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Effect of Reynolds Number at Orifice Outflow and Flotation Zone on the Fatty Acid Dispersion in Correlation with Deinking Flotation Performance

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Abstract

In flotation deinking, hydrodynamic shear force is created as an effect of bubbling mechanism from air injected through orifices. To assist and improve the separation process of ink particles from fibers, surfactant is added but in some cases fatty acid could be added. The importance mechanism of bubbling is to generate suitable Reynolds number for hydrodynamic shear force and flotation, with bubbles move upward and ink – contaminated froth is collected at the upper part of the flotation medium. The fibers free from ink are moves downward and discharge from the bottom of flotation tank. The critical Reynolds number at orifice outflow (Re_o) and in flotation zone (Re_{vi}) are defined as the maximum Reynolds numbers of fluid at some distance from nozzles and at flotation zone to create turbulence without proper mixing, so that it will be able to separate ink particles from fibers. Proper mixing should be avoided to ensure the best performance of deinking flotation. Air with difference flow rate is injected into flotation tank through orifice with difference sizes. The Reynolds numbers that are able to disperse fatty acid is evaluated by the achievable brightness and ERIC. From the experiment it is concluded that fatty acid need higher Reynolds number for its dispersion and creates hydrodynamic shear force that able to detach ink from fiber surfaces. To high Reynolds number gave proper mixing instead of flotation, results poorer flotation performances and give poor results. Difference lipophilic and hydrophilic character of substance used in the deinking flotation need difference region of turbulence (Reynolds number) to achieve proper deinking flotation results. The critical Reynolds number suitable for this deinking flotation is 40.000 – 50.000 at some distance escape from orifice, and 10.000 – 13.000 in flotation zone.

Keywords: hydrodynamic shear force, Reynolds number, ink detachment, fatty acid dispersion, orifice outflow, flotation zone

1. Introduction

Flotation deinking is a separation process of the detached ink from fiber by the use of air that injected into flotation tank. The air injection will create bubbles to transport upward the ink particles into froth zone. For being able to transport upward the detach ink, an interaction between ink particles and bubble should exist. In this case, a substance that has interconnection between ink particles (oil based) with bubbles (bubble - water interface) is needed. In order so, the used of surfactant in deinking flotation to assist the separation of ink particles from fibers is unavoidable. Surfactant can be distributed evenly in a flotation medium (water) because its head has hydrophilic properties, in other side its tail that has lipophilic character, able to penetrate into the disperse ink particles. This process is apparently simple as long as the surfactant used has the appropriate HLB value. Research concerning HLB value of surfactant for deinking flotation has been done. Surfactant with high HLB value is favorable for cellulose activity and low HLB value is favorable for ink removal [1]. HLB value of surfactant is closely relate to the hydrocarbon structure, the longer the hydrocarbon chain and the more the un-saturated structure presence, the better the surfactant performance for deinking flotation [2]. The probability of surfactant and ink interaction is modeled by the probability of ink attachment on bubbles [3].

Nomenclature

ERIC Effective Residual Ink Concentration

HLB Hydrophilic Lipophilic Balance

SLS Sodium Lauryl Sulfate

SS Synthetic Surfactant

FA Fatty Acid extracted from Morinda citrifolia L.

FAMC Fatty Acid of Morinda citrifolia L.

A_{v_o} : *Area covered by bubbles at orifice outflow*

A_{v_t} : *Area covered by bubbles at flotation zone*

d_o : *diameter of orifice*

d_{B_o} : *diameter of bubble at orifice outflow zone (at some distance from thr orifice)*

d_{B_t} : *diameter of bubble at flotation zone*

Re_o : *Reynolds number at orifice outflow zone*

Re_{v_t} : *Reynolds number at flotation zone*

v_o : *velocity of bubble at orifice outflow zone*

v_t : *velocity of bubble at flotation zone*

ρ : *density of fluids*

μ : *viscocity of fluids*

Numerical code: 20, 40, 60 are orifice diameter of 2, 4, and 6 mm.

To know the turbulence performance, Reynolds number at orifice outflow and flotation zone is evaluated:

$$Re_o = \frac{\rho\, v_o\, d_{B_o}}{\mu} \qquad (1)$$

$$Re_{v_t} = \frac{\rho\, v_t\, d_{B_t}}{\mu} \qquad (2)$$

In this case:

$$v_o = \frac{Air\ flow\ rate\ through\ orifice}{\frac{\pi}{4}\, {d_o}^2} \qquad (3)$$

With v_t is measured by dividing the distance of bubble path by the increment of time in 0.25 second (by controlling the video of bubbles movement). The bubbles diameter dB_o and dB_{vt} was measured as the average bubbles size using Image J.

$$d_{B_o} = \sqrt{\frac{4}{\pi} A_{v_o}} \qquad (4)$$

$$d_{B_{v_t}} = \sqrt{\frac{4}{\pi} A_{v_t}} \qquad (5)$$

With Av_o and Av_t is the area covered by bubbles at orifice outflow and flotation zone respectively, as it was measured by Image J.

