

Investigating Mass Transfer Phenomena in Batch Solvent Extraction of Rice Bran Oil

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Abstract

In this study, we will point out the correlation of critical parameters in designing scale-up of process equipment for commercial rice bran oil extraction with different types of rice paddy, solvent, and physicochemical condition. Advantageously, this research was also intended to enhance the discoveries of novel sustainable production method for resilient agro-based food, energy, and chemical industries. In our experiment, the extraction of rice bran oil was organised in a batch agitated vessel and showed a profile of first order system. The most important factors which profoundly contributed towards the yield of rice bran oil from Saigon I and Padi Besar variety are temperature (T), impeller speed (N), ratio of bran to solvent (s/L), and ratio of impeller's height-off bottom to tank diameter (h/d). For the mass transfer constant and the rate of extraction as consequence, factors that significantly influenced the correlation were temperature (T), impeller speed (N), ratio of impeller diameter to tank diameter (d/D), and ratio of impeller's height-off bottom to tank diameter (h/d). For the dimensionless yield, generalised equation is provided with coefficient of determination 0.95, while that of the mass transfer equals to 0.63, reflecting the yield correlation to be more accurate in predicting further experimental results. These correlations are furthermore unique for different rice varieties, of which in this case belongs to Saigon I. Application for other rice species is relevant as by inserting additional correction factor which also exemplified in this research for Padi Besar.

Keywords: rice bran oil; batch extraction; storage time; mass transfer, rate, yield

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INTRODUCTION

Processed rice paddy will provide around 70% of endosperm (called white rice) and other by-products such as shell (20%), bran (8%), and germ (2%) (Gul *et al.*, 2015; Zúñiga-Díaz *et al.*, 2017). Significantly, as one of the highest consumed staples worldwide, rice production has been at the level of 480 million metric

tones annually (Muthayya *et al.*, 2014). In Indonesia itself, the production is targeted to increase by 5% per annum, with surplus was 10 million metric tones by 2015 (Panuju *et al.*, 2013; Mariyono, 2015). Even though such production scale does contribute to massive agrowastes, this also triggers ample opportunities for agriculture valorisation and supports

sustainable development goals 2030 (Zaccheria *et al.*, 2015). For instance, rice bran constitutes on average 12-22% oil, 11-17% protein, 6-14% fiber, 10-15% moisture, and 8-17% ash, and this number is varied by one to another depending on climate and sub-species (Daud *et al.*, 2018). In one hand, edible oil products have superiorities as foods and pharmaceuticals for their linoleic fatty acids and bioactive compounds, involving antioxidants: tocopherols, tocotrienols, and oryzanol (Afinisha *et al.*, 2011; Sahu *et al.*, 2018; Nagendra Prasad *et al.*, 2011). Meanwhile, their non-edible counterparts can be utilised as biofuels (El Boulifi *et al.*, 2013; Lei *et al.*, 2011; Banapurmat *et al.*, 2009) and analytical solvents (Wongwaiwech *et al.*, 2019).

There are plenty of researches intended to commercialise extraction process of the rice bran oil with different techniques. Interestingly, solvent extraction is the most popular method, and can be based on organic solvents (Nagendra Prasad, *et al.*, 2011; Kamimura *et al.*, 2017; Liu *et al.*, 2015), enzymatic-water reaction (Ren *et al.*, 2016; Fang *et al.*, 2014; Hanmoungjai *et al.*, 2002), supercritical carbon dioxide (Sookwong and Mahatheeranont, 2017; Sarmiento *et al.*, 2006; Chen *et al.*, 2008), microwave system (Terigar *et al.*, 2011; Shukla and Pratap, 2017), or ultrasound-assisted aqueous extraction (Khoei and Chekin, 2016; Soares *et al.*, 2018; Cravotto *et al.*, 2004; Piogo-Bravo *et al.*, 2010; Widayat *et al.*, 2017). While process with vast range of solvents could be arranged, the mode of operation for this extraction is preferably conducted in an agitated vessel due to its flexibility, among other things, capability to be broken down into stages and each vessel principally approaches the ideal model of agitated tank. Hitherto, the constraints of this system, like different process condition strategies, pretreatment, to what extent the storage of brans effects final product's quality, and how we optimise the yield and extraction rate from various rice bran varieties, have been impeding the simplification of scale-up strategies (Kamimura *et al.*, 2017; Oliviera *et al.*, 2012; Liu and Mamidipally., 2005; Proctor and Bowen, 1996; Oliviera *et al.*, 2012).

