Asian Journal of Engineering and Technology (ISSN: 2321 – 2462)
Volume 03 – Issue 03, June 2015

An Application of Small Hydrocyclones for Separating Yeast in the Brewing Industry

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ABSTRACT--- ***The separation performance of the dewatering (MZ) and the deoiling (HY1) hydrocyclones for separating yeast in the brewing industry were investigated. Their applications in the liquid clarification and yeast recovery processes were studied. The feed suspensions used in these experiments were taken from the fermentation tank in the brewing plant. For the liquid clarification application, both hydrocyclones demonstrated their ability to clarify liquid with up to 50% clarification efficiency. The clarification efficiency was found to increase with an increase in pressure drop. Only the dewatering hydrocyclone could provide solid classification for both studied suspensions. Additionally, a high operating pressure drop did not provide any benefit to the classification because yeasts have low time constant, which are turbulence sensitive.***

Keywords--- Hydrocyclone, Yeast, Clarification, Solid Recovery, Solid-Liquid Separation

1. INTRODUCTION

The biotechnology industry has been rapidly grown worldwide due to the demand for the products of microbe's metabolites which are of enormous benefit because of their food and medical use, etc. There are a number of fundamental challenges and difficulties which bio-processes present to the engineer and many of these impinge directly upon separation process requirements, which affect directly the quality of products and the costs of production. Yeast is widely used in the biotechnology industry such as beverage industries, pharmaceutical industries, citric acid industries, etc. The bio-separation in these industries is mostly concerned with the separation of yeast to clarify the product, to recovery yeast or to clean process water. An example of the biotechnology process using yeast is a brewery plant as shown in Figure 1. Conventionally, centrifugation and filtration are used, but both of these techniques have significant limitations. Centrifuges are high cost in terms of both operation and maintenance. In filtration, filter aids such as Kieselguhr are needed. This would unavoidable lead to an increase in production costs, and moreover, the environmental problem caused by the disposal of used filter aids. Hydrocyclones do not need any separation aids. So they are absolutely environmentally friendly. Moreover, hydrocyclones have the advantage of being low cost in terms of purchasing, installation, operation and maintenance, small space requirement, ease of cleaning and also because installations are modular. There are some other research works on the application of small hydrocyclones for micro-organism separation, which are [1], [2], [3] and [4]. Cillier and Harison [1] studied the effect of viscosity on the recovery and concentration of Bakers' yeast from glucose' water solution using a 10-mm dewatering hydrocyclone. They found the solid recovery decreasing for higher feed concentrations. Yuan et al. [2] did the experimental works to explore the yeast separation with various types of hydrocyclone. The suspensions used in their experiments were Nylon powder, Baking yeast, and Brewing yeast in sucrose's water solution. They reported that their deoiling type hydrocyclone, which was developed for the separation of dispersed oil in water, gave better liquid separation results than other types of hydrocyclone. Rickwood et al. [3] investigated the possible used of a 10-mm dewatering hydrocylcone and a 35mm deoiling hydrocyclone for the recycling of used Kieselguhr by removing yeast into the overflow, while the bulk of the Kieselguhr is in the underflow. The suspension used was dry Kieselguhr in distilled water. Their results showed that the de-watering hydrocyclone design gave an efficient separation of Kieselguhr and yeast suspension.

The main aim of the work presented here was to investigate the performance of small hydrocyclones for separating yeast in the brewing industry utilising the actual suspension from the Pathumthani Brewery Co. Ltd., Thailand. Two different hydrocyclones, 11-mm deoiling hydrocyclone developed by [2] (HY1), and 10-mm dewatering hydrocyclone from Richard Mozley Ltd. (MZ) were used. There were two separation applications considered, which were the liquid clarification for the pre-filter unit and the yeast recovery for the fermentation unit. The feed suspensions used in these experiments were taken from the middle and bottom parts of the fermentation tank in the brewing plant.

