Effects of Magnetic Field on Physical Properties of Activated Sludge in Treating Palm Oil Mill Effluent

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Abstract. The production of palm oil results in large quantities of polluted wastewater that commonly called as palm oil mill effluent (POME) makes it very critical and important to be treated. In the recent years increasing attention has been taking account the possibility of wastewater treatment by static magnetic field. The aim of this study was to determine the effects of magnetic field on physical properties of activated sludge that has the potential to enhance the efficiency of removal performances in the POME treatment process. The objective of this study is to identify the main and interaction effects of magnetic field and exposure time towards biomass concentration, aggregation, settling velocity and chemical oxygen demand (COD) of the POME treatment process. Later, this study is to determine to obtain the optimum values of the magnetic parameters that could enhance the physical properties of activated sludge in treating POME.The experiments are conducted in batch test scale using a shaker that been fabricated to allow installation of permanent magnets of NdFeB that exposed to the POME. The range of magnetic field used is 9 and 30 mT while exposure time is between 6 and 24 hours. Factorial design and response surface methodology (RSM) were applied for experimental design analysis and optimization. Based on the results, all the studied parameters of magnetically-exposed activated sludge in POME were positively affected by magnetic field except for biomass concentration. Based on the CCD analysis, all responses, the predicted optimized conditions occurred at magnetic field intensity of 30 mT and 9.7 hours of exposure time achieved the maximum of biomass concentration, aggregation, settling velocity and COD removal was 1532.9 mg/L, 53.8%, 2.23 cm/s and 54.7%, respectively.

Introduction

POME which is a thick brownish liquid is being generated from palm oil processing [1]. The conventional activated sludge is occasionally facing a problem in treating POME particularly in terms of separation and settling of the biomass. Then, it resulted in low of the removal performances of the treatment system. In recent years, increasing attention has been directed to the possibility of improvement of wastewater treatment by static magnetic field [2]. This application which has been implemented in activated sludge process is hypothesized to increase the biodegradation process of treating POME through the enhancement of the physical properties of activated sludge.This study is aimed: (i) to identify the main effects of magnetic field and exposure time on the physical properties of activated sludge in treating POME, (ii) to investigate the interaction effects between magnetic field and exposure time towards biomass concentration, aggregation, settling velocity and COD and (iii) to determine the optimum values of the magnetic parameters that could enhance the physical properties of activated sludge in treating POME. The experiments are conducted in batch test scale using a shaker that being fabricated to allow installation of permanent magnets. The range of magnetic field used is 9.0 and 30 mT while exposure time is between 6 and 24 hours. The responses to be analysed are biomass concentration, aggregation, settling velocity and COD.The central composite design (CCD) approach was employed to quantitatively analyse the effects of those factors, the interactions between them and to indicate any correlation between the factor and the responses.

Previous Studies

There a several treatment methods that have been implemented to treat POME. Among of the treatments are anaerobic digestions [3], aerobic oxidation [4], combination of aerobic and anaerobic digestion [5], electrocoagulation [6] and membrane technology [1]. Most of these methods showed higher efficiency of removal performances in the POME treatment process. The responses and various parameters involved in the previous study are turbidity, chemical oxygen demand (COD), biochemical oxygen demand (BOD), mixed liquor suspended solids (MLSS) , total suspended solid (TSS), organic loading rate (OLR), sludge loading rate (SLR) and mixed liquor volatile suspended Solid (MLVS) concentration.

There was also a study that useda separate and combined process concept of activated carbon adsorption with facilitation of to treat POME. From the experiments, it was found that the removal efficiencies increased from 28.35% to 29.02%, and 65.9%, to 68.05%, 93.71% and 100%, respectively by increasing the dosage of activated carbon from 5 to 20 g/100 ml for colour, TSS and COD respectively. However, with regards to knowledge gap, not much of the research study or reported on the use of magnetic field application solely using bulk permanent magnets.