As there is no previously detail experiment regarding practical design relationship, in connection with addressing the challenges by transport phenomena correlation during this process; hence, we firstly identify the major factors influencing the yield and extraction rate of selected rice bran in an agitated vessel. Secondly, general empirical correlations are developed to bridge quantitatively the experimental variables with the rate of extraction, as well as the yield of oil.

MATERIALS AND METHODS

Description of the apparatus and experimental scheme

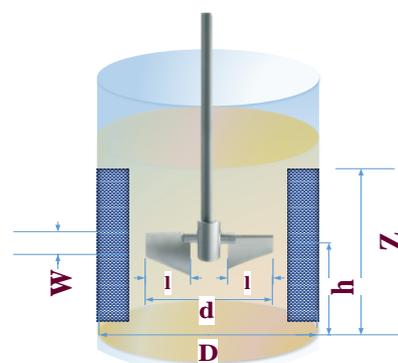
Apparatus used in this experiment can be seen in Figure 1. The important part was a cylindrical vessel

made of stainless steel with 1.5 mm thickness, 14 cm in diameter, and 19 cm height. Two baffles of 15 cm length, 1.1 cm width, and 1.5 mm thickness were fitted inside the tank. In addition, the vessel was also covered with stainless steel (3 mm thickness and 19 cm diameter), a condenser of 40 cm and 3.8 cm in diameter. There were three holes for input, namely A, B, and C. Hole A (diameter 2 cm) was used for holding a sensing element made from a negative resistance component (YSI type 1517694 IEA). This element was placed inside a stainless-steel rod and connected onto YSI thermo-controller type 63RC. On the other hand, hole B (3 cm diameter) was designed to hold a thermometer and that of hole C (diameter 4 cm) was for a sampling port.

We divided this experiment into four primary steps, which was (1) Soxhlet extraction, (2) agitation vessel extraction, (3) sample preparation, and (4) spectrophotometer calibration. Firstly, the purpose of the Soxhlet extraction was to find out the difference of oil content and extraction rate between stored (pretreated) and fresh (untreated) brans. Our bran was provided by three rice milling units in Bandung (West Java, Indonesia), and comprised of Saigon I, Padi Besar, and CianjurSelip varieties.



(a)



(b)

Figure 1. Experimental set up of agitated vessel used for rice bran oil extraction: (a) outlook design and (b) inside geometric configuration.

If the yield and extraction rate in Soxhlet did not differ when fresh or stored bran was used, we could therefore estimate the same condition for extraction in agitated vessel. For the procedure of extraction in agitated vessel, prior to mixing with the solvent, we needed 20 to 50 grams of bran, depending on the certain ratio of solvent to bran. Extraction was started by heating hexane until its boiling point, and after stopped for cooling, the extract should be kept closed until analysis is done. We used hexane as it is the most widely employed solvent for rice bran oil extraction and would be of great interests for industrial benefits (Pandey and Shrivastava, 2018). Procedures in agitation vessel were initialised by setting up the apparatus as shown in Figure 1.

After thermo-controller and thermometer was fitted in, solvent was fed into the vessel and condenser was operated. Following this, the motor was on and bran can be added to the system. While reaching 2 hours, extraction was ended.

For every run of experiment there were about 7 to 9 samples (each 7-8 cc) would be analysed. The bran was not taken together with the samples because it may inhibit the extraction process to continue. It was worth noting that the size of agitated vessel was affected by the quantity of samples as the more the sample, the bigger the vessel size could be in order to avoid bias error. In this experiment, thereby, the guide of maximum solid to liquid (s/L) ratio that was suitable for the vessel's volume and would ensure proper range of variation is 1:1.4 (500 grams per 1,100 cc) and minimum of 1: 2.2 (300 grams per 1,510 cc).

