Microbubbles Size Distribution at Different Palm Oil Mill Effluent (POME) Temperatures for Oil Recovery Study

Nurul Hazwani Mohamad[1], Alawi Sulaiman[1], Jagannathan Krishnan[2], Mohd Noriznan Mokhtar[3], Azhari Samsu Baharuddin[3]

[1]Tropical Agro Biomass Research Group, Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.
[2]Department of Chemical Engineering, SSN Institution, Chennai, India.
[3]Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
E-mail: dr_alawi@salam.uitm.edu.my

Received: 7 February 2017
Accepted: 9 October 2017

ABSTRACT

Palm Oil Mill Effluent (POME) is the largest contributor of biomass from the palm oil milling industry. Conventional method of POME treatment using ponding system should be improved because of huge land resource requirement. In this study, microbubbles technology was applied to understand the recovery rate of residual oil from POME at different operating temperatures. Temperature for POME was set at 27 ^{o}C, 30 ^{o}C and 50 ^{o}C to determine the microbubble size distributions and characteristics at different POME temperature. At each temperature, the size of microbubbles was measured based on six size range; <10 μm, (11-20) μm, (21-30) μm, (31-40) μm, (41-50) μm and >50 μm. The results showed that at different temperatures, the microbubbles size distribution varies and the smallest group of microbubbles (<10μm) was generated at 50^{o}C. According to Stoke-Einstein equation, at higher temperature, smaller size of microbubbles is generated because of the gas diffusion factor into liquid.

Keywords: *palm oil mill effluent (POME), size distribution, temperature, Stokes-Einstein equation*

INTRODUCTION

In Malaysia, more than 50 million tonnes of Palm Oil Mill Effluent (POME) were produced every year from the palm oil industry [1]. In average, for every one tonne of crude palm oil (CPO) produced, about 3.5 tonnes POME will be produced [2]. POME is a thick brownish liquid that contain 95-96% water, 0.6-0.7% oil and 4-5% total solids including 2-4% suspended solids discharged to the environment at temperature 80-90^{o}C [3]. Although the percentage of oil and grease in POME is less than 1.0%, the accumulated oil is significant and worth for to be recovered by considering the total volume of POME produced in Malaysia [4]. The oil in POME is present in the form of free oil droplets and attached oil. Previous study also showed that the oil droplets in POME varies in sizes and the smallest size measured under light microscope was <10 μm and cause difficulty in the recovery process using sludge-pit conventional method [4]. Therefore, an advanced technology known as microbubbles was proposed in order to encounter the problem.

Microbubbles are colloidal bubbles of approximately 10-50 μm in size [5], [6]. It can be generated by various means such as air-liquid diffusion method, and power ultrasound. Each method in generating microbubbles has its own advantages and flaws. In this study, in relation to the size of oil droplets present in POME, smaller sizes of microbubbles need to be generated. Therefore, the generation method used need to be able to generate stable and small microbubbles. Many experimental works and researches had been done in order to identify the microbubbles characteristics so that smaller microbubbles can be generated [7].

As an advantage of its small size, microbubbles technology is one of the technology that is being used in waste water treatment process, purifying lakes or rivers water, cleaning agent for seafood and corals ultrasound and drug delivery agent in medical field [7], [8]. In Malaysia, the application of microbubbles is limited since narrow research has been done on this topic. Thus, the use of microbubbles in residual oil recovery process can be one of the contributing factors towards the development of palm oil milling industry in Malaysia. From simple calculation considering the current price of CPO, the recovery of residual oil from POME can increase the profit of palm oil mills daily [4].

This study was carried out in order to determine the microbubbles size distribution at different POME temperatures. The purpose of this study is to create as much small microbubbles as possible so that even the smallest oil droplets present in POME can be recovered. Maximum recovery of oil droplets from POME will increase the oil extraction rate (OER) in a palm oil mill at the same time increasing their profit with the economically and environmentally friendly new technology.