Methodology

Wastewater and Activated Sludge

The wastewater used in this study is POME was collected at Felda Bukit Besar similar sampling site location was involved for the collection of activated sludge. Both samples POME and activated sludge were preserved in the cool room under the temperature of less than 4°C.

Experimental Procedure

A total volume of 250 mL that contained a mixture of measured wet volume of activated sludge biomass of 2000 mg/L and POME was mixed in a glass flask that placed in a shaker. The shaker was fabricated to allow an installation of the permanent magnets of sizes 100 x 50 x 5 mm. The magnets were arranged at both side surfaces of the flask in a alternate order. The effective magnetic flux area is 100 x 50 mm. The variation of magnetic field applied ranges from 9.0 to 30.0 mT. The mixture of activated sludge was exposed within the exposure time of 6.0 to 24.0 hours.

The initial values of the responses were measured before batch test started. Throughout the experiments, the mixture was mixed under a specified mixing intensity (300 rpm). After the exposure of the magnetic field, the mixture was allowed to idle for 10 minutes before 10 mL of the liquid samples were collected and analyzed for final the final measurement. The whole experiments were conducted based on the factorial design (MINITAB™) and central composite design (CCD) (Design Expert®). For the factorial design, a total of 8 were carried out, a total of 21 runs were conducted. These experimental designs were employed to quantitatively analyze the effects of those factors: magnetic field and exposure time, the interactions between them and to indicate correlation between the factors and responses: biomass concentration, aggregation, settling velocity and COD. Table 1 shows the range values of the factors considered in the experiments.

Table 1 : Range value of the factors

Variables	**Factorial**	
	-1	**+1**
A: Magnetic Field (mT)	9.0	30
B: Exposure Time (hr)	6.0	24

Analytical Methods

Biomass Concentration. The mixed liquor suspended solids (MLSS) was measured based on Method No. 2540D and 2504E, respectively. The empty filter paper was initially weighed (M_a). Ten (10) mL of the samples then filtered using 47 mm diameter filter paper (Wartmann) through a filter apparatus (DOA-P504-BN). The filter paper with samples was heated at 105^{o}C for one hour. After the heating, samples were then allowed to cool in the desiccators and were weighed (M_b).

Mixed liquor suspended solids (MLSS) = $\left\{\frac{Mb-Ma}{V}\right\} \times 1000$ (1)

Aggregation. Aggregation was evaluated in terms of turbidity measurement. After the batch test reaction under magnetic field exposure was stopped, turbidity of 10 mL was immediately measured and recorded as turbidity at 0 min (T_0). The residual turbidity of the supernatant is then measured after 10 min and the value is recorded as final turbidity (T_f).

Ag (%) = $\left\{\frac{T0 - Tf}{T0}\right\} \times 100$ (2)

Settling Velocity. The settling velocity was determined by recording the average time taken for the magnetically-exposed activated sludge to settle at a certain height in a glass column filled with tap water [2].

Chemical Oxygen Demand (COD) Removal. Chemical oxygen demand (COD) was quantified using a HACH Spectrophotometer (DR 4000) based on Method No. 5220D. Each sample was added to the COD reagent (High Range Digestion for COD), Cat. 21259-25) and was digested at 150^{o}C for 2 hours in COD reflux (Model DRB 200). After the digestion was completed, the sample was allowed to cool at room temperature before the COD levels were measured using the spectrophotometer.

COD (%) = $\left\{\frac{COD\ raw - COD\ experiment}{COD\ raw}\right\} \times 100$ (3)

Results and Discussions

This section provides discussion on the findings regarding the influence of magnetic field and exposure time towards biomass concentration, aggregation, settling velocity and COD removal of activated sludge.

Factorial Design Analysis

The effect of the variables was presented by the change of responses in the level of the investigated factors. The interaction effects were also investigated when the effect of one variable is affecting the responses of other variables. The experimental results for factorial design analysis are given in Table 2. The analysis resulted in the biomass concentration with ranged 486 to 1340 mg/L., aggregation with ranged 49.98 and 66.6%, settling velocity with ranged 2.11 to 3.12 cm/s and COD removal with ranged 26.43 to 66.13%.