As much as 2 cc of sample was a prerequisite for spectrophotometer analysis. The data collected from this analysis was presented as yield in Table 2. This sample was thereafter mixed with 8 cc acetone to separate the remaining wax by Whatmann 44 and 50 in a closed system. Final solution could be directly analysed or if not, must be kept in a closed bottle. In regard to spectrophotometer, UV Shimadzu UV-Vis 120-02 with wavelength 250 nm is opted and two samples, including wax-free oil and oil with wax had to be prepared for calibration. For the wax-free oil, y grams of oil free wax were put in the 50 mL measuring flask and diluted with hexane until the total volume reaches 50 mL. After that, 10 mL aliquot was separated and mixed with 40 mL acetone could be tested using spectrophotometer, and actual concentration corresponded to 20y gram/L. Procedure for oil with wax was conducted likewise the wax-free oil calibration, with exception: reasonable amount of wax added into y gram oil in such a way that the final volume needed to be lower than 50 mL, suspended solid formed after diluting with acetone was removed by Whatmann Filter Paper 44 and 50 in a closed system. Actual concentration would also be equal to 20y gram/L (based on our regression result).

Description of mass transfer in general batch extraction

Solvent extraction of oil from seeds or brans is principally a mass transfer process between two phases. The oil in the solid is extracted and transferred into the liquid by means of diffusional mechanism (Amarasinghe and Gangodavilage, 2004). The mass transfer is proportional to both the surface area of the particles and the concentration gradients of the oil from the particle surface to the bulk, as represented in:

$$N_a = ka_p(C_0 - C) \quad (1)$$

Where,

N_a = mass transfer rate per unit volume of liquid [gram/(L.sec)]

k = mass transfer coefficient [cm/second]

a_p = interface's contact area per unit volume of liquid [cm²/cm³]

C = concentration of oil in the bulk solution [gram/L]

C_0 = concentration of oil in the interface between solid and bulk [gram/L]

For a batch process, mass balance per unit volume of the liquid phase is formulated as:

$$N_a = \frac{dc}{dt} = ka_p(C_0 - C) \quad (2)$$

Assuming that is constant during extraction, integration of Eq.2 will give:

$$\frac{c}{C_0} = 1 - e^{-t/\tau} \quad (3)$$

With $\tau = 1/ka_p$

From the above description, the mass transfer rate, besides being affected by the concentration gradient and particles' surface area, is governed by the mass transfer coefficient (k). At a given temperature, k is *per se* dependent on the characteristics of oil and solvent, and thus highly influenced by the magnitude of diffusion coefficient. Equation 3 is also used to determine ka_p by graphical methods like in Figure 5. During an immersion-type solvent extraction process, the solvent and the particles interact in a static manner if agitation is absent. On the contrary, however, in a batch agitated vessel, the agitation creates a flow pattern that increases the mass transfer rate.

This flow pattern can be determined by: (1) the physical properties of the fluid or slurry, (2) the intensity of agitation, and (3) the geometric configuration and impeller construction (Storck *et al.*,1981). Investigation related to mass transfer in agitated vessel had shown a correlation of:

Table 1. Half factorial design

Variable	Interaction description	Run															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
E1	s/L	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
E2	T	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1
E3	h/d	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1
E4	N	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1
E5	d/D	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1
E12	s/L and T	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1
E13	s/L and h/d	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
E14	s/L and N	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1
E15	s/L and d/D	-1	-1	1	1	1	1	-1	-1	1	1	-1	-1	-1	-1	1	1
E23	T and h/d	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1
E24	T and N	1	1	-1	-1	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1
E25	T and d/D	-1	1	-1	1	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1
E34	h/d and N	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1
E35	h/d and d/D	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1	1	-1	-1	1
E45	N and d/D	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1

Note: (-1 is variable at its minimum value, while that of 1 stands for maximum value. Please look for the values in table 2)

