IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

The efficiency removal of oil in water (OIW) by application of milliscale air bubbles

To cite this article: H A M Yusof *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1347** 012009

IOP Conf. Series: Earth and Environmental Science **1347** (2024) 012009 doi:10.1088/1755-1315/1347/1/012009

The efficiency removal of oil in water (OIW) by application of milliscale air bubbles

H A M Yusof[1,3], M A M Razi[2,3*], M F M Yusof[3] , N F M Zulkifli[3], M I Setiawan[4]

[1] Pusat Penyelidikan Petronas Fo, Jalan Air Hitam, Seksyen 11, 43650, Bandar Baru Bangi, Selangor, Malaysia
[2] EcoHytech Research Centre, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat 86400, Malaysia
[3] Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat 86400, Malaysia
[4] Fakultas Teknik, Universitas Narotama, Jl. Arief Rachman Hakim 51, Sukolilo Surabaya (60117), Indonesia
*Corresponding author: adib@uthm.edu.my

Abstract: The existing technology for separating oil in water (OIW) can bring harm to the environment, particularly to marine life. A new environmentally friendly technique has been proposed, involving the use of milliscale air bubbles. This study was conducted to determine the suitable retention time for injecting the milliscale air bubbles into the OIW. The significance of this study lies in its ability to separate OIW through a procedure that is environmentally safe and does not impact the ecosystem or marine life. The method used in the study involved mixing palm oil with water on a volumetric hydraulic bench. Retention times of 5 minutes, 15 minutes, 30 minutes, and 60 minutes were used in the study. The results indicated that separating oil in water required a substantial amount of time when utilizing milliscale air bubbles. In this study, a 60-minute retention time exhibited a significant number of separations, producing 512 bubbles compared to 44 bubbles generated in 5 minutes for 200 mL of oil. The longer the retention time, the more bubbles were produced. Overall, milliscale bubbles can effectively be used for the separation of oil in water.

1. Introduction

The result and effect of discharging produced water on the environment has recently become a significant environmental concern due to the increasing volume of waste worldwide in the current decade. This is because there are more people producing waste than recycling it. Historically, many physical, chemical, and biological techniques have been used in generating water treatment. Compact physical and chemical systems are often used because of the limited space available on offshore platforms.

On the other hand, the technologies that are available today are unable to recover minute oil particles that are suspended in liquid or components that have dissolved. In addition, most chemical treatments have large upfront and continuing costs, generating potentially harmful sludge. Biological pre-treatments of oily wastewater in onshore facilities could be a safe solution for the environment and save money.

The oil and gas sector has a plethora of helpful technology for separating oil from water (OIW). Gravity settling and corrugated plate interceptors, hydrocyclone centrifugal separation, and gas flotation are the only examples of separation technologies. Each of these innovations has its own set of advantages and disadvantages. Non-dissolved oil removal now relies on gravity settler and hydro cyclone systems. However, less buoyancy between the two phases makes these systems inefficient when the density difference between oil and water decreases. So, gas flotation is the only way to get rid of oil that has not been dissolved in the water that is made.

Despite this, the gas flotation technique has flaws since it does not effectively eliminate OIW. Oil and minuscule solid particles in the water stream can attach themselves to these gas bubbles and float to the surface, where they are subsequently skimmed off. It was found that the efficacy of gas flotation in oil removal varied from around 54% up to 96% [1]. This uncertain effectiveness is not favorable and must be avoided.

One of the significant reasons milli bubble technology is being proposed to replace the existing technology is that the existing technology can harm the environment, specifically marine life. Adult fish subjected to oil may suffer from stunted development, enlarged livers, altered heart and respiratory rates, erosion of the fins, and impaired reproduction due to exposure [2].

The importance of this study comes from the fact that it will separate the OIW by using a procedure that is safe for the environment and will not have any impact on the ecosystem or marine life. Therefore, using multiscale air bubbles will help lift the oil, which will result in the oil component being separated from the water.