If air is injected continuously through a nozzle into water medium, the air jet immediately breaks up into an array of bubbles which range in a diameter from almost zero up to a maximum value. This diameter is depends upon the air discharge and the gravitational acceleration g [4].

The used of surfactant has certain effect on the physical properties of water when it is added and dissolved on water, such as decreasing water surface tension, decreasing mean diameter of bubbles, increasing gas hold up and gas movement [5, 6, 7]. These all might be related with the hydrogen bonding presence between the hydrophilic part of surfactant and water molecule. In case of fatty acid is used instead of surfactant, hydrogen bonding does not available abundantly. The only interaction is between the fatty acid and fatty ester presence in ink structure. This might be happened when fatty acid can reach (contact) fatty ester of ink. In order to disperse fatty acid evenly, turbulences should be created and the hydrodynamic shear forces presence will assisting the separation of ink particle from fiber. The critical Reynolds number to create hydrodynamic shear forces is elucidated in this research. The result is compared with the critical Reynolds number when surfactant is used in flotation deinking.

2. Experiment

Experiment was performed in the flotation tank as it is depicted in Fig. 1. Air was injected at difference flow rate through orifice. The Reynolds number was calculated based on the speed of outflow air through orifice (Re_o), and based on the average speed of rising bubble (Re_{vt}). The orifices used in this experiment were 2, 4, and 6 mm of diameter. Old newspaper pulp was prepared by disintegrate it in a pulper at 5 % of consistency for 10 minute. Sodium Lauryl Sulfate was injected as a foaming agent at 0.6 % of dosage. Fatty acid of Morinda citrifolia L. (FAMC) and synthetic surfactant used for deinking flotation was studied comparatively. The achievable brightness and ERIC was measured with Technidyne – Color Touch 2 models ISO. The maximum Reynolds number that able to create the necessary hydrodynamic shear force for ink liberation without proper mixing was studied to know the lipophilic character of any surfactant or fatty acid for ink liberation. To evaluate the deinking flotation performance, brightness (Tappi T 452) and ERIC (Tappi T 567 om-04) measurement was performed.

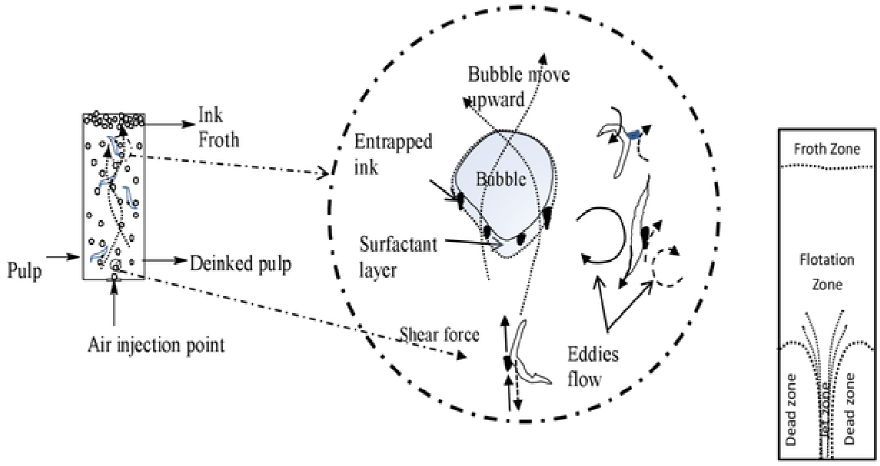


Fig 1. Basic thinking of experimental.

2. Ink Detachment Analysis

It is assumed that the bonding between fiber and ink particles has been rupture by the hydrodynamic shear force and friction force during pulping. In deinking flotation hydrodynamic shear force is also presence. When hydrodynamic shear force is created, the ink particle will be pulled out of intact from the fiber surface. Hydrodynamic shear force is created by pressurized air escape from nozzles. This force is a function of Reynolds number. In case of synthetic surfactant is used for flotation, the surfactant will distribute easily into flotation medium because of its HLB value is properly designed. In case of fatty acid is used for flotation, the fatty acid does not easily distribute into the flotation medium, because it has higher lipophilic character, and it will easily penetrate into ink particles when they are in touch to each other. The maximum Reynolds number to create hydrodynamic shear force without proper mixing is searched in this experiment. When both synthetic surfactant and fatty acid is able to reach the ink particle, then the ability to detach ink particle is resembles, this mean the created hydrodynamic shear force is sufficient to remove ink particle from the fiber surface. If the ability to detach ink particle is quite difference this mean the lipophilic character (fatty acid diffusivity into ink particle) should be improved.

