. The saline tracing method associated with a conductimetric follow-up made it possible to determine the residence times and the mixing time in the reactor at 4 different points both in recirculation and in the absence of recirculation. Gas retention was measured by the manometric method. The experiments were carried out at different temperatures of 25 ° C, at 45 ° C, with a variable air flow rate of 0.5 to 16 mL / s and different solutions (osmosis water, ammonium formate solution, solution ammonium formate + salt, synthetic rubber effluent). The results show that the mixing time varies from one point to another and the recirculation of the mixture reduces the mixing time. One of the positions is limiting, the transfer is done most by diffusion with a mixing time of 115 min without circulation and 65 min with circulation. Gas retention increases with aeration rate and temperature. On the other hand, the more the medium becomes rich in organic substances, the more the gaseous retention decreases. The homogeneous fine-bubble regime is obtained for an air flow rate of between 3 and 10 mL / s of aeration. Beyond this flow rate, the regime becomes heterogeneous without a transition phase for ammonium formate and formate ammonium + salt solutions.

Keywords: Hydrodynamic, gas retention, submerged membrane bioreactor, Influence of temperature, Oxygen mass transfer coefficient

1. Introduction

In a submerged membrane bioreactor, the contribution of aeration plays three roles: (i) supply oxygen to the microorganisms essential for the life and the oxidation of pollutants, (ii) stir the reactor by keeping the particulate matter in suspension (ie the micro-organisms) while ensuring a perfect mixture with the substances to be oxidized and especially (iii) generate turbulence in the vicinity of the membrane in order to reduce the deposition (clogging of the membranes) which is formed during the convective movement related to filtration. Low aeration, or a discontinuous aeration mode are therefore unfavorable to the mixture (settling and / or creation of dead zones) or cause an accelerated clogging of the membranes due to an almost frontal filtration mode [1, 2]. Membrane Bioreactors thus have energy consumption over conventional activated sludge processes due to membrane air averaging around 42% of requirements [3,1,4,5]. The energy costs of typical membrane bioreactor stations in municipal wastewater treatment therefore remain higher than the conventional activated sludge process. [6] notes that the Heenvliet membrane bioreactors equipped with Toray flat membranes consume between 0.8 and 1.2 kWh / m^3 of permeate produced. Overall, the authors agree that these consumptions can be reduced to reach a level of 0.7 - 0.8 kWh / m^3 compared to 0.6 for conventional processes (40 kW / PE / year).

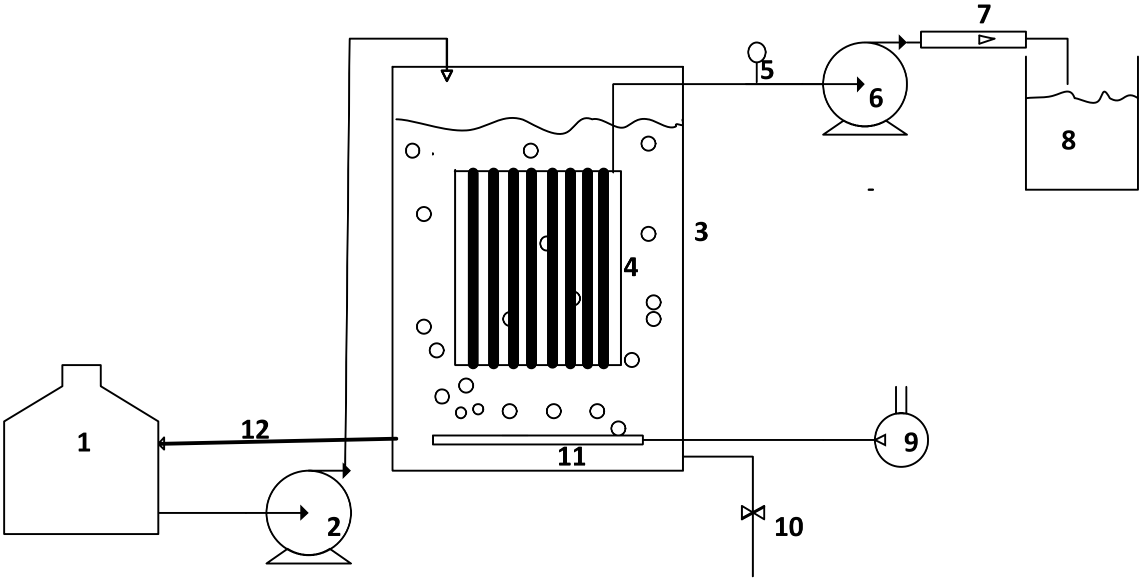
It then becomes necessary to see it crucial to control and optimize aeration as well as the various operating parameters that can influence aeration. In the literature, the majority of studies have focused mainly on the influence of the design variables (type, arrangement, density and immersion height of the diffusers) and of the operating variables (gas velocity, horizontal velocity of circulation) in order to reduce operating costs, optimize treatment and reduce membrane clogging [7]. However, physicochemical parameters such as environmental composition and temperature also influence oxygen transfer, mixing time and gas retention, and these parameters have been the subject of very few studies.