Figure 1 to Figure 4 show the Pareto chart generated by MINITAB™ for biomass concentration, aggregation, settling velocity and COD of activated sludge. The vertical red line represents the significance level determined by the statistical software. The horizontal column bar that does not reach the red line would imply the insignificance of the model term.

Table 2: Experimental results for factorial design

Run	Magnetic intensity (mT)	Exposure time (hr)	Biomass concentration (mg/L)	Aggregation (%)	Settling velocity (cm/s)	COD (%)
1	9.0	6.0	1221	66.60	2.89	26.43
2	9.0	6.0	1224	65.40	2.72	27.89
3	30.0	24.0	510	60.59	2.24	59.09
4	30.0	6.0	486	49.98	2.11	65.58
5	30.0	6.0	1014	50.27	2.23	66.13
6	30.0	24.0	1340	61.90	2.26	47.89
7	9.0	24.0	897	62.11	3.04	53.16
8	9.0	24.0	901	61.70	3.12	51.35

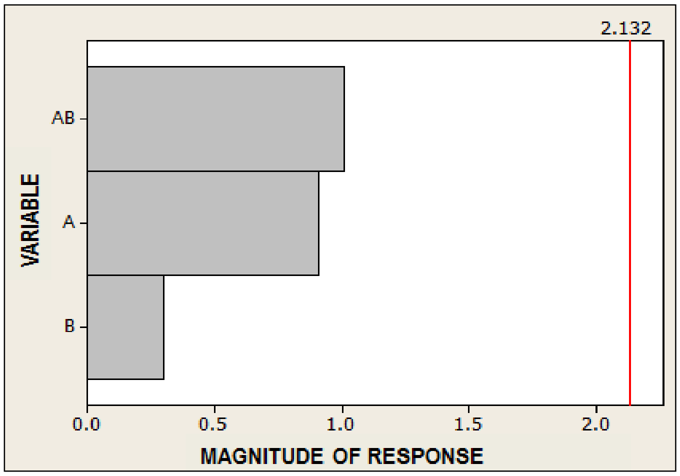

Figure 1: Pareto chart of biomass concentration (A: Magnetic field; B: Exposure time)

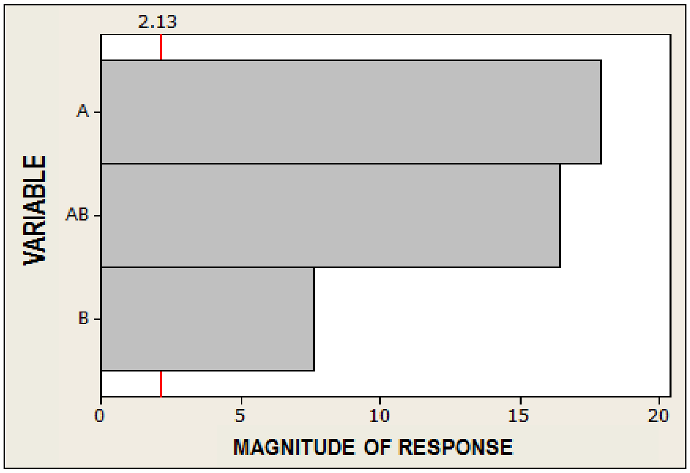

Figure 2: Pareto chart of aggregation (A: Magnetic field; B: Exposure time)