Reynolds number is the property of turbulence. In flotation deinking, there are dead zone, jet zone, flotation zone and froth zone. The ink detachment is mostly happened in jet zone, and the separation of detached ink from fiber is mostly happened in flotation zone. Dead zone is dominated by sedimentation of fiber. In froth zone, the detached and floated ink particles are collected. When the deinked pulp quality is almost the same, this mean the ink separation in the flotation zone has the necessary Reynolds number to create turbulent for flotation deinking. In other case, when the ability of flotation is resembles, this can be inferred that the hydrophilic character of surfactant and fatty acid is quite strong enough to keep in touch the ink particle from bubbles.

3. Result and discussion

From Fig. 2, it is shown that: (a) the addition of synthetic surfactant and FAMC result the higher velocity of rising bubbles; (b) the addition of synthetic surfactant and FAMC reduces the diameter of rising bubbles. This result is supported by other research experiment that the used of surfactant give effect on decreasing of water surface tension, decreasing of mean diameter of bubbles, increasing of gas hold up and gas movement [5, 6, 7].

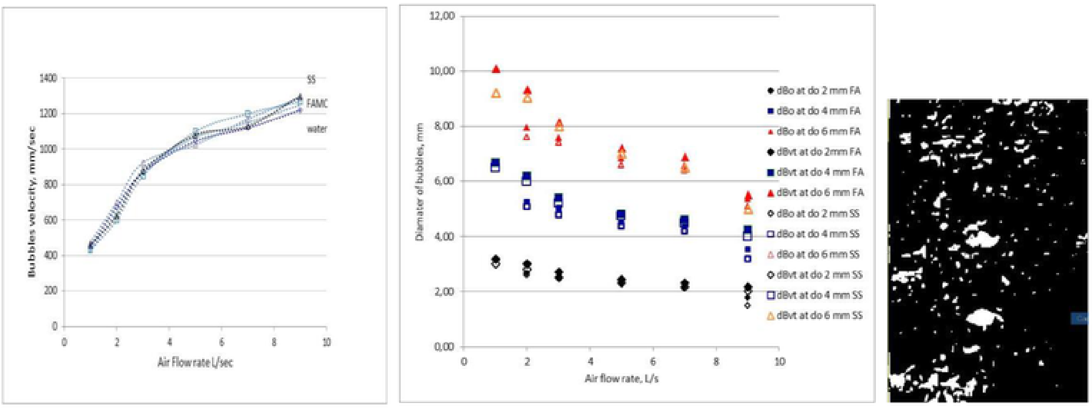
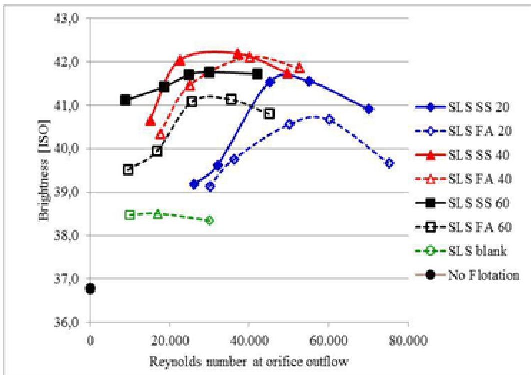


Fig. 2. Correlation of (a) bubble velocity and air flow rate; (b) Diameter of bubbles and air flow rate - through nozzle; (c) Image J of bubbles for air flow rate of 5 L/s from orifice of 5 mm (in flotation zone).

From Fig. 3 (a) it is shown that brightness was increase as the Reynolds number increase but at a certain Reynolds number the brightness was declined. For synthetic surfactant the optimum Reynolds number at orifice outflow is in the range of 20.000 – 40.000 and for FAMC in the range of 40.000 – 50.000 when orifice with diameter of 4 mm and 6 mm was used. If orifice with diameter of 2 mm was used higher Reynolds number is needed. From Fig. 3 (b), the ERIC reaches the lowest value at the same Reynolds number as it was performed for brightness. From this result it can be concluded that fatty acid need higher Reynolds number for its dispersion. When fatty acid has been disperse well, as it was in the above Reynolds number, the brightness and ERIC achievement is approaching of the deinking flotation result using synthetic surfactant, so it can be inferred that the lipophilic properties of FAMC is almost the same with the lipophilic properties of synthetic surfactant. FAMC can reach the best performance as surfactant at Reynolds number of 40.000. In case of the achievable brightness ("and ERIC") of deinking pulp with FAMC is still lower ("higher") than the one with synthetic surfactant, this might be correlated with its hydrophilic properties.