For this reason, this study is devoted to global knowledge of the influence of temperature and substrate concentration on the hydrodynamics (mixing time and gas retention) of a submerged membrane bioreactor pilot.

2. Materials and methods

2.1. Experimental Set-up: Bioreactor membrane

The submerged membrane bioreactor pilot studied consists of a plexiglass feed tank with a capacity of 40L with 35L of useful volume. A RENA brand compressor is used to inject air at the bottom of the reactor through a thin cylindrical PVC bubble diffuser 8 cm in diameter. The aeration cycles were fixed using a COGEX brand timer in order to have a maximum oxygen concentration of 6 mg.L-1 in the medium. The pilot is powered by a peristaltic pump (GILSON ™ Model minipuls 2) connected to a feed tank with a capacity of 30 L. The treated water is suctioned with a peristaltic pump (CEBILON Model Reverse Osmosis System) through a polyvinylidene fluoride (PVDF) microfiltration membrane from A3 GmbH Germany. The Membrane Module contains 8 parallel plates spaced 12 mm apart. The plates were connected together and act as a single membrane module with a membrane effective area of 0.2 m2 and a cut-off of 0.14 µm. A flowmeter (PLATON ModelU-32703-50), is used control flow at the exit of the membrane. A pressure sensor (KELLER MANNO 200 Model LEO 2) with an accuracy of 0.01 bar is used to measure the transmembrane pressure (PTM).



1. Stockage tank , 2.Feed pump, 3.Bioreactor, 4.membrane Module, 5.Manomèter,
6.Permeat pump, 7.Flowmeter, 8.Perméat, 9.Compressor, 10. Evacuation vanne,
11. Air diffuser , 12. Recirculation chanel

Figure 1: Experimental Set-up: Bioreactor membrane

2.2. Determination of the mixing time

The tests were carried out both in two-phase air-water (aeration) with recirculation and without recirculation and at four measurement points (Figure 2). In both cases, the injected air flow rate (Qg) was set at 6 ml / sec and 20 ml tracer of a 350 g.L^{-1} Sodium chloride solution were injected at point I. The tracking of the tracer concentration is done with a conductivity meter (HANNA, model HI 8733) thus making it possible to determine the curve of distribution of the circulation time which characterizes the mixture in the reactor.

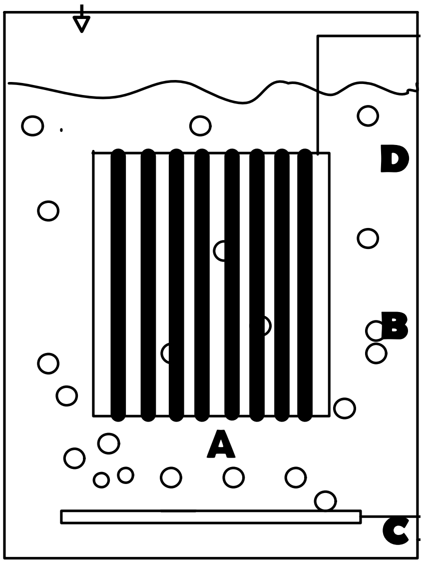


Figure 2: Position of the conductivity probe in the reactor (C: 2 cm from the surface of the reactor, B: Same horizontal axis as A, D: Deep in the corner of the reactor. A: On the axis of the diffuser at 10 cm from the diffuser)