This study aims to discuss the application of air bubbles in water quality improvement. The next objective is to determine the effects of retention time on the removal efficiency of cooking oil. This paper will focus more on objective number two.

2. Air bubbles

An air bubble is a droplet of one substance suspended in another, most frequently gas in a liquid. Because of the Marangoni effect, bubbles may maintain their integrity even after reaching the surface of the absorbing material. The mass transfer at the interface of two fluids due to a difference in surface tension is called the Marangoni effect.

When temperature dependence is present, this mechanism is called thermo-capillary convection. Distillation, absorption, flotation, and spray drying are just a few of the processes that benefit from using bubbles by chemical and metallurgical engineers. Fluid dynamics is used to model the complicated processes that must be considered when moving mass and heat [3].

Calculating bubble volume concentrations and bubble rise velocities both need knowledge of the density of air bubbles, which is a fundamental feature of air bubbles. The pressure, temperature, and humidity all affect the density of the air bubbles. The production of bubbles with a size distribution ranging from 10–100 m or greater, with generally smaller mean sizes found for higher saturator pressures, is called "bubble size distribution."

When modeling the contact zone, a mean value of 60 microns is a reasonable estimate for Dissolved Air Flotation (DAF) saturator pressures of about 500 kilopascals [4]. Even though the hydrostatic pressure decreases deeper into the contact zone, the bubble size is assumed not to change [5]. Figure 1shows the different bubble categories by their size.

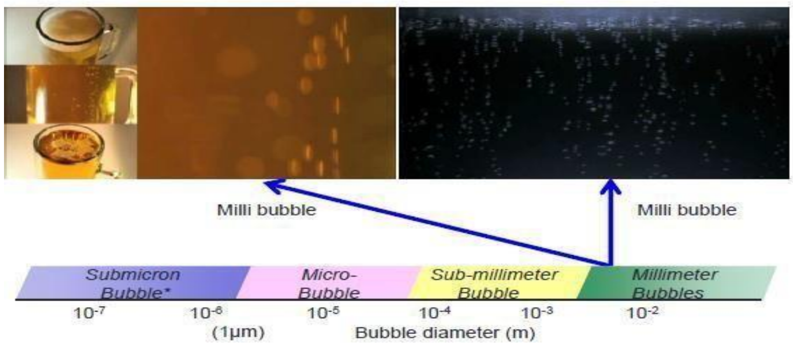

Figure 1. Millimetre bubble [6]

Since this investigation uses the notion of density in a fluid, it is essential first to describe and then define density. The proportion of a fluid's mass to its volume is referred to as its density. Temperature and pressure both affect the density of a fluid, which may alter. The density is measured in kilograms per cubic meter. For the sake of simplicity, assume that the density of water is 1000 kg/m3. In math, density is the ratio of how much something weighs to how much space it takes up [7]. Each kind of fluid has its unique density. Because oil and water have such different densities, it is possible to tell them apart using the principle of density. The formula of density is as follows:

$$\rho = \frac{m}{V} \tag{1}$$

where ρ = density,
m = mass,
V = volume.

3. Surface tension of oil in water

Wetting, spreading, foaming, and emulsification demand a lower surface tension solvent. All of these activities will not be performed by all molecules that reduce surface tension, but none of these desired features will be conducted by molecules that do not reduce surface tension. Water has a high surface tension of 0.072 newtons per meter (N/m). It can be reduced to values between 0.032 and 0.035 N/m using typical water-soluble fatty surfactants. As a result, correctly designed fatty surfactants in aqueous solutions can moisten, foam, emulsify, or assist in spreading [8].

The surface tension of oil and water is the most significant difference. Because oil has a surface tension of 0.030 to 0.035 N/m, oil-soluble fatty surfactants do not lower the surface tension of oil in the required manner. Silicone and its fluoro derivatives form the foundation for the classes of chemicals capable of reducing surface tension to 0.030 to 0.035 N/m.