2. SEPARATION PERFORMANCE

2.1 Selectivity curve

The selectivity function is defined as the fraction of each particle size in the feed flow reporting to the underflow product. It represents the separation efficiency of particles with a particular (particle) size. This function is usually plotted as a monotonic curve on a log-linear scale, and is known as the selectivity curve, partition curve, performance curve, tromp curve or grade efficiency curve. This curve will not pass though the origin because a portion of the flow bypasses the classification region as a result of flow division. For any particle size d the selectivity function, *S(d)*, is defined as

$$S(d)=\frac{\dot{U}\dot{u}(d)}{\dot{F}\dot{f}(d)} \qquad (1)$$

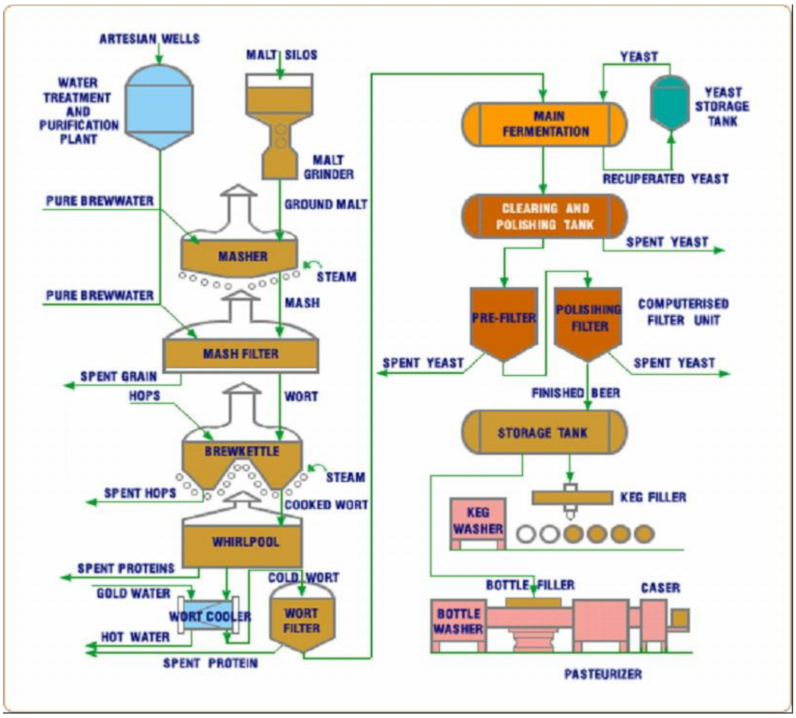


Figure 1. Schematic diagram of a brewery plant.

where $\dot{F}$ and $\dot{U}$ are the mass flow rates of solids and $\dot{f}$ *(d)* and $\dot{u}$ *(d)* are the weight fractions of particle size *d* in the feed and underflow stream, respectively. The above equation evaluates the performance of a hydrocyclone based on experimental data. The cut size, d_{50}, is one of the methods used to determine the hydrocyclone separation efficiency. It is defined as the particle diameter, which has an equal probability of reporting to both the underflow and overflow. The cut size can be obtained from the selectivity curve. Plitt (1976) commented that the corrected cut size is a more fundamental parameter because it is a measure of the separation forces operating on the particles in the hydrocyclone. The other important parameter is the throughput ratio, R_f, which is the ratio between the volumetric flow rate of the underflow and that of the feed, yields the recovery of the suspension to the underflow.

2.2 Clarification Efficiency

The separation efficiency also can be evaluated with the clarification efficiency defined as follows (Yuan and Thew, 1996):

$$Ec = 1 - (C_o/C_i) \qquad (2)$$

where C_o and C_i are volumetric concentration of solid particles in overflow and feed streams, respectively.

3. EXPERIMENTAL METHOD

3.1 Equipment

The hydrocyclones were equipped and set up with a feed pump and pressure gauge to measure the feed inlet pressure (see Figure 2). The geometrical hydrocyclone parameters are shown in Figure 3 and Table 1. Hydrocyclone overflows and underflows were directed back to the sump for recirculation. The operating pressure drop was varied from 20 kPa to 200 kPa by varying the inlet feed flow rate. Hydrocyclone tests were performed at 25°C. The feed suspensions used in the experiments were taken from the fermentation tank in the brewing plant of Pathumthani Brewery Co. Ltd., Thailand. For the liquid clarification application, the feed suspension was taken from the middle part of the fermentation tank, and was called Suspension type A. For the yeast recovery application, the feed suspension was taken from the bottom part of the fermentation tank, and was called Suspension type B. The density of brewing yeast is 1,204 kg/m^3. Yeast cells show a narrow size distribution with the dominant diameter measured as 8.9960 μm by laser diffraction technique, as shown in Figure 4. The properties of the suspensions are summarised in Table 2.