Table 2. Summary of varied parameters and collected results for each run

Run	s/L []	T (°C)	h/d []	N (rpm)	d/D []	Yield* (gram/L)	ka_p^* (min^{-1})
1	0.2752	31.2	0.2750	305	0.2857	8.8668	0.2146
2	0.6290	30.2	0.2714	306	0.5000	22.0345	0.2729
3	0.2752	59.5	0.2714	300	0.5000	16.9709	0.0770
4	0.6290	59.5	0.2750	302	0.2857	28.7706	0.1261
5	0.2752	29.2	0.6429	297	0.5000	12.8206	0.1442
6	0.6290	29.6	0.6500	297	0.2857	20.8764	0.1047
7	0.2752	60.0	0.6500	300	0.2857	18.1054	0.1380
8	0.6290	60.0	0.6429	297	0.5000	36.8145	0.1035
9	0.2752	30.0	0.2714	697	0.5000	12.3872	0.1482
10	0.6290	31.0	0.2750	700	0.2857	25.3027	0.1830
11	0.2752	60.0	0.2750	702	0.2857	20.1116	0.3096
12	0.6290	60.5	0.2714	702	0.5000	40.2209	0.1779
13	0.2752	29.7	0.6500	702	0.2857	13.3725	0.0922
14	0.6290	31.0	0.6429	700	0.5000	24.7230	0.1705
15	0.2752	60.5	0.6429	695	0.5000	22.8530	0.1173
16	0.6290	59.5	0.6500	702	0.2857	42.0563	0.1386

* Those values are the results of this experiment while the system was in steady state

$$\frac{ka_p d_p}{D_1} \approx \left[\frac{\rho v d_p}{\mu} \right]^{i_1} \left[\frac{\mu}{\rho D_e} \right]^{i_2} \quad (4)$$

and thus,

$$Sh \approx [Re]^{i_1} [Sch]^{i_2} \quad (5)$$

Where,

- ka_p = mass transfer constant
- d_p = particle diameter
- D_1 = diffusion coefficient

ρ and μ = density and viscosity of continuous phase

v = velocity characterising the fluid motion

i_1 and i_2 = a number of power constant

Sh = Sherwood number

Re = Reynolds number

Sch = Schmidt number

Further considerations need to be account for geometric configuration of the tank and impeller construction though, like d/D, h/d, d/z, d/w, d/l, and n_1/n_2 as they have significant influences on mass transfer in the agitated vessel. To reduce the redundancy of calculation, Sch can be omitted on account of strong temperature dependence for all

physical parameters constituting this number. Yet, the temperature can be expressed in the exponential form. These in turn lead to the simplification of unknown parameters like ρ , μ , and D_1 in further calculations. Finally, we got the preliminary general function of:

$$\text{Yield} = f(Re, T, \frac{s}{L}, \frac{d}{D}, \frac{h}{z}, \frac{d}{w}, \frac{d}{l}, \frac{n_1}{n_2}) \quad (6)$$

$$\text{Mass transfer rate} = f(Re, T, \frac{s}{L}, \frac{d}{D}, \frac{h}{z}, \frac{d}{w}, \frac{d}{l}, \frac{n_1}{n_2}) \quad (7)$$

Where,

T	= temperature
s/L	= solid to liquid ratio
d	= impeller diameter
D	= tank diameter
h	= bottom of impeller's height-off
z	= liquid depth
w	= width of the blade
l	= length of the blade
n_1, n_2	= number of baffles

Approach to the problem

In order to attain an expression concerning the influence of various factors on the mass transfer rate and the yield in rice bran oil extraction, a set of agitated vessels with fixed design of impeller can be used (see Fig 1b). In this observation, we incorporated a type of impeller with disk flat blade turbine, so the ratio of d/w and d/l will be standardised. The tank has two baffles, and extraction mixture is loaded with respect to the liquid height is kept in the range of 10 to 11 cm for all runs. With these arrangements, the factors d/w , d/l , n , and z are constant and thus eq. 6 and 7 are simplified to include only five out of the nine original factors.

$$\text{Yield} = f(Re, T, s/L, d/D, h/d) \quad (8)$$

$$\text{Mass transfer rate} = f(Re, T, s/L, d/D, h/d) \quad (9)$$

To determine the significant factors influencing the yield and mass transfer rate, we implemented the half-factorial design as shown in Table 1 and selected parameters in Table 2. By including only, the most reliable factors into the general equation, we will have the form:

$$\text{Yield} = ARe^a \frac{d^b}{D} \frac{h^c}{z} \frac{s^d}{L} e^{E/T} \quad (10)$$

$$\text{Mass transfer rate} = A'Re^{a'} \frac{d^{b'}}{D} \frac{h^{c'}}{z} \frac{s^{d'}}{L} e^{E'/T} \quad (11)$$