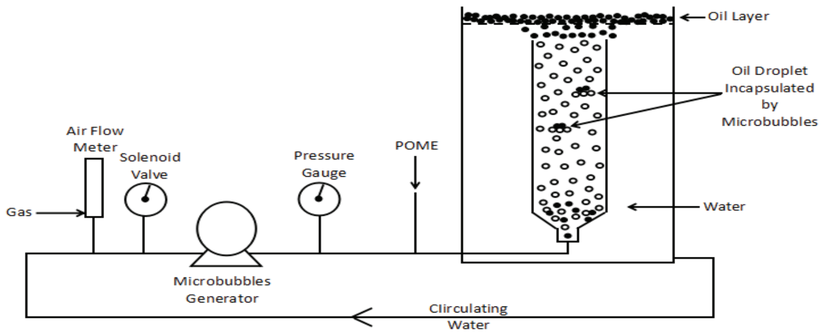
METHODS

Preparation of Samples

POME sample was collected from the outlet of the sludge pit at Felda Sungai Tengi Palm Oil Mill, Selangor, Malaysia. The sample was stored at -20°C for further use. For this experiment, the sample was heated to 89^{o}C to imitate the actual temperature of POME at the mill.

Generation of Microbubbles

Figure 1 shows the experimental set-up of the microbubbles system. The tank was filled with water until 80% (226.2L) of its maximum volume (282.7 L). In each experiment, the general start-up procedure of microbubble generator was completed before the water temperatures were set at 27^{o}C, 35^{o}C and 50^{o}C. For each temperature, microbubbles (MBs) generated were allowed to stabilise before further analysis.



Visualisation Microbubbles Image

The MBs were trapped using polyvinyl chloride (PVC) solvent cement that was applied on the surface of parafilm tape. The solvent was allowed to dry under room temperature (27^{o}C) with the MBs being trapped before the imaging process. Then, the image of MBs was captured and the size of MBs was determined by using Dino-Lite Digital Microscope (AnMo Electronics Corporation, Taiwan). The size measured was divided into six size range; <10 µm, 11-20 µm, 21-30 µm, 31-40 µm, 41-50 µm and >50 µm.

Determination of Microbubbles Size Distribution

The determination for the MBs sizes was done with the help of Dino Capture 2.0 software. Grid was applied on the image captured. The diameter of MBs was measured one by one using the same software. MBs sizes were determined according to the size range mentioned above. For each size range three replication were made and the average value was calculated. The number of microbubbles was converted to percentage as expressed in Equation 1:

$$A(\%) = \frac{1}{n} \times \sum_{i=1}^{n} x_i \times 100 \qquad (1)$$

Where:

A(%) = average in percent
n = number of trials
x = number of microbubbles counted

RESULTS AND DISCUSSION

Temperature Effects on Microbubbles Size Distribution

One of the factors affecting the generation of microbubbles is temperature. Generally, according to the gas law, temperature should have an inversely proportional relationship with air solubility [9]. As the temperature is increase, the solubility of gas into liquid reduces, hence producing less microbubble. According to Van't Hoff-type relationship, the relation between Henry's constant and temperature can be interpreted as in Equation 2.

$$\log K_c = \frac{-H^0}{2.3RT} + K \qquad (2)$$

Where:

Kc = Henry constant

H^o = heat absorbed in the evaporation of 1 mol of gas from solution, kcal/kmol

R = universal gas constant, 1.98 kcal/kmol

T = absolute temperature, °K

K = individual gas constant

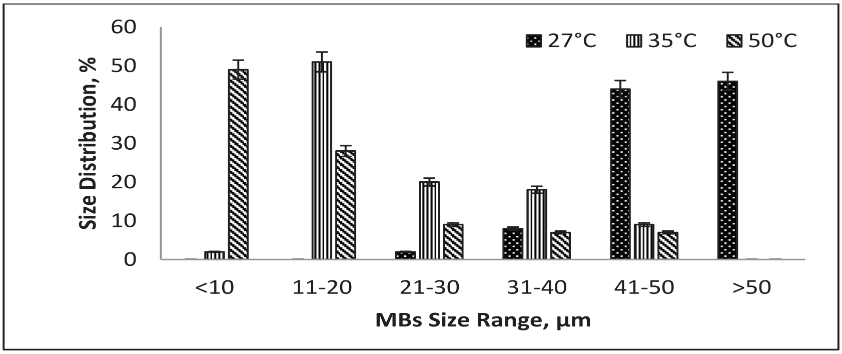


Figure 2: MBs Size Distribution

Figure 2 shows the size distribution of microbubbles generated at different temperatures. As the temperature increased, the production of small size microbubbles increased. As reported in previous studies, the diffusivity rate of air into water will increase as temperature increased [9-10]. According to Van't Hoff-type relationship, cooler temperature will increase the bubble production, however, at certain temperature, the production of microbubbles will increase as the temperature increases. The availability of air to diffuse into water molecule will increase as the temperature increases. Therefore, more microbubbles will be produced. Theory of Brownian Motion proposed by Einstein explains the diffusivity of air into water by Equation 3 [11-12].

$$D = \frac{RT}{N_A}\frac{1}{6\pi\eta r_u} \quad (3)$$

Where:

N_A = Avogadro number
T = temperature
η = viscosity
r_u = solute radius

Many experiments had been done in relation to the equation above. From all those experiments, a researcher concluded that increasing the temperature will increase the diffusion of air into liquid as it changed from viscosity independent to hopping motion [13].