With the proper silicone surfactants, the surface tension of oils can be decreased to 0.020–0.025 N/m. With the chosen adequate fluorosurfactants, the surface tension of silicones and oils can be reduced to less than 0.020 N/m [8]. The phrase "properly chosen" refers to amphiphilic molecules, soluble in the solvent of choice (clear) and capable of correctly orienting themselves at the solvent's surface to lower surface tension. Figure 2 shows the effect of proper silicone surfactantsto the oil in water with no surfactants. Formulators should carefully consider surface tension reduction and its impact on formulation when selecting oil or water phase components.

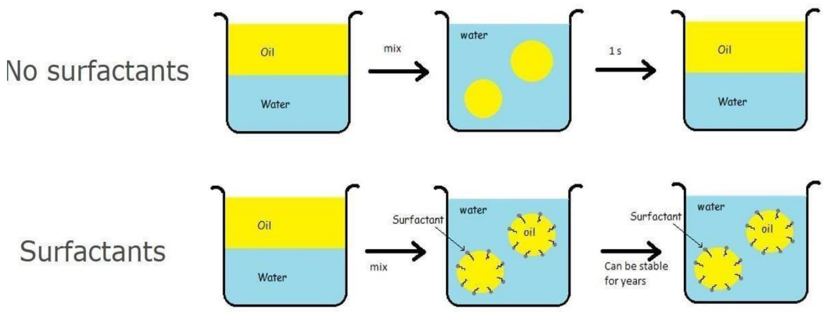

Figure 2. Effect of no surfactants and with surfactants [9]

4. Material and methods

The study utilized several types of laboratories and non-laboratory equipment to analyze the efficiencyof removing oil in water.

4.1. Volumetric hydraulic bench

The volumetric hydraulic bench provides a controlled water flow for numerous laboratory experiments. A sump tank with a submersible pump, a volumetric weighing system, and a working surface make up the bench. All parts are made of a material that resists corrosion. Figure 3 shows the bench that can be used on almost any hydraulic circuit thanks to the sump outlets. The bench does not need any water from the outside once it is complete.

Before starting the pump, ensure that it is turned off. The water supply is attached for open-channel flow or the close-conduit device that will be tested at the water inlet. Each connection is secured. The dump valve is made sure to be opened, and the supply valve is closed. The pump is then turned on. Once the pump is turned on, the supply valve is gradually opened to allow water to flow through the bench. The necessary measurement is made when the device is being tested for a particular setting of the supply valve.

Figure 3. Volumetric hydraulic bench

4.2. Aquarium battery pump

A fish tank accessory known as an aquarium water pump aerates and circulates water to make it healthier for marine life. A water pump's current ensures that every drop of water in a tank passes through the filter. The tube is being cut, making sure to have the same length for all tubes. The tube is then plugged into the pump. Another part of the tube is plugged into the pipe distributor. Two new tubes are then plugged into the pipe distributor. The tubes' ends are then plugged into the air stone mineral. The tubes that connect to the air stone mineral are placed in the basin of the volumetric hydraulic bench, which contains oil in water. The pump is switched on for 5 minutes, 15 minutes, 30 minutes, and 60 minutes. Figure 4 shows all the non-laboratory equipment involved in this study.

Figure 4. Aquarium battery pump (portable), tube, pipe distributor and air stone mineral

5. Result and analysis

The interpretation of the findings focuses on the implications for theory, practice, and future research, providing a comprehensive understanding of the research outcomes.

5.1. Result

The use of crude oil is replaced with palm oil since it is hard to get crude oil. Even so, palm oil is acceptable because the density of palm oil and crude oil is almost the same, with only 4 kilogram/m^3. The data gained in this chapter is to study the link between the volume of oil used and the time taken for milli bubbles to separate OIW.