Next, the factors of A , A' , E , E' , a , b , c , d , a' , b' , c' , and d' will be searched by transforming the equation into a logarithmic form, from which multiple regression analysis is performed. After reaching the

final expression of yield and mass transfer rate, those equations will then be checked with two runs of experiments around mid point (zero level) and two other runs using brans from different variety of rice paddy. Effects calculation of a half factorial design is the difference between response at high level and response at low level. Both effects and coefficient of determination in this experiment was analysed using Minitab 17™.

RESULTS AND DISCUSSION

The effects of rice bran storage on yield and mass transfer rate during extraction in Soxhlet and agitation tank

Following the procedure of Soxhlet extraction, we found that the total oil did not depend upon the length of bran storage. To illustrate, experiment shown in Figure 2 indicated that after one hour of extraction, the amount of oil extracted remained at approximately 16.94% of the original weight of both the fresh (untreated) and stored (pretreated) brans from CianjurSelip variety. Accordingly, the determination of the oil content from Soxhlet operation can be done after one-hour extraction. The same characteristic for different variety of bran was also observed as for rice bran from Padi Besar, either 2, 3, or 5 hours of extraction, the total oil content were 15.22, 15.56, and 15.29%, respectively. With regards to the rate of extraction of the stored (pretreated) bran, they were almost the same as for the fresh (untreated) bran as depicted in Figure 3.

se phenomena generally validated that the length of storage did not affect the extraction rate of Soxhlet extraction and was likely predicted not to affect extraction rate in agitation vessel.

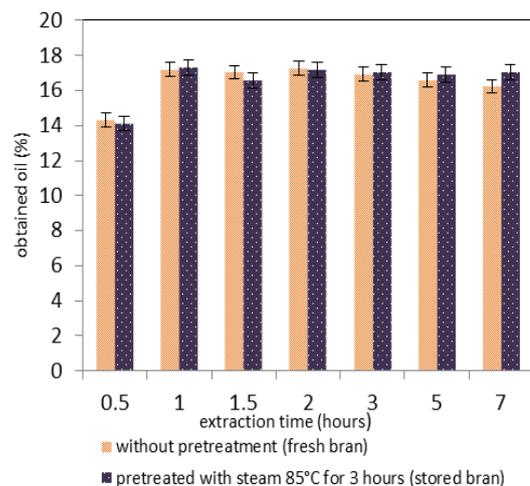


Figure 2. Total oil from rice bran of CianjurSelip variety with different Soxhlet extraction time (Experiment conducted with ratio of solvent to bran (weight basis) was 3:1. Extraction time 3 to 7 minutes used one-week old rice bran, while that of fresh rice bran was 0.5 to 2 minutes)

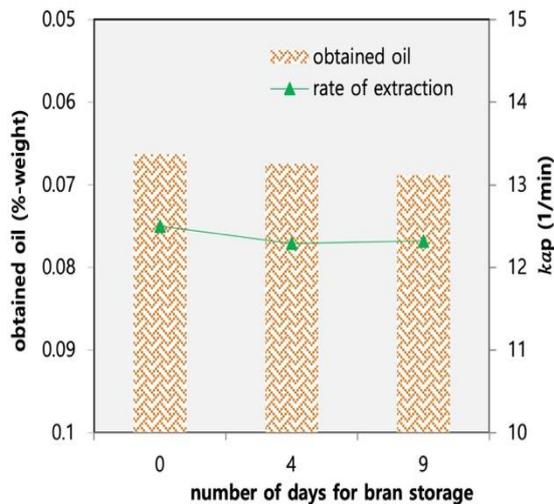


Figure 3. Effect of storage on obtained oil and extraction rate of rice bran from Saigon I variety (Conducted with no pretreatment and ratio of solvent to bran (weight basis) was 4.8:1)

The effect of storage on the rate and yield of extraction in agitation vessel is shown in Figure 4, from which we know that the yield and the mass transfer rate were independent from the storage duration. Furthermore, the results of extraction in agitation vessel using bran from Saigon I variety showed that the concentration of oil in the solvent (hexane) increased with time following a first order behaviour. The plots of $\log(1-C/C_0)$ vs time for some selected experimental runs resulted in straight lines as shown in Figure 5.