2.3. Measurement of gaseous retention (εg)

In this work, εg was determined experimentally by the manometric method based on static pressure measurements between two points of the reactor separated by a height. The difference in pressure is measured by a manometer of mark (Handheld manometer, USA, Series 8205). Friction losses by friction are negligible and as ϱg << ϱL, the global gas retention can be calculated by the following relation

$$\boldsymbol{\varepsilon_g = 1 - \frac{(\Delta P)}{\rho_L . g . \Delta h}} \quad \textbf{Equation 1}$$

ε_g corresponds to the vacuum fraction within the reactor, that is to say the ratio between the volume occupied by the gaseous phase and the total volume of the reactor. ΔP is the static pressure difference between the two sensors placed a distance Δh.

2.4. Oxygen mass transfer coefficient

Gas-liquid contact is a matter of decisive importance for describing systems involving biological processes. Mass transfer between phases may often become the limiting step of the overall process rate. In such cases, the volumetric oxygen transfer coefficient, KLa, must be known in order to carry out the design and scale up of bioreactors [8,7,9]. The transfer coefficient kla was determined by following the standard method of measuring oxygen transfer in fresh water published by the American Society of Civil Engineering [10]. First, the dissolved oxygen level in the reactor was reduced to zero by adding 1,000 mg/1 of sodium sulphite (Na2SO3) and 16.7 mg/L of cobalt (CoC12) as a catalyst. During the re-aeration phase, the concentration of dissolved oxygen increases progressively in the reactor (positive step); The material balance on the oxygen in the liquid phase makes it possible to determine the value of K_{La} according to the equation 2.

$$\boldsymbol{\frac{dC}{dt} = k_{La}(C^* - C)} \quad \textbf{Equation 2}$$

Where C* is the oxygen solubility and C is the oxygen concentration in the liquid. Assuming the liquid phase is homogeneous and C_0 is the oxygen concentration at t = 0, the integration of the previous equation leads to:

$$\boldsymbol{\ln(C^* - C) = \ln(C^* - C_0) - k_{La} \times t} \qquad \text{Equation 3}$$

The volumetric mass transfer coefficient can now be determined by plotting ln (C* - C) against time (t).

2.5. Condition of study

In this study, several conditions were studied namely:

Variation in temperature 5 temperature ranges were studied (25, 30, 35.40 and 45 ° C).

Variation in the composition of the medium (osmosis water, ammonium formate solution, ammonium formate solution + salt.

3. Résultats and discussion

3.1. Distribution of residence times (mixing time t_m)

The variation of the conductivity in the bioreactor as a function of the position of the conductivity probe was measured as a function of the study conditions (without recirculation (Figure 2) and with recirculation (Figure 3).

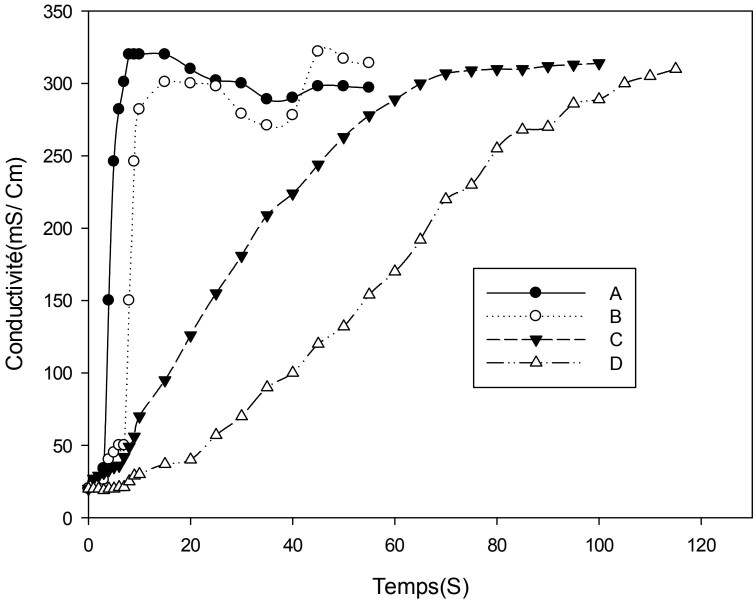


Figure 3: Variation of the conductivity as a function of time without recirculation of the fluid at different positions (A, B, C, D) with a constant airflow.