Table 1. Hydrocyclone dimension.

Size(mm)	D	D_S	D_I	D_O	D_U	L	L_S	L_O	L_U	$\theta(^o)$	$\theta_S(^o)$
HY1	11.0	20.0	5.0	2.3	6.0	473.0	37.4	0.0	165.0	1.2	20.0
MZ	10.0	1.0.	2.2	2.0	2.0	90.0	0.0	4.0	0.0	9.0	0.0

Table 2. Properties of the feed slurry.

Suspension type	Particle size (μm)	Viscosity (cSt) at 25 ^{o}C	Density (kg/m^3) at 25 ^{o}C
A	0.0582 – 301.6802	1.800	1000.0
B	0.0582 – 301.6802	2.934	1000.3

3.2 Method of sampling and analysis

The feed pressure was recorded with both of the outlets open to the atmosphere. The volume flow rates of feed, overflow and underflow were measured. From each experiment, samples were collected from the feed, overflow and underflow streams. The collected samples were weighed and mass flow rates determined. The concentration of each stream was determined by their dry weight. The samples were filtered through Cellulose Acetate 0.45 μm filters and dried in an oven at 50°C. The particle size distribution of each stream was measured by using the laser-diffraction size-analysis technique. To achieve repeatability, multiple samples were taken and averaged values used. The results for particles below approximately one micron were generally unreliable according to the limitation induced by the sensitivity of the laser diffraction instrument.

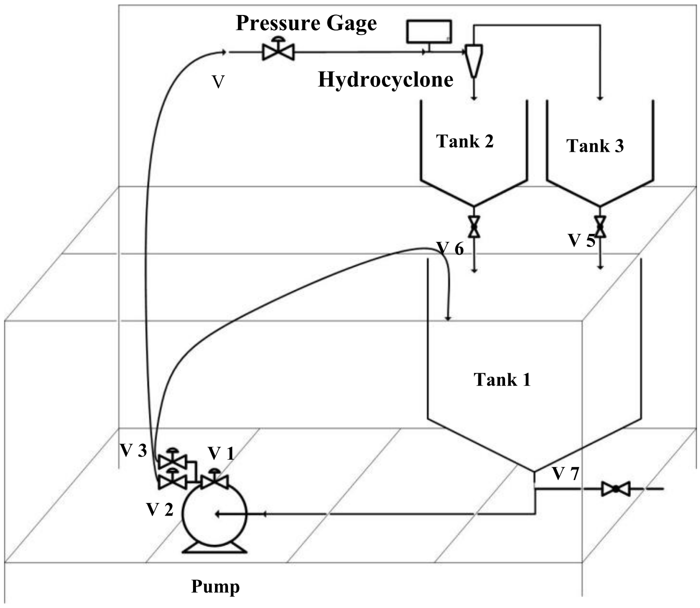
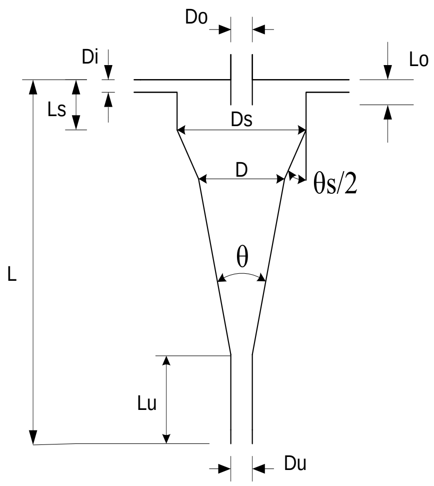


Figure 2. Hydrocyclone apparatus.



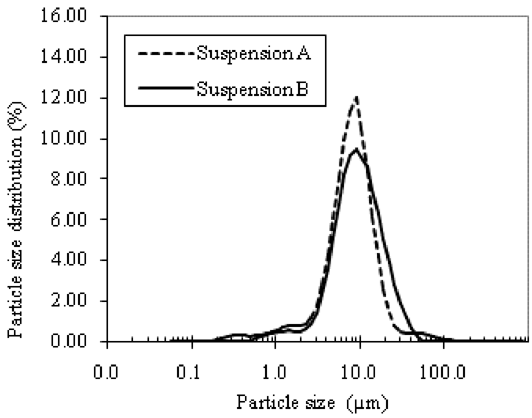


Figure 3. Schematic diagram of

Figure 4. Particle size distribution in the feed hydrocyclone suspension A and B.