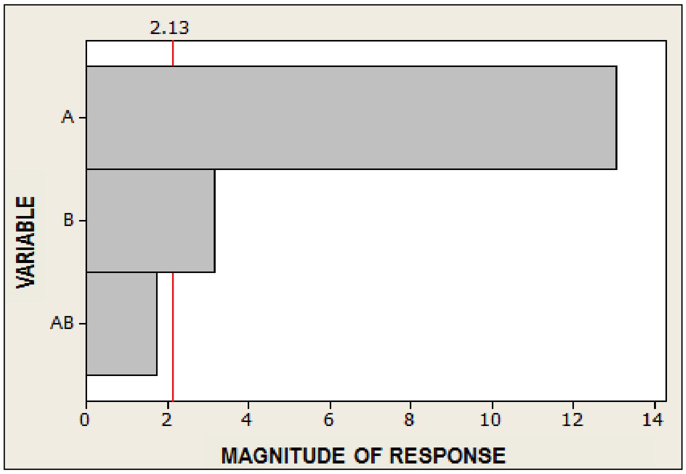

Figure 3: Pareto chart of settling velocity (A: Magnetic field; B: Exposure time)

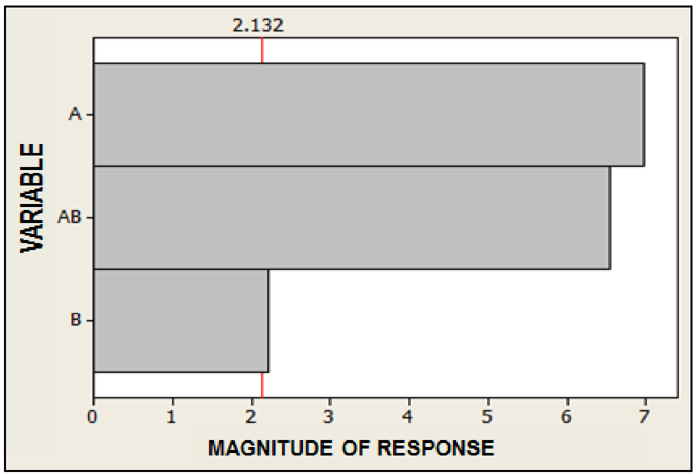

Figure 4: Pareto chart of COD (A: Magnetic field; B: Exposure time)

Factorial Design Analysis: Biomass Concentration

Main Effect. Figure 5 illustrates the main effect of magnetic field and exposure time on biomass concentration. Based on the figure, the magnetic intensity increased from 9 to 30 mT caused decreasing of biomass concentration from 1060 to 840 mg/L by 20%. Similar observation was obtained by the variable of exposure time as it prolonged from 6 to 24 hours, the biomass concentration were reduced from 970 to 910 mg/L by 6%.

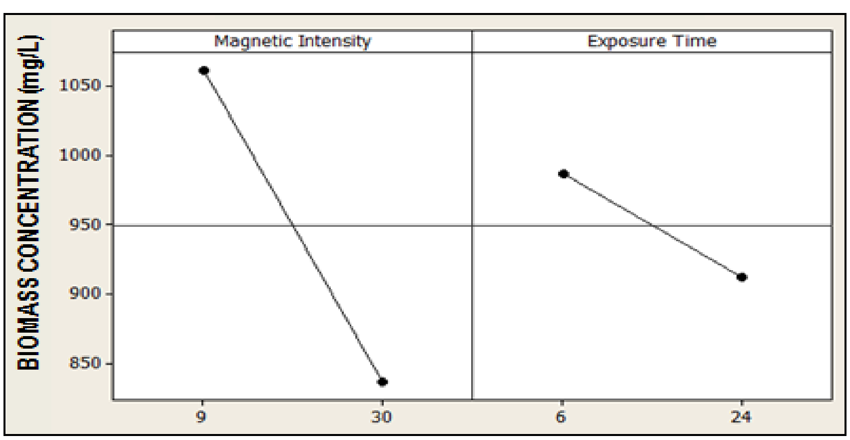

Figure 5: Main effects of magnetic field and exposure time on biomass concentration

Interaction Effect. Figure 6 presents interaction effects of magnetic field and exposure time on biomass concentration. Based on the figure, different intensity of magnetic field exhibited different effect towards biomass concentration as the exposure time increases from 6 to 24 hours. As the magnetic field increases resulted in higher of biomass concentration from 740 to 920 mg/L by 20% whereas lower magnetic field led to lower biomass concentration from 1210 to 910 mg/L by 25%.