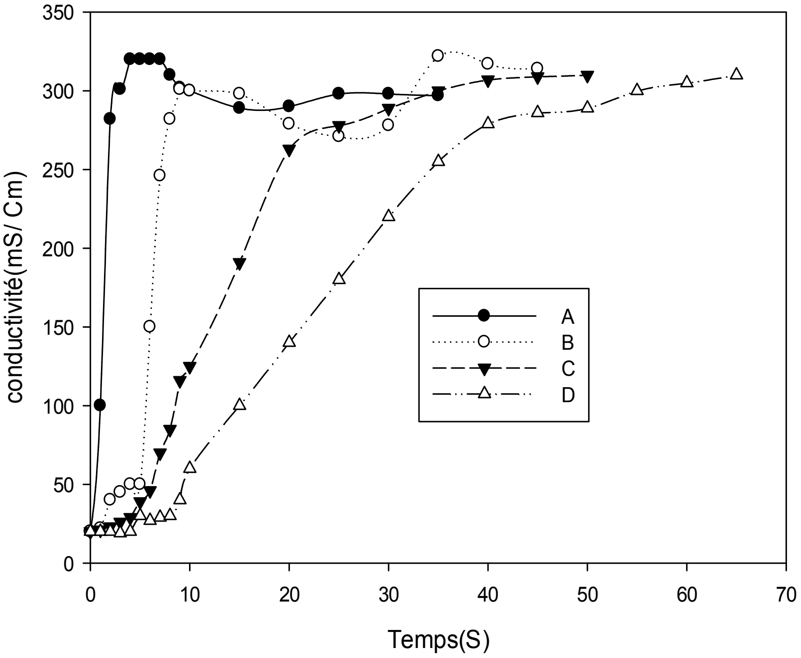


Figure 4: Variation of the conductivity as a function of time with recirculation of the fluid at different positions (A, B, C, D) with a constant airflow

Two types of responses are observed: The first for points A and B show a rapid evolution of concentrations followed by small oscillations. The signal is therefore a short-circuit type with recirculation. The second type of response is more traditional with average mixing times. The mixing time, which is the time when 95% of homogeneity in the bioreactor is obtained, decreases with the presence of recirculation. As we can see in Table 1.

Table 1: Mixing time in recirculation (tma), without recirculation (tms) and deviation of the two conditions according to the position of the conductivity meter probe with a constant airflow.

Position	A	B	C	D
t_{ms}(without recirculation) in S	10	15	85	115
t_{ma} (with recirculation) in S	5	10	55	65
Deviation (t_{ma}- t_{ms}) in S	5	5	30	50

The positions A and B are in the vicinity of the diffuser and at this point the transfer of the NaCl is mostly by convection that's why we have a quick appearance of the first peaks at position A tms (10S) and tma (5S). At position B tms (15S) and tma (10S). We find that between position A and B the difference is 5min this is explained by the fact that at the position A, convection intensity is higher than at position B. The appearance of peaks which shows that in this position the reactor is perfectly agitated. At position C the convection transfer becomes weak. NaCL transferd by diffusion becomes preponderant. At position D which is not on the path of the air diffuser the tms (115S) and tma (65S) are high. The observed pseudo lag time indicates that the mixture is not not uniform at any point in the reactor evidence of the existence of dead zones caused by a poor oxygenation of the medium. According to [11], the tracer will enter these areas by diffusion. Recirculation reduces the mixing time by promoting the distribution of the tracer in the liquid phase and, consequently, increases the homogeneity rate. At position A and B we observe two peaks. The difference between two consecutive peaks determines the travel time of a loop of travel by the liquid and corresponds to the traffic time reflecting on the one hand, the speed with which the tracer is transported and secondly, the intensity of its distribution within the liquid contained in the reactor. Position D is the limiting position in our reactor to reduce the low yields of our reactor, the mixing time is t_{ms} (115S) or t_{ma} (65S) depending on the conditions.

3.2. Gas retention εg

The gaseous retention εg makes it possible to identify the different types of flow regime likely to prevail in the reactor according to the hydrodynamic conditions imposed and give us more information on the intensity of mixing within the reactor as shown in the figure 5 below.