4. DISCUSSION OF RESULTS

4.1 Liquid clarification

The clarification efficiency of both hydrocyclones treating suspension A was examined. The operational data (pressure drop), the concentration and flow rate of each stream, the cut size and throughput ratio (R_f) of each run are shown in Table 3 and 4. The clarification efficiency of HY1 and MZ hydrocyclones treating Suspension A are shown in Figure 5. It can be seen that an increase in operating pressure drop leads to an increased flow rate in all flow streams but also results in a decreased concentration of solid particles in the overflow stream. The pressure drop has less affect on the concentration of solid particles in the underflow. HY1 produced a very high throughput ratio that increased with an increase in pressure drop. However, the throughout ratio of the MZ hydrocyclone was found to decrease where the pressure drop was increased due to the reversed flow caused by higher velocity flow and the small diameter of the underflow outlet.

Table 3. Experimental results of Suspension A separation.

Run	Hydro-cyclone	Pressure drop (kPa)	Feed		Overflow		Underflow	
			Flow rate (l/min)	Concen-tration (% wt.)	Flow rate (l/min)	Concen-tration (% wt.)	Flow rate (l/min)	Concen-tration (% wt.)
1	HY1	20.0	4.65	0.16	0.30	0.14	4.35	0.16
2	HY1	40.0	11.89	0.16	0.35	0.11	11.54	0.16
3	HY1	50.0	14.33	0.16	0.37	0.10	13.96	0.16
4	HY1	60.0	15.93	0.16	0.39	0.09	15.54	0.16
5	MZ	50.0	3.28	0.16	1.08	0.12	2.20	0.19
6	MZ	100.0	4.94	0.16	1.88	0.1	3.06	0.21
7	MZ	200.0	6.68	0.16	2.62	0.08	4.06	0.21

Table 4. Experimental results of Suspension A separation.

Run	Hydrocyclone	Pressure drop (kPa)	%Ec	d_{50} (μm)	R_f
1	HY1	20.0	15.38	-	0.94
2	HY1	40.0	31.25	-	0.97
3	HY1	50.0	38.46	-	0.97
4	HY1	60.0	50.00	-	0.98
5	MZ	50.0	23.08	0.6707	0.67
6	MZ	100.0	38.46	0.7000	0.62
7	MZ	200.0	50.00	0.5757	0.61

It was also found that the operating pressure drop range of the two hydrocyclones were around five times different, although they were operating with the same pumping power. The range of the operating pressure drop of HY1 and MZ hydrocyclones were 200-600 kPa and 500-2500 kPa respectively. HY1 produced a higher feed flow rate than MZ however, as a result of its relatively low throughput ratio the MZ hydrocyclone can generate greater overflow production. The tests demonstrated that both hydrocyclones can provide a clarification efficiency of up to 50%. An increase in operating pressure drop leads to an increase the clarification efficiency. The clarification efficiency of HY1 is very responsive to the change in pressure drop and from the obtained efficiency curve it can be predicted that further increases of the pressure drop could provide significantly better separation performance. In contrary, the MZ efficiency curve indicates that any further pressure drop increase is unlikely to significantly improve the clarification efficiency of the MZ hydrocyclone. The classification performance of the two hydrocyclones was also examined and the obtained selectivity curves are presented in Figures 6 and 7. HY1 could not provide any classification for all operating pressure drop values and therefore the cut size could not be obtained, which is due to its high throughput ratio. The MZ hydrocyclone gave poor classification and the cut size obtained was between 0.5757-0.6707 microns. Furthermore, the selectivity curve for the 500 and 1000 kPa operating cases did not correspond to the theoretical relationship due to the effect of high turbulent dispersion and the fluid-particle interaction [7].

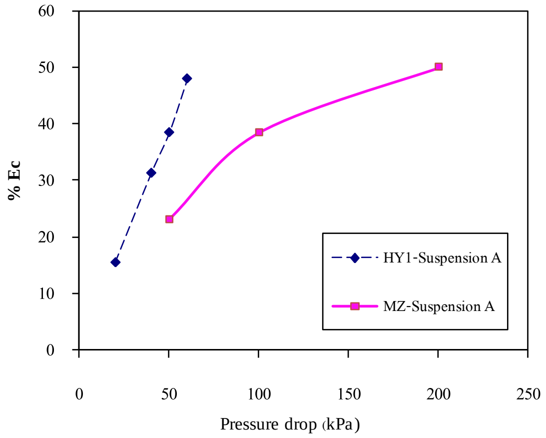


Figure 5. Clarification efficiency of HY1 and MZ hydrocyclones treating Suspension A.