Microscopic View of Microbubbles

Figures 3(a), (b) and (c) show the microbubbles image at 27°C (ambient), 35°C and 50°C. A previous study conducted reported that the size of microbubbles always depends on the internal pressure of the bubbles itself [13]. Apart from that, the relation between internal pressures of bubbles with bubbles diameter can be shown by Young-Laplace equation as below:

$$\Delta P = \frac{2\sigma}{r} \quad (4)$$

Where:

ΔP = pressure difference across the liquid surface
σ = liquid surface tension
r = radius

From the above equation, it is clear that as the pressure increases, the bubbles diameter decrease [14]. The behaviour of microbubbles in water can be explained by several other equations as referred to liquid-gas law such as Henry's Law and Stokes Law [15]. As known, the relation between temperature and pressure is always directionally proportional. Therefore, as the temperature is increased, the internal pressure of the MBs will also increase and the diameter will automatically decrease. Hence, smaller size of MBs will be generated.

Smaller MBs are always favoured as it will show better performance. MBs during collapsing process as measured by Stoke's Law have low rising speed as compared to the normal bubbles. This is due to the small bubbles diameter that can assist in encapsulating smaller particles such oil droplets in POME. Therefore, higher recovery of residual oil can be achieved.

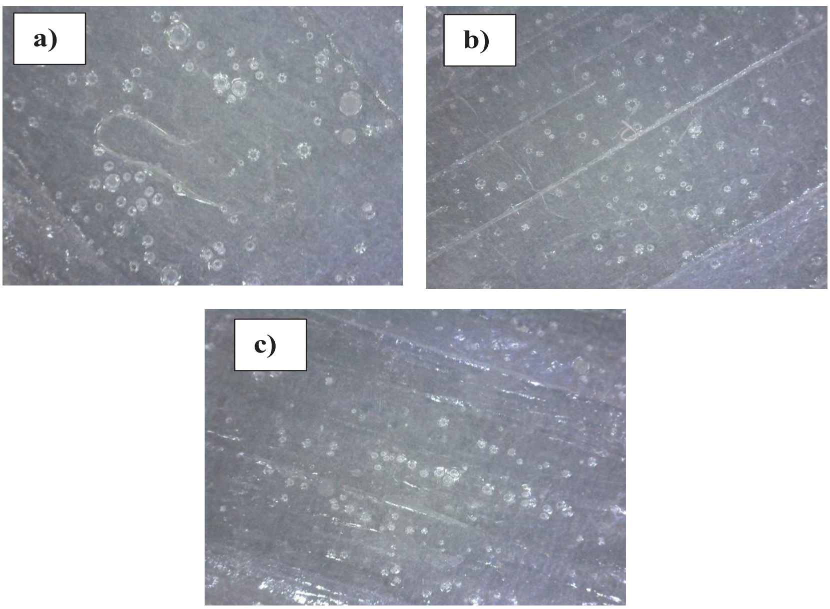


Figure 3: (a) MBs Image 250x at 27°C (b) MBs Image at 35°C (c) MBs Image at 50°C

CONCLUSION

In conclusion, the air diffusivity into water will increase as the temperature increases. The diffusion of air increases as the thin layer around water molecule tends to get thinner as higher temperature was applied. This will cause higher production of microbubbles. Smaller size of microbubbles will be produced with high temperature in relation to the microbubbles internal pressure itself. By applying the concept of Henry's Law, Stokes Law and Young-Laplace equations, internal pressures affect the diameter of microbubbles inversely. Therefore, it can be concluded that as temperature increases more small microbubbles will be produced.

ACKNOWLEDGEMENT

The author would like to thank the Ministry of Higher Education (MOHE) LRGS Research Grant (600/RMI/LRGS 5/3 1/2012) and Fundamental Research Grant Scheme (FRGS) 600-RMI/FRGS 5/3 (39/2014) for providing financial assistance to support this study. Special thanks also to the Universiti Teknologi MARA, Universiti Putra Malaysia and FELDA Palm Industries Sdn Bhd.