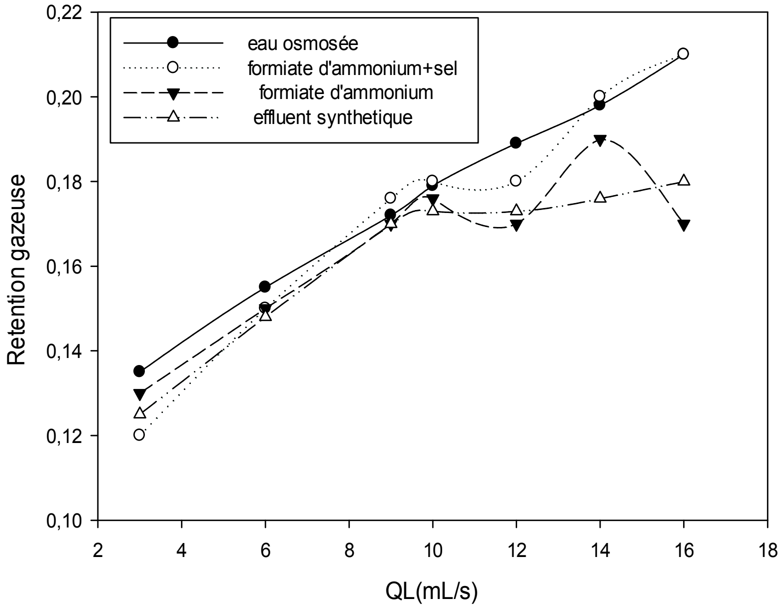


Figure 5: Variation of the gas retention as a function of the different aeration rates at different composition of the solution (osmosis water, ammonium formate solution, formate + salt solution, synthetic rubber effluent).

The figure shows two phases. The first phase which is between [3 -10mL / S] we has a proportional relationship between the superficial gas velocity and gas retention. This linear profile on this portion would translate according to [2, 12] a homogeneous regime which is characterized by a dispersion of the gas in the liquid in the form of small bubbles. Note that whatever the experimental conditions, gas retention increases linearly with the flow of air circulation. This is explained by the fact that the higher the flow of circulation, the more the quantity of dissolved air increases. The increase in gas retention with the flow of gas is the unanimity of researchers working in this field [13, 14, 1]. In the second phase, the regime becomes heterogeneous without transition phase for solutions of ammonium formate, and ammonium formate + minerals. The dispersion of the gas during this regime is in the form of bubbles of larger sizes and highly variable. This regime is characterized by poor gas dissolution and high energy consumption. For the synthetic effluent, after the homogeneous regime, we observe a regime transient characterized by an almost flat profile of gas retention in this profile, [12] shows that as the heterogeneous diet the dissolution of air is limited by the presence of large bubbles.

3.3. Influence of temperature on overall gas retention

The temperature influences the dissolution of the air in the medium as we see in the figure below

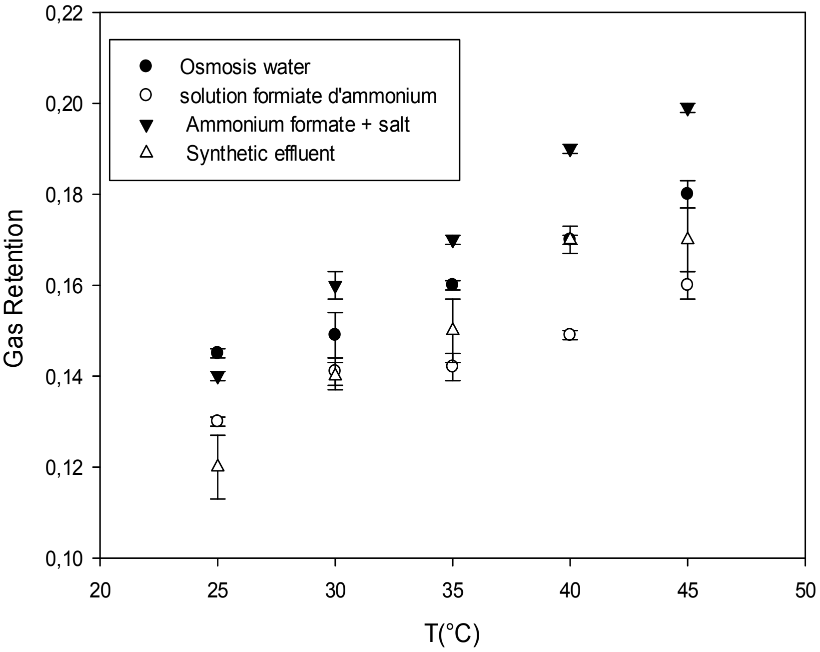


Figure 6 : Variation of gas retention with different temperatures (25 ° C, 30 ° C, 35 ° C, 40 ° C and 45 ° C) to different composition of the solution (osmosis water, ammonium formate solution, formate + mineral solution, synthetic rubber effluent) with constant gas flow rate.