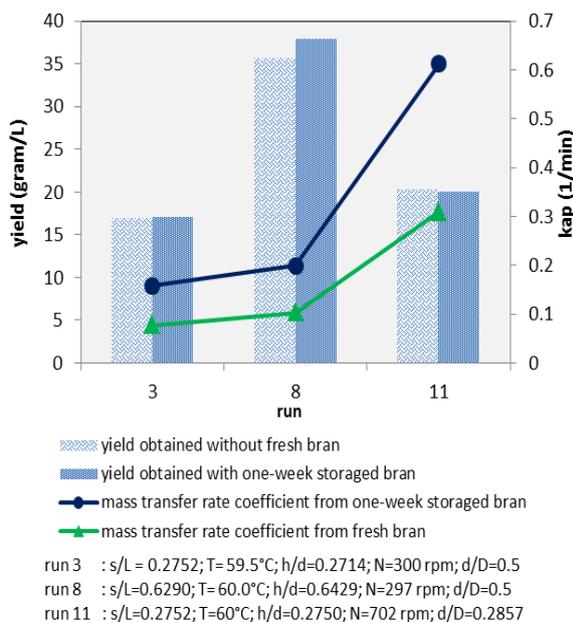


Figure 4. Yield and mass transfer rate constant profile in agitated vessel for selected runs of fresh vs one-week stored rice bran extraction

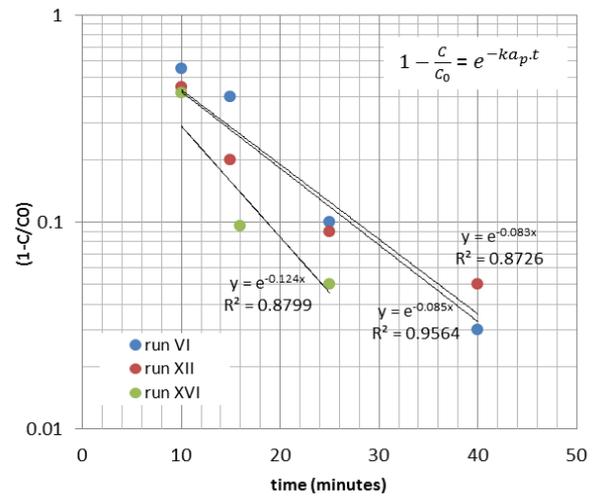


Figure 5. Example of $(1-C/C_0)$ vs time for selected runs to determine ka_p

From the graph, it can be seen that the lines did not pass through $\log(1-C/C_0) = 0$ at time = 0. This deviation may be subjected to the solvent evaporation which occurs more often at the beginning of extraction due to its high concentration. In addition, this deviation may also be caused by the nonhomogeneous system during the first few minutes of extraction.

The factors influencing the yield and mass transfer rate

The most significant factors influencing yield and mass transfer rate were determined based on half factorial design. From the calculation of effects, the factors that had significant influenced on the yield of extraction are: temperature (T), speed of impeller (N), ratio of bran to solvent (s/L), ratio of the impeller's height-off bottom to diameter (h/d), and ratio of impeller diameter to tank diameter (d/D). These values are higher compared to others (Table 3) as per represented by their coefficient of determination (Table 4). On the other hand, towards the mass transfer rate (expressed by the mass transfer constant (ka_p)), it was found that temperature (T), speed of impeller (N), ratio of the impeller's height-off bottom to diameter (h/d), and ratio of impeller diameter to tank diameter (d/D). Exclusively, s/L has no effect to this parameter since the value is relatively small.