REFERENCES

[1] A. Sulaiman, M. Tabatabaei, M. Z. Mohd Yusoff, M. F. Ibrahim, M. A. Hassan, and Y. Shirai, 2010. Accelerated Start-up of a Semi-Commercial Digester Tank Treating Palm Oil Mill Effluent with Sludge Seeding for Methane Production, *World Applied Science Journal, Vol. 8*(2), pp. 247-258.

[2] Y. S. Madaki, and L. Seng, 2013. Palm Oil Mill Effluent (POME) from Malaysia Palm Oil Mills: Waste or Resource. *International Journal of Science, Environment and Technology, Vol. 2*(6), pp. 1138-1115.

[3] M. K. Lam, and K. T. Lee, 2011. Renewable and Sustainable Bioenergies Production from Palm Oil Mill Effluent (POME): Win-win Strategies Toward Better Environmental Protection, *Journal of Biotechnology Advances, Vol. 29*, pp. 124-141. DOI: 10.1016/j.biotechadv.2010.10.001.

[4] W. S. S. A. Wan Sharifudin, A. Sulaiman, N. Mokhtar, A. S. Baharuddin, M. Tabatabaei, M., Z. Busu, and K. Subbian, 2015. Presence of Residual Oil in Relation to Solid Particle Distribution in Palm Oil Mill Effluent, *BioResource Vol. 10*(4), pp. 7591-7603.

[5] S. Sirsi, and M. Borden, 2009. Microbubble Compositions, Properties and Biomedical Applications. Bubble Science Engineering Technology 1, Vol. 1-2, pp. 3-17. DOI: 10.1179/175889709X446507.

[6] M. Takahashi, Ibaraki, K. Chiba, and Miyagi, 2013. *Method for Collapsing Microbubbles*, United States Patent, US8349192 B2.

[7] A. Agarwal, W. J. Ng, and Y. Liu, 2011. Principle and Application of Microbubbles and Nanobubble Technology for Water Treatment, *Chemosphere, Vol. 84*, pp. 1175-1180. https://doi.org/10.1016/j.chemosphere.2011.05.054.

[8] J. Owen, P. Rademeyer, D. Chung, Q. Cheng, D. Holroyd, C. Coussios, P. Friend, Q.A. Pankhurst, and E. Stride, 2015. Magnetic Targeting of Microbubbles against Physiologically Relevant Flow Conditions, *Interface Focus, Vol. 5*(5), pp. 20150001. DOI: 10.1098/rsfs.2015.0001.

[9] A. Dassey and C. Theegala, 2012. Optimizing the Air Dissolution Parameters in an Unpacked Dissolved Air Floatation System, *Water, Vol. 4*, pp. 1-11. DOI: 10.3390/w4010001.

[10] W. S. Broecker, and T. H Peng, 1974. Gas Exchange Rates Between Air and Sea. *Tellus, Vol. 26*(1-2), pp. 21–35. DOI: 10.1111/j.2153-3490.1974.tb01948.x.

[11] E. L. Deacon, 1977. Gas Transfer to and Across an Air-Water Interface, *Tellus, Vol. 29*, pp. 363-374. DOI: 10.1111/j.2153-3490.1977.tb00746.x.

[12] M. Sharma, and S. Yashonath, 2007. Size Dependence of Solute Diffusivity and Stokes-Einstein Relationship: Effect of van der Waals Interaction. *Diffusion Fundamentals, Vol. 7*(11), pp. 11.1-11.5.

[13] B. Bagchi, 1994. A Molecular Explanation of the Transition from Viscous to Hopping Motion Mechanism of Mass Transport in the Supercooled Liquid Near the Glass Transition. *The Journal of Chemical Physics, Vol. 101*, pp. 9946. https://doi.org/10.1063/1.467896.

[14] H. Liu, and G. Cao, 2016. Effectiveness of the Young-Laplace Equation at Nanoscale. *Scientific Reports, Vol. 6*, pp. 23936. DOI: 10.1038/srep23936.

[15] Q. Xu, M. Nakajima, S. Ichikawa, N. Nakamura, and T. Shiina, 2008. A Comparative Study of Microbubble Generation by Mechanical Agitation and Sonication, *Innovative Food Science and Technology, Vol. 9*, pp. 489-494. https://doi.org/10.1016/j.ifset.2008.03.003.