Table 1. Result of oil in water separation for 200 mL of oil

Oil	Time	Number of Bubbles Produced
200 (mL)	5 (min)	44
	15 (min)	149
	30 (min)	315
	60 (min)	512

Table 2. Result of oil in water separation for 500 mL of oil

Oil	Time	Number of Bubbles Produced
500 (mL)	5 (min)	48
	15 (min)	267
	30 (min)	587
	60 (min)	679

Table 3. Result of oil in water separation for 1000 mL of oil

Oil	Time	Number of Bubbles Produced
1000 (mL)	5 (min)	177
	15 (min)	384
	30 (min)	604
	60 (min)	743

The experimental results indicate a time-dependent behavior of the separation process when using milli bubbles. Within the initial five minutes following the injection of the milli bubbles, the oil separation occurs slowly, yielding only a minimal separation. However, for 15 minutes, the observation reveals the presence of small particles of milli bubbles effectively separating the oil. This suggests that the bubble-aided separation process gains momentum over time.

As the experiment progresses for 30 minutes, a substantial number of milli bubbles can be observed within the oil. This abundance of bubbles contributes to significant oil separation, preventing larger quantities of oil from remaining bound. The effectiveness of the milli bubbles becomes evident as they facilitate the separation process, reducing larger oil particles into smaller ones.

Meanwhile, for 60 minutes, the milli bubbles successfully separated larger oil particles into smaller particles. This outcome highlights the capabilities of the bubbles in promoting efficient oil separation. Notably, these bubbles are readily visible to the naked eye, allowing for their measurement and observation throughout the experiment. The average diameter of each bubble, determined in this research, was 0.2 mm, providing valuable insights into the size distribution of the bubbles involved in the separation process.

Figure 5 shows these findings shed light on the potential of milli bubbles in oil separation applications. However, further research is worth exploring to optimize bubble size, duration, and other factors to improve the efficiency and effectiveness of the separation process.

Figure 5. Milli bubbles in oil

5.2. Discussions

This research found that the longer the microbubbles were injected into the oil, the greater the number of oils extracted from the water. This can be seen in the increase in the number of air bubbles in oil over time. For instance, for 200 mL of oil, the number of bubbles produced in 5 minutes is 44; after 60 minutes, it is 512. The conclusion is the same for 500 mL and 1000 mL of oil. A second finding from this research is that the number of bubbles produced in oil increases as the volume of oil increases. For instance, in 5 minutes, bubbles are 44 for 200 mL of water, 48 for 500 mL of oil, and 177for 1000 mL of oil. The same thing happened at other times.

The same thing happened at other times. The number of bubbles produced in 200 mL of oil in 15 minutes was 149, while the number of bubbles produced in 500 mL of oil was 267. With the same amount of time (15 minutes), the number of bubbles in 1000 mL of oil keeps increasing to 384. The efficiency of the separation process is influenced by several factors, including the density difference between the oil and the continuous fluid and the size of the oil droplets, as described by Stokes' Law. Figure 6 shows the number of bubbles produced in different volumes of oil versus time.

According to this law, the separation rate is directly proportional to these factors. In the case of gas bubbles, their size plays a significant role in their ascent through the liquid. Smaller gas bubbles, due to their larger surface area-to-volume ratio, rise at a slower rate compared to larger gas bubbles. This characteristic makes smaller bubbles more favorable for effective separation processes. The advantage of using smaller bubbles, such as micro and nano-sized bubbles, lies in their increased surface area, which facilitates the aggregation of oil droplets.

The larger surface area allows for enhanced interactions between the bubbles and the oil, promoting the formation of larger droplets that are more easily separated from the continuous fluid. Consequently, by employing smaller bubble sizes, the separation process is anticipated to be more efficient than larger, millimeter-sized bubbles. By harnessing the benefits of micro and nano-sized bubbles, researchers and engineers can optimize the separation efficiency, improving outcomes in various industries, including oil and gas, wastewater treatment, and chemical processing. The utilization of smaller bubbles offers a promising avenue for enhancing the effectiveness ofseparation techniques and achieving higher rates of oil droplet removal from liquid systems.