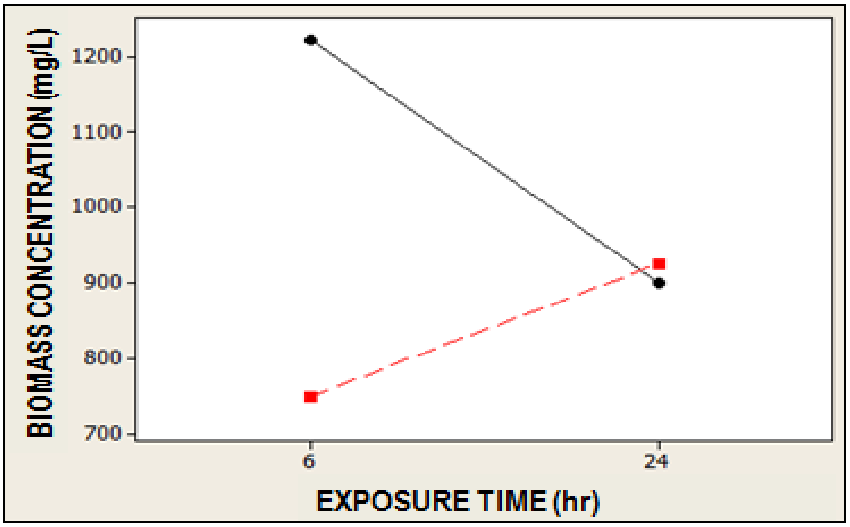

Figure 6: Interaction effects of magnetic field and exposure time on biomass concentration (—●— Low range magnetic field of 9 mT; ■ High range magnetic field of 30 mT)

Factorial Design Analysis: Aggregation

Main Effect. Figure 7 indicates the main effect of magnetic field and exposure time on aggregation. Based on the figure, the magnetic field increased from 9 to 24 hours caused lower in aggregation from by 13%. In contrast, increased in exposure time resulted in the higher aggregation by 6%.

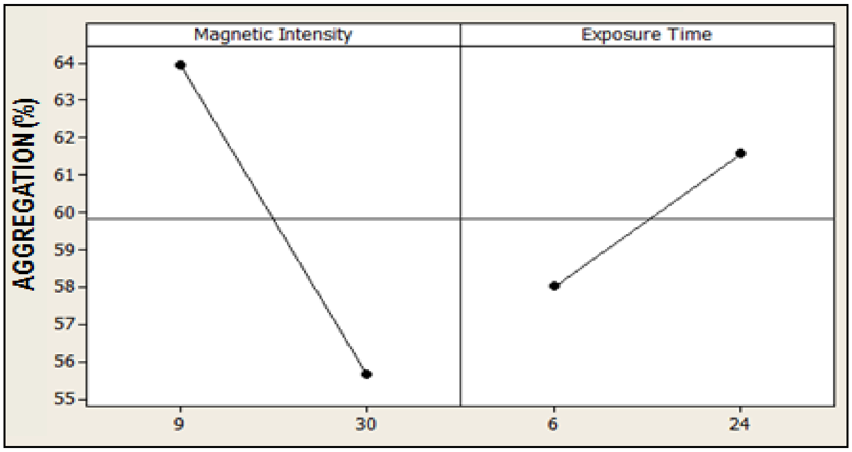

Figure 7: Main effects of magnetic field and exposure time on aggregation

Interaction Effect. Figure 8 shows interaction effects of magnetic field and exposure time on aggregation. Based on the figure, the higher magnetic field of 30 mT increased the aggregation from 51 to 61.8% by 17% as the exposure time increased from 6 to 24 hours. In contrast, the low magnetic field of 9 mT led to slightly decreased of aggregation from 66 to 62% by 6%.