Figure 6 above shows the variation of gas retention as a function of temperature. The observation is clear the temperature also influences this retention and in effect the more the temperature is increased the more the gas retention also increases this can be explained by the increase in the viscosity of the water. Indeed, the apparent viscosity of the air causing a slowing of the rate of rise of the gas bubbles and therefore leading to an increase in the residence time of the bubbles and the gas volume present in the medium. A comparison of the gas retention in the three liquids (osmosis water, ammonium formate solution, formate + salt solution, synthetic rubber effluent), shows that the gas retention increases with the composition of the medium, This increase in retention can be explained by a decrease in the size of the bubbles, which results in a longer residence time of the gas in the reactor. [15] think that bubbles burst because they follow mechanical shock molecules in the water. Since the rate of rise of small bubbles is lower than that of large bubbles, the residence time is therefore higher, which has the effect of increasing gas retention.

3.4. Influence of the temperature on the transfer volume coefficient

We note from the figure that the transfer volume coefficients decrease with temperature.

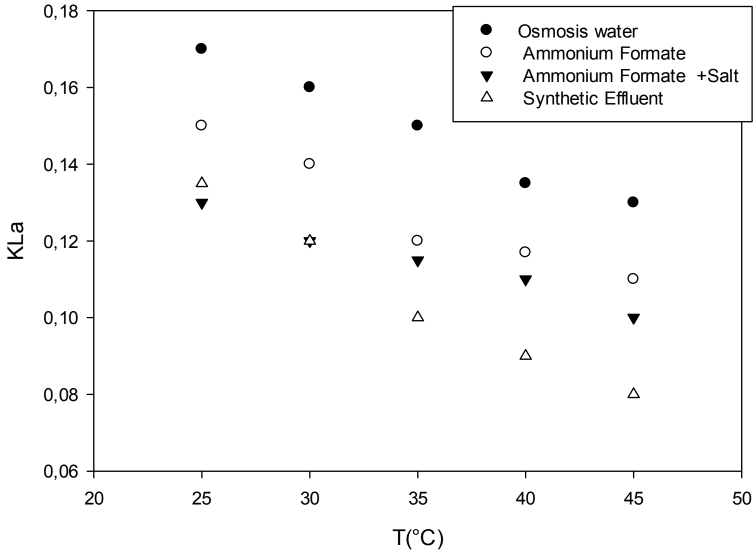


Figure 7: Variation of the transfer volume coefficient with different temperatures (25 ° C, 30 ° C, 35 ° C, 40 ° C and 45 ° C) to different composition of the solution (osmosis water, ammonium formate solution, formate + mineral solution, synthetic rubber effluent) with constant gas flow rate.

The decrease can be caused by the increase in the viscosity of the gas, which increases with temperature, thus favoring the coalescence of the air bubbles, which leads to an increase in the size of the bubbles and consequently a reduction of the interfacial air exchange of air bubbles and therefore the volume coefficient of transfer. The volume transfer coefficient is more affected by the effluent because in this medium we have the presence of free fatty acids which are surfactants and will trap the air bubbles that will diffuse very slowly in the medium. [16] shows that the presence of surfactants at the interface can have effects on the behavior of the bubbles generated and on the associated training frequency even if the concentration is very low. Indeed, these surfactants can then delay the transfer of material from the bubble to the liquid by two different mechanisms: the delay of the renewal of the gas / liquid interface and the constitution of a barrier for the passage of gaseous molecules at the interface. [17,18] confirmed this in their work. On the other hand, a comparison of the transfer coefficient of ammonium formate in the presence and absence of salt shows that the salt allows an increase the transfer coefficient. Indeed the presence according to [19] who studied the influence of salinity on the bubble size distribution in an air-lift type reactor. They found that the average bubble diameter appears to be lower in salt water than in pure water and explained that bubble size is controlled by two factors. The first is the hydrophilic repulsive force that inhibits the coalescence of the bubbles while the second is the Laplace pressure that controls the coalescence and rupture of the bubbles. . The decrease in the size of the air bubble thus favors the increase of the interfacial air between the air bubbles and the liquid, hence its diffusion in the water.