4.2 Yeast recovery

Suspension B was used in the yeast recovery experiments and because it was taken from the bottom part of the fermentation tank, its viscosity was very high. The performance of the HY1 and MZ hydrocyclones operating with Suspension B was measured. The operational data, the concentration and flow rate of each stream, the cut size and throughput ratio (R_f) of each run are shown in Table 5 and 6. As a result of the high viscosity of Suspension B, the highest operating pressure drop obtained from the HY1 runs was 500 kPa. Also, as can be seen from Table 5, the effect of the pressure drop on the flow rate in all flow streams, on the solid concentration of the overflow stream, and on the throughput ratio, are consistent with the results obtained in the liquid clarification experiments. For HY1, the solid concentration of the underflow stream increased with an increase in operating pressure drop, whilst an increase in the operating pressure drop of MZ resulted in a decrease in the solid concentration of the underflow stream.

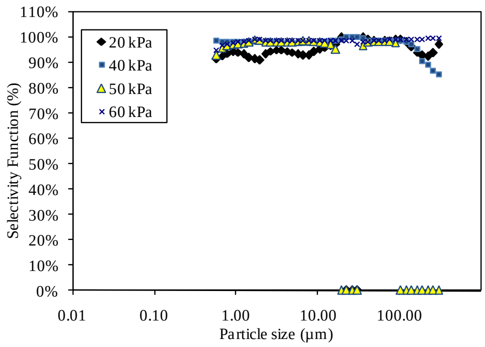


Figure 6. Selectivity curves of HY1 hydrocyclone treating Suspension A.

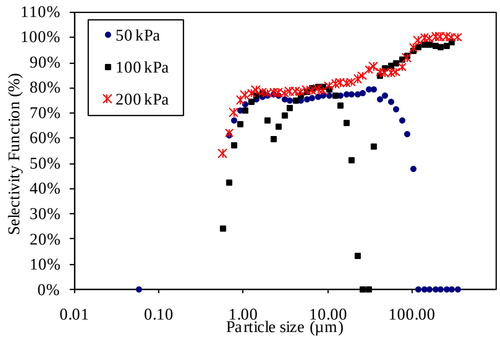


Figure 7. Selectivity curves of MZ hydrocyclone treating Suspension A.

Table 5. Experimental results of Suspension B separation.

Run	Hydro-cyclone	Pressure drop (kPa)	Feed		Overflow		Underflow	
			Flow rate (l/min)	Concen-tration (% wt.)	Flow rate (l/min)	Concen-tration (% wt.)	Flow rate (l/min)	Concen-tration (% wt.)
8	HY1	20.0	3.72	1.02	0.24	0.86	3.48	1.08
9	HY1	50.0	11.47	1.02	0.30	0.80	11.17	1.14
10	MZ	50.0	2.62	1.65	0.86	0.84	1.76	1.51
11	MZ	100.0	3.92	1.65	1.50	0.64	2.45	1.49
12	MZ	200.0	6.10	1.65	2.40	0.59	3.70	1.17

Table 6. Experimental results of Suspension B separation.

Run	Hydrocyclone	Pressure drop (kPa)	%Ec	d_{50} (μm)	R_f
8	HY1	20.0	15.29	-	0.94
9	HY1	50.0	21.18	-	0.97
10	MZ	50.0	49.28	0.2443	0.67
11	MZ	100.0	61.50	0.2443	0.63
12	MZ	200.0	64.50	2.2757	0.61