Correlation of factors governing yield and mass transfer rate

Based on the preceding analysis and the information (Eq. 10 and 11), we determine the value of each constant by applying the multiple linear regression analysis to the logarithmically transformed equations. The final equations for bran from Saigon I are:

$$Dimensionless\ yield\ \frac{C_0V}{sX} = 3.19 (Re)^{0.22} (d/D)^{-0.31} (h/d)^{0.13} (s/L)^{-0.21} e^{-1415.7/T} \quad (12)$$

Table 3. Calculation of effects of yield and mass transfer constant

Variable	Interaction	Yield	Mass transfer constant ($\times 10^a$)
E1	s/L	-0.1100	0.8275
E2	T	0.2969	-9.235
E3	h/d	0.0673	-13.63
E4	N	0.1216	-24.93
E5	d/D	-0.0410	1.595
E12	s/L and T	-0.0358	4.432
E13	s/L and h/d	-0.0286	3.773
E14	s/L and N	-0.0085	1.075
E15	s/L and d/D	0.0088	13.95
E23	T and h/d	0.0218	7.925
E24	T and N	0.0435	14.83
E25	T and d/D	-0.0060	11.07
E34	h/d and N	-0.0208	2.652
E35	h/d and d/D	0.0020	-3.870
E45	N and d/D	0.0334	2.522

Table 4. Coefficient of multiple determinations for yield and mass transfer constant

Variable	Coefficient of correlation		Coefficient of determination	
	Yield	Mass transfer constant	Yield	Mass transfer constant
1/E2	0.83703	0.79306	0.70062	0.62894
ln E1	0.88945	0.79504	0.79113	0.63209
ln E45	0.93803	0.49066	0.87990	0.24075
ln E35	0.95899	0.78701	0.91967	0.61938
ln E5	0.97627	0.70331	0.95310	0.49465

$$23.68 (Re)^{-0.83} (d/D)^{1.52} (h/d)^{-0.41} e^{-\frac{N}{351.5/T}} = \frac{ka_p}{N} \quad (13)$$

With:

- C_0 = concentration of oil in final extracted solution (gram/L)
- V = working volume (L)
- s = bran mass (gram)
- X = total oil fraction inside the bran (dimensionless)

Both equations can be used within the range of:

- s/L = 0.2752 to 0.6290 (dimensionless)
- T = 302.6 to 333.5 (Kelvin)
- h/d = 0.27 to 0.65 (dimensionless)
- d/D = 0.286 to 0.5 (dimensionless)
- N = 297 to 710 (rpm)

From Eq. 12, the corresponding coefficient of determination showed a value of 0.95. It means that about 95% of the experimental results for yield can be approximated by this expression; thus, Eq. 12 provided satisfactory correlation. As opposed to the first case, the coefficient of determination for the relationship between mass transfer constant of bran oil and the solvent (eq. 13) was only about 0.63. We therefore verified the applicability of those equations under two radically different experimental conditions (parameters tabulated in table 5): one set (run 17 and 18) was held around mid point using the same variety of bran (Saigon I) and the other (run 19 and 20) utilised Padi Besar.

The experimental values obtained from the experimental runs of the first set as showed in Table 6

gave negligible deviation from estimation. Additionally, a comparison with the second set indicated that Eq. 13 and 14 are applicable for wide range of rice bran if the constant (A and A') are both adjusted. For this purpose, we have calculated the adjusted constant for Padi Besar variety to be 3.14 and 28.77, respectively. These results represented that further investigations are required to be performed to improve the above correlations. So, we suggested that the influence of impurities, such as broken kernel and husk in the bran should be taken into consideration.

From the above correlation, the yield of oil must increase along with higher temperature, Reynolds number (Re), and ratio of h/d as represented by the positive power of Re , T , and h/d . Consequently, the yield will lower when d/D and s/L is higher. Likewise, the rate will also faster under constant driving force ($C_0 - C$), increased temperature and d/D , and decreased Re and h/d . Relevant to those implications, reduced in Reynolds number portrayed higher impeller speed (N) on account of:

$$\begin{aligned} \frac{ka_p}{N} &= A(Re)^{-0.83} x f T, \frac{h}{d}, \frac{d}{D} \\ &= A \frac{\rho N d^2}{\mu}^{-0.83} x f(T, \frac{h}{d}, \frac{d}{D}) \end{aligned} \quad (14)$$