3.5. Correlation between gas retention, volume transfer coefficient and temperature

We present in this study the results with the rubber effluent. It appears from the figure that the gas retention is inversely proportional to the volume transfer coefficient, this as a function of the temperature.

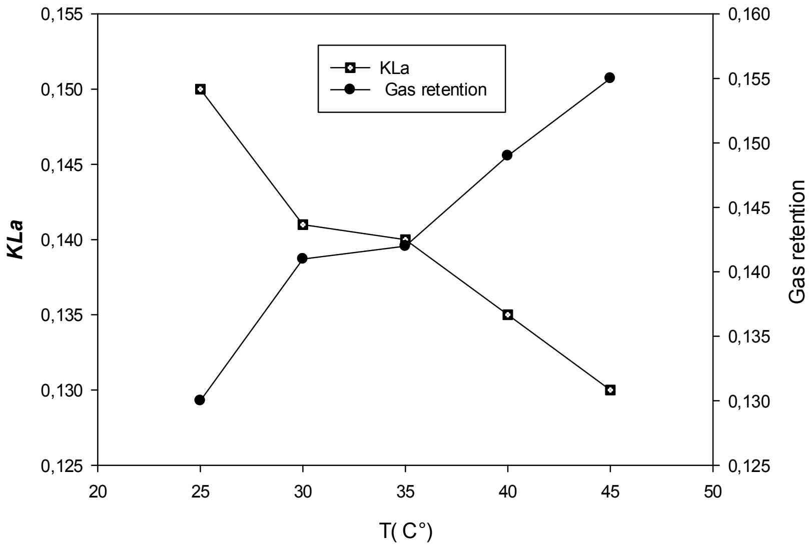


Figure 8: Relationship between mass transfer coefficient and gas retention at different temperatures

It will then be necessary to find a compromise between the temperature, the volume transfer coefficient and the gaseous retention to reduce the energy consumed and in our case the compromise is around 30 ° C where the two curves are approaching at 35 ° C although the gaseous retention curve and the transfer volume coefficient intersect are at one point. although the gaseous retention curve and the transfer volume coefficient intersect at one point. Nevertheless, this temperature is above the range of the range where our yeast strains have optimal growth growth. But for better profitability it would be wise to take the point where there is a point of intersection between the two curves to reduce the energy dependence.

Conclusion

Membrane bioreactors are processes that allow reuse of water after treatment. But only are energy-consuming processes. In order to reduce this energetic consumption, an optimization of the aeration and the hydrodynamics of the system is necessary. This study shows that the mixing time varies from one point to another and recirculation of the mixture reduces the mixing time. One of the positions is limiting, with a mixing time of 115 S without circulation and 65 S with circulation. The more the medium becomes rich in organic substances, the gas retention increases and K_{La} decreases. The homogeneous fine-bubble regime is obtained for an air flow rate of between 3 and 10 mL/S of aeration. Beyond this flow rate, the regime becomes heterogeneous without a transition phase for the ammonium formate solutions, and the synthetic effluent. At 30 ° C, the k_{La} of the ammonium formate solution is 0.83 greater than 0.62 representing the k_{La} of the rubber effluent. There is a correlation between temperature, K_{La} and gas retention.

doi:10.20944/preprints201809.0574.v1

Acknowledgments: The authors would like to thank Marc Heran for the donation of the membrane support material.

Conflicts of Interest: The authors declare no conflict of interest.

Références

1.Duran. C, Y. Fayolle, Y. P.echaud, A. Cockx, S. Gillot. Impact des proprietes des boues activees sur leur comportement rheologique et sur le transfert d'oxygene dans les bioreacteurs aeres. Recents Progres en Genie des Procedes, 2013, 8 p.

2. KOUAKOU, Edouard. *Etude de la Nitrification Partielle d'Eaux Ammoniacales dans un Bioréacteur Membranaire.* Thèse de doctorat : Chimie Appliquée. Liège : Université de Liège.2007, 233 p.