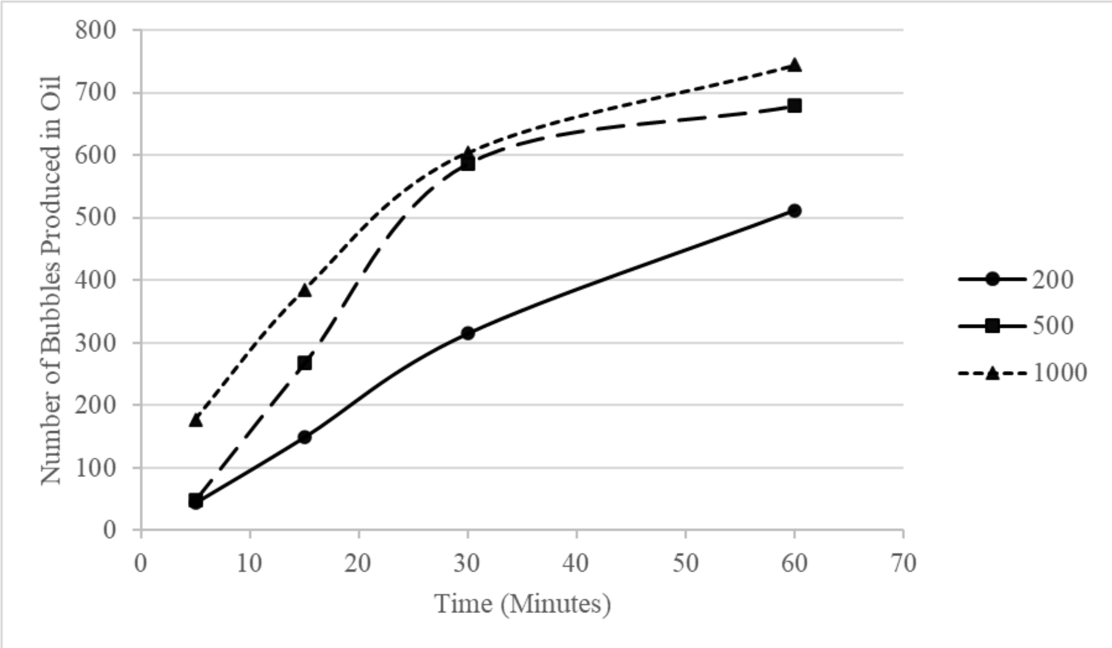

Figure 6. Graph of the number of bubbles produced in different volumes of oil versus time

6. Conclusion

Milli bubbles can separate oil in water (OIW), but it takes a long time. For instance, even when injecting 200 milliliters of oil, there is still a significant amount of surface area that does not separate after 60 minutes. It was discovered that the longer the process takes, the more oil can be separated. This is supported by the number of bubbles produced in oil increasing over time for all volumes of oil being tested. The large volume of oil produced lots of bubbles, indicating the separation process of OIW, but that does not represent the time to separate the OIW in a quick phase. The large number of oil particles causes many bubbles in a large volume instead of the small number of oil particles in a small volume.

Using microbubbles and nanobubbles is highly recommended to enhance the effectiveness and potential outcomes of the future. These tiny bubbles exhibit unique properties that can contribute to improved results. Researchers can explore their enhanced efficiency and promising characteristics by incorporating microbubbles or nanobubbles into the research methodology. Another aspect worth considering is the method employed to quantify the number of bubbles. It is acknowledged that the existing approach utilized in this research may not be as efficient as desired.