From the effect calculation, there was no interaction between d and N as E45 reflected small value's proportion (see Table 3). Hence, Eq. 14 can be re-arranged into this formula:

$$ka_p = A \frac{\rho d^2}{\mu}^{-0.83} x N^{0.17} x f T, \frac{h}{d}, \frac{d}{D} \quad (15) \quad \left[\frac{\rho_o}{\rho_s} \right]^f \text{ and } \left[\frac{\mu_o}{\mu_s} \right]^g \quad (17)$$

We finally can argue that according to Eq. 15, the mass transfer constant increases along with faster impeller speed, and how factors with respect to d/D and h/d should be considered in designing the tank and in selecting operating conditions, beneficial to obtaining the maximum yield and mass transfer rate. To add more information, these general relationships define explicitly the influence of the process variables on the yield and rate of extraction, which is useful for practical application for similar geometric and kinematic principles. By and large, a big scale plant can be engineered to obtain the same yield and extraction rate, assuming the ratio variables are remaining the same.

RECOMMENDATION FOR THE FUTURE WORK

The primary challenge in providing good data at the initial period of extraction is the solvent evaporation. At this time, their evaporation rate is higher due to low oil content, and thus the solvent fraction in the gas phase is very high. Another difficulty is that feeding bran only from one hole led to the non-homogenous solution during the first few minutes of extraction; thereby, in order to avoid this inaccuracy, batch experiment for each sample is suggested. Yet, further experiments should employ the higher quantity of sample for analysis.

Also, it is necessary to investigate brans from different rice paddy varieties since this will unravel the effects of diverse impurities. To determine how these impurities, affect extraction process, we have to insert some terms into prior equations. For instance, firstly, the ratio of oil quantity in the impurities to oil in the bran is of great interest because the main difference of the impurities (husk and broken kernel) with bran lies in their oil contents. This term is represented by:

$$\left[\frac{Y_k X_k}{Y_b X_b} \right]^m \text{ and } \left[\frac{Y_h X_h}{Y_b X_b} \right]^n \quad (16)$$

Where,

Y_k = fraction of the broken kernel in the total bran
 Y_h = fraction of the husk in the total bran
 Y_b = fraction of the bran in the total bran
 X_k = oil content of the broken kernel
 X_h = oil content of the hull
 X_b = oil content of the bran

Secondly, the effect of the variety of bran involves the chemical composition of the oil, which can be expressed by physical properties of the oil. In turn, this influences the density and viscosity.

Where,

ρ_o, ρ_s = density of oil and solvent
 μ_o, μ_s = viscosity of oil and solvent

Finally, the general equation for the yield and mass transfer constant respectively are written as follow:

$$\text{Yield} = f Re, \frac{h}{d}, T, \frac{s}{L}, \frac{Y_k X_k}{Y_b X_b}, \frac{Y_h X_h}{Y_b X_b}, \frac{\rho_o}{\rho_s}, \frac{\mu_o}{\mu_s} \quad (18)$$

$$ka_p = f Re, \frac{d}{D}, T, \frac{h}{D}, \frac{Y_k X_k}{Y_b X_b}, \frac{Y_h X_h}{Y_b X_b}, \frac{\rho_o}{\rho_s}, \frac{\mu_o}{\mu_s} \quad (19)$$

CONCLUSION

The extraction of rice bran oil in an agitated tank when carried out as a batch process showed the characteristics of first order system with the time constant values less than 15 minutes (time constant equal to $1/ka$). This condition portrayed that more than 60% of oil extraction process was completed within the first 15 minutes period. Furthermore, The most important factors which profoundly contributed towards the yield of rice bran oil from Saigon I and Padi Besar variety are temperature (T), impeller speed (N), ratio of bran to solvent (s/L), and ratio of impeller's height-off bottom to tank diameter (h/d). For the mass transfer constant and the rate of extraction as consequence, factors that significantly influenced the correlation were temperature (T), impeller speed (N), ratio of impeller diameter to tank diameter (d/D), and ratio of impeller's height-off bottom to tank diameter (h/d). In this research, the general relationships developed for the yield and mass transfer indicated good results in terms of applicability. For the different bran types, however, the values of the constants (A and A') required re-evaluation.

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