3. Jiménez Melanie. Étude du transfert de matière gaz/liquide en milieux complexes : quantification du transfert d'oxygène par techniques optiques.these de doctorat Institut National des Sciences Appliquées de Toulouse (INSA de Toulouse).2013.

4. HAOUECH Latifa. Elaboration et validation d'un modèle de simulation dynamique d'un chenal d'oxydation : couplage du modèle ASM1 et du modèle piston avec dispersion. Thèse de doctorat de l'institut des sciences appliquées de Toulouse génie des procédés et de l'environnement. 2012.

5. Krzeminski, Pawel; Graaf, Jaap H.J.M. van der; Lier, Jules B. van. Membrane bioreactors (MBRs): Activated sludge filterability and full-scale MBR functioning. 2013, ISSN 0042-2592. Vol 48 No3 s341-350.

6. Mulder, J. W. Operational experiences with the hybrid MBR Heenvliet, a smart way of retrofitting. In: Proceedings of final MBR Network Workshop, 31 March–1 April .2009, Berlin, German.

7. Gillot, S., S. Capela-Marsal, M. Roustan et A. Héduit.Predicting oxygen transfer of fine bubble diffused aeration systems - Model issued from dimensional analysis, Water Research.2005, 39(7) , pp. 1379-1387.

8. Ferreira, A., C. Ferreira, J.A. Teixeira et F. Rocha. Temperature and solid properties effects on gas-liquid mass transfer, Chemical Engineering Journal.2010, 162(2), pp. 743-752.

9. Garcia-Ochoa F, Gomez E. Mass transfer coefficient in stirred tank reactors for xanthan gum solutions. Biochem Eng J .1998, 1(1):1–10.

10. ASCE. ASCE Standard Measurement of Oxygen Transfer in Clean Water. American Society of Civil Engineers, New York,1992..

11. Wang .Y., Sanly, M. Brannock, G. Leslie. Diagnosis of membrane bioreactor performance through residence time distribution measurements -a preliminary study. Desalination .2009, 236 (2009) 120–126.

12. Fransolet, E. et al.. "Analysis of electrical resistance tomography measurements obtained on a bubble column," Meas. Sci. Technol. 2001, 12, pp. 1055-1060.

13. Xu Ying, Zhu Ningwei, Sun Jianyu, Liang Peng, Xiao Kang, Huang Xia. Evaluating oxygen mass transfer parameters for largescale engineering application of membrane bioreactors.Process Biochemistry.2017,**http://dx.doi.org/10.1016/j.procbio.2017.05.020**

14. Fayolle Y. a., Moretti b., Canler .J.P., Gillot .S. Modélisation du transfert d'oxygène en eau claire dans un réacteur biologique à lit fluidisé à l'aide de l'analyse dimensionnelle .Récents Progrès en Génie des Procédés. 2013, Numéro 104 – 2013.

15. Lazarova V., Julien M., Laurent D., Jacques M. A novel circulating bed reactor: hydrodynamics, mass transfer and nitrification capacity. Chem. Eng. Sci. 1997, 52 (21-22), 3919-3927.

16. Loubiere K..*Croissance et détachement de bulles générées par des orifices rigides et flexibles dans des phases liquides Newtoniennes : Etude expérimentale et modélisation*.2002,Thèse N°663, INSA Toulouse

17. Linek V., Korda M., Fujasová M. & Moucha T. *Gas–liquid mass transfer coefficient in stirred tanks interpreted through models of idealized eddy structure of turbulence in the bubble vicinity* Chemical Engineering and Processing, 2004. Volume 43, Issue 12, December 2004, Pages 1511-1517.

18. Alves S.S., Orvalho S.P. And Vasconcelos J.M.T. *Effect of bubble contamination on rise velocity and mass transfer* Chemical Engineering Science. 2005, Volume 60, Issue 1, January 2005, Pages 1-9.

19. Ruen-Ngam D., Wongsuchoto P., Limpanuphap A., Charinpanitkul T., & Pavasant P., *Influence of salinity on bubble size distribution and gas-liquid mass transfer in airlift contactors* Chemical Engineering Journal.2008,Vol. 141, Pp.222-232.