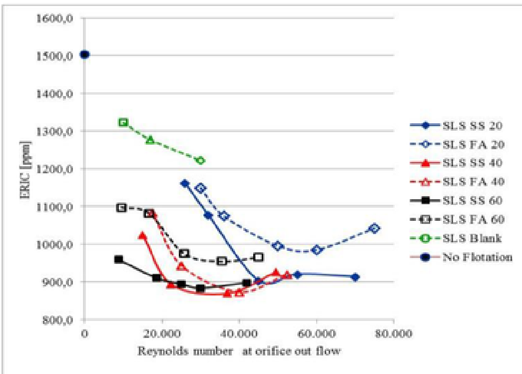


Fig. 3. (a) Brightness of floated pulp; (b) ERIC of floated pulp vs Reynolds number at orifice outflow

From the result presented on Fig. 3 it is clearly seen that Reynolds number of 40.000 at the orifice outflow seems the most appropriate for the above system. It gives the best performance for deinking flotation result. At this Reynolds number, the created hydrodynamic shear force gave the best performance for ink particles detachment.

From Fig. 2 and Fig. 3, it is clearly seen that orifice with diameter of 4 mm gave the most appropriate bubbles size suitable for deinking flotation. It produces the deinked pulp with highest brightness and lowest ERIC. This may correlates with the ability of suitable bubbles size in lifting the detached ink into froth zone, and the probability of collision between ink particle and bubble [8,9].

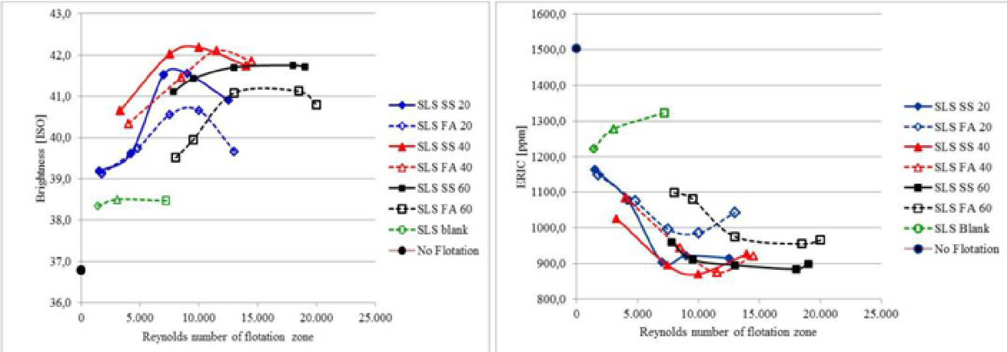


Fig. 4. (a) Brightness and; (b) ERIC of deinked pulp vs Reynolds number at flotation zone

Fig. 4 shows, the correlation of Reynolds number in the flotation zone with the quality of deinked pulp. Bubbles diameter produces from orifice diameter of 4 mm, gave the best performance for deinking flotation. In this case, when synthetic surfactant is used, Reynolds number of 7500 – 11.500 is the appropriate Reynolds number for deinking flotation to achieve highest brightness and lowest ERIC. When FAMC is used, the appropriate Reynolds number was higher. The Reynolds number was 10.000 – 13.000.

Conclusion

From the above experiment, it is conclude that fatty acid need higher Reynolds number for its dispersions, and synthetic surfactant need lower Reynolds number. The Reynolds number needed is 40.000 – 50.000 in the orifice outflow zone and 10.000 – 13.000 in flotation zone for fatty acid dispersion, and 20.000 – 40.000 in the orifice outflow zone and 7.500 – 11.500 in the flotation zone for synthetic surfactant dispersion. Orifice diameter of 4 mm gives the suitable bubbles size for flotation deinking at the above Reynolds number. This could achieve the best performance for both fatty acid and synthetic surfactant dispersion, and for deinking flotation results. It can be inferred that when the disperse fatty acid can reach ink particles, the ability of bubbles to lift the detached ink is still questionable and this could be improved. It may relate with the interaction among air bubbles, bubbles – water interface, and the hydrophilic character of fatty acid.

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