To address this, a recommended solution is the implementation of the TD 500D apparatus. The TD 500D offers advanced capabilities for bubble quantification, enabling researchers to obtain more accurate and reliable data. However, it is essential to acknowledge that utilizing the TD 500Dapparatus may come with a considerable cost, which could be a limiting factor for some researchers. Despite this limitation, the data obtained in the current research remains relevant and valuable. It is worth noting that the bubbles produced in this study are on a milli scale, allowing for their measurement through the observation counting method.

Although not as precise as the TD 500D, this approach still provides valuable insights into bubble formation and behavior. For future investigations, it is strongly recommended that microbubbles or nanobubbles be incorporated into the study while employing the TD 500D apparatus for precise bubble measurement and analysis. This combination of advanced technology and methodology can contribute to a deeper understanding of the efficiency and characteristics of these bubbles, ultimately leading to more comprehensive and insightful research outcomes.

7. References

[1] Kumar A., Selvam, P., & Dudek, M. (2018). Removal of dispersed oil drops by induced gas flotation.

[2] National Oceanic and Atmospheric Administration (NOAA) (2021). How does oil impact marine life? (n.d.). How Does Oil Impact Marine Life? Retrieved 2 June 2022 from https://oceanservice.noaa.gov/facts/oilimpacts.html

[3] Subramanian, R. Shankar; Balasubramaniam, R. (2001). The Motion of Bubbles and Drops in Reduced Gravity. Cambridge University Press. ISBN 9780521496056.

[4] J. Haarhoff and J.K. Edzwald, J. (2004). Water Supply Res. Technol. - Aqua, 53 (2004) 127.

[5] T. Takahashi, T. Miyahara and H. Mochizuki, J. (1979). Chem. Eng. Jpn., 12 (1979) 275.

[6] Toshihiro Fujita (2016). The status and future of fine bubble generation, measurements and applications. 7th International Symposium of Fine Bubble Technology, Sydney, Australia. Fine Bubble Industries Association.

[7] Tom Benson (2021). The National Aeronautic and Atmospheric Administration's Glenn Research Center. "Gas Density Glenn research Center".

[8] Anthony J. O'Lenick Jr., Siltech LLC (2010). Comparatively Speaking: Lowering Surface Tension in Water vs. Oil. Date Access: 13 January 2023. Retrieved from: https://www.cosmeticsandtoiletries.com/research/methods-tools/article/21834581/comparatively-speaking-lowering-surface-tension-in-water-vs oil

[9] Susanna Laurén (2020). Evaluation of emulsion stability by interfacial rheology measurements. Biolin Scientific. Retrieved from: https://www.biolinscientific.com/blog/evaluation-of-emulsion-stability-by-interfacial-rheology-measurements

Acknowledgments

The authors sincerely thank Universiti Tun Hussein Onn Malaysia for its unwavering support throughout this research. All the guidance, opportunities, and encouragement have been invaluable in shaping the study, fostering critical thinking, and propelling the authors to excel.

The efficiency removal of oil in water (OIW) by application of milliscale air bubbles

1) H A M Yusof is a master's student at the Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia (UTHM), and works at Pusat Penyelidikan Petronas, Malaysia. H A M Yusof role as the principal author of this paper will focus on data collection and analysis and writing a final report.
2) M A M Razi is an associate professor at the Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia (UTHM), and the head of the Eco Hydrology Technology Research Centre (Eco-Hytech). He is the Corresponding author for this paper. He is a Subject matter expert in the flood inundation model and will be the person who gives an idea for solving the flood problem.
3) M F M Yusof is an undergraduate student at the Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia (UTHM). He is good at mathematical modeling.
4) N F M Zulkilfi is a postgraduate student at the Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia (UTHM); she will focus on Validation, Writing - Review & Editing.
5) M I Setiawan is a professor at the Fakultas Teknik, Universitas Narotama, Jl. Arief Rachman Hakim 51, Sukolilo Surabaya (60117), Indonesia. He will focus on the project's conceptualization, administration, and Funding acquisition.