The classification performance of these hydrocyclones is illustrated by their respective selectivity curves. Figure 8 shows that there was no solid classification observed for HY1 operating at 500 kPa and when operating HY1 at 200 kPa only a very poor classification was measured. The classification efficiency for MZ operating at 500, 1000 and 2000 kPa can be compared in Figure 9. The selectivity curves for 500 and 1000 kPa are similar and provide better classification than the 2000 kPa curve due to the considerably smaller cut size and the higher sharpness or gradient of the curve. The higher pressure drop causes highly turbulent flow, which has an adverse effect on the separation of particles with a low time constant, such as yeasts, because they are turbulence sensitive and as a result they are more likely to be re-mixed or re-entrained by the flow reversal. However, it is important to note that both types of hydrocyclone produce a low solid recovery percentage, which perhaps is due to the suspension concentration or viscosity being too high to begin with. Figure 10 and 11 present a comparison between the clarification efficiency obtained from both hydrocyclones treating the two types of suspension. It can be seen that HY1 provides better clarification efficiency when dealing with lower concentration or viscosity, whereas MZ provides greater clarification efficiency when dealing with higher concentration or viscosity. However, MZ can produce as much solid recovery percentage as HY1 and MZ can also provide solid classification; an increase in the pressure drop leads to an increase in the clarification efficiency, but a decrease in the classification efficiency.

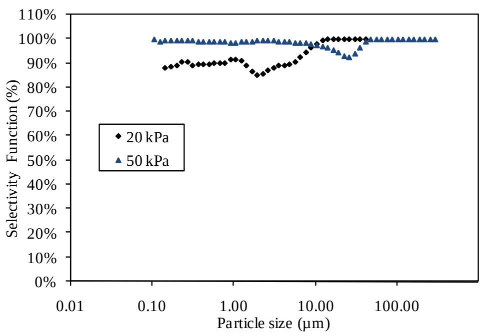


Figure 8. Selectivity curves of HY1 hydrocyclone treating Suspension B.

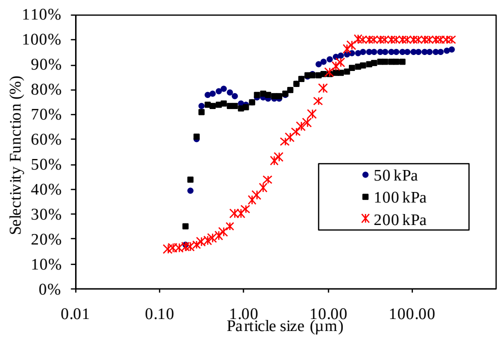
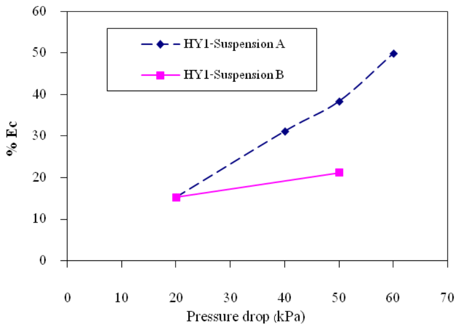


Figure 9. Selectivity curves of MZ hydrocyclone treating Suspension B.



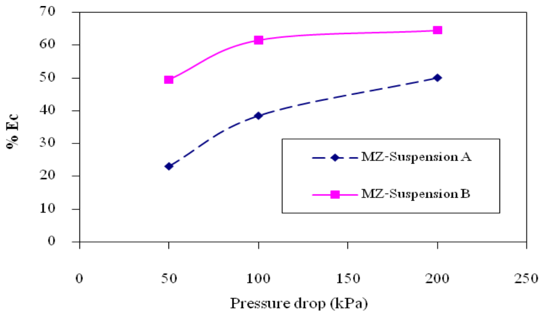


Figure 10. Clarification efficiency of HY1 hydrocyclone. Figure 11. Clarification efficiency of MZ hydrocyclone.

5. CONCLUSION

Both deoiling (HY1) and dewatering (MZ) hydrocyclones demonstrated their ability to produce up to 50% liquid clarification in the pumping power range of this study. However, the clarification efficiency of HY1 was found to be very responsive to the pressure drop and it can be predicted that further increases of the pressure drop could provide significantly better separation performance. Only the dewatering hydrocyclone could provide solid classification for both suspensions studied. Additionally, a high operating pressure drop did not provide any benefit to the classification because yeasts have low time constant, which are turbulence sensitive. However, both types of hydrocyclone produce a low solid recovery percentage, which perhaps is due to the suspension concentration or viscosity being too high to begin with.

6. ACKNOWLEDGEMENTS

Acknowledgements are due to Mr. Chumpon Phiancharoen of Pathumthani Brewery Co. Ltd. for supplying us with brewing yeast, and to the Thailand Research Fund for financial support (MRG5080035).

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