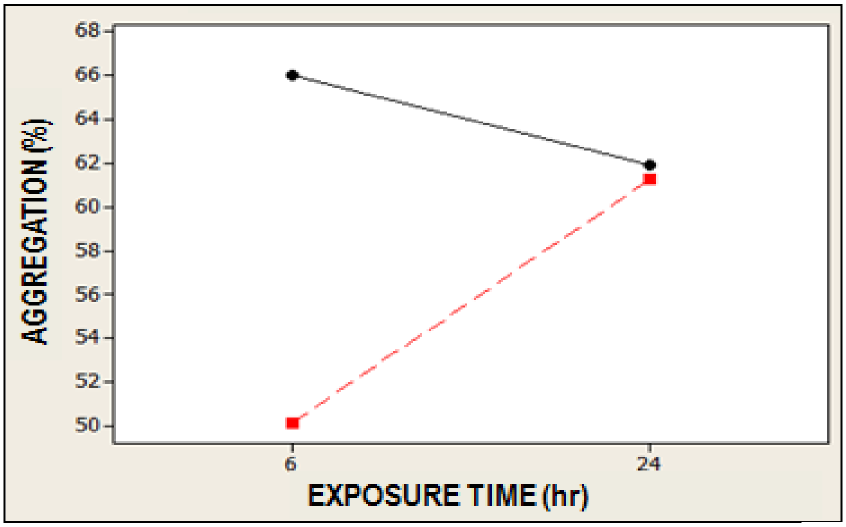

Figure 8: Interaction effects of magnetic field and exposure time on aggregation (—●— Low range magnetic field of 9 mT; ■ High range magnetic field of 30 mT)

Factorial Design Analysis: Settling Velocity

Main Effect. Figure 9 presents the main effect of magnetic field and exposure time on settling velocity. Based on the figure, the magnetic field increased from 6 to 24 hours caused lower in settling velocity from 2.95 to 2.2 cm/s by 25%. In contrast, increased in exposure time resulted in the higher settling velocityfrom 2.5 to 2.65 cm/s by 6%.

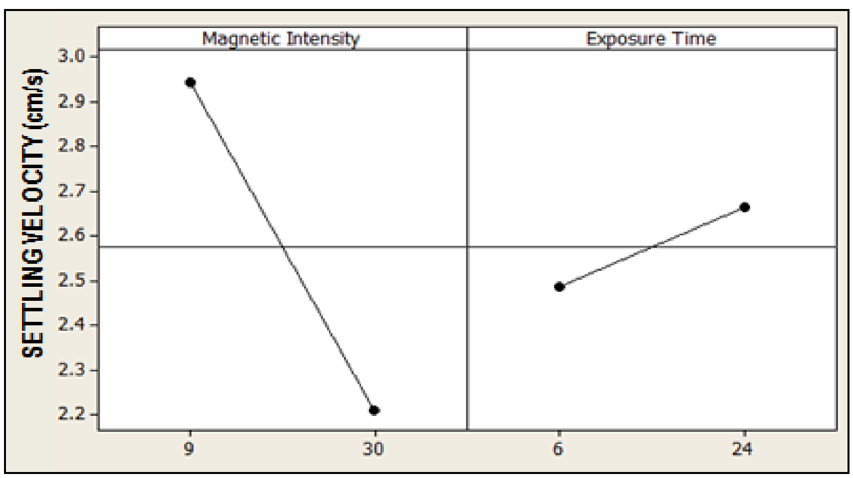

Figure 9: Main effects of magnetic field and exposure time on settling velocity

Interaction Effect. Figure 10 presents interaction effects of magnetic field and exposure time on settling velocity. Based on the figure, both of the magnetic field show the settling velocity increased as the exposure time increased from 6 to 24 hours. The higher magnetic field of 30 mT slightly increased the settling velocity from 2.18 to 2.25 cm/s by 3%. In contrast, the low magnetic field of 9 mT led to increase of settling velocity from 2.8 to 3.08 cm/s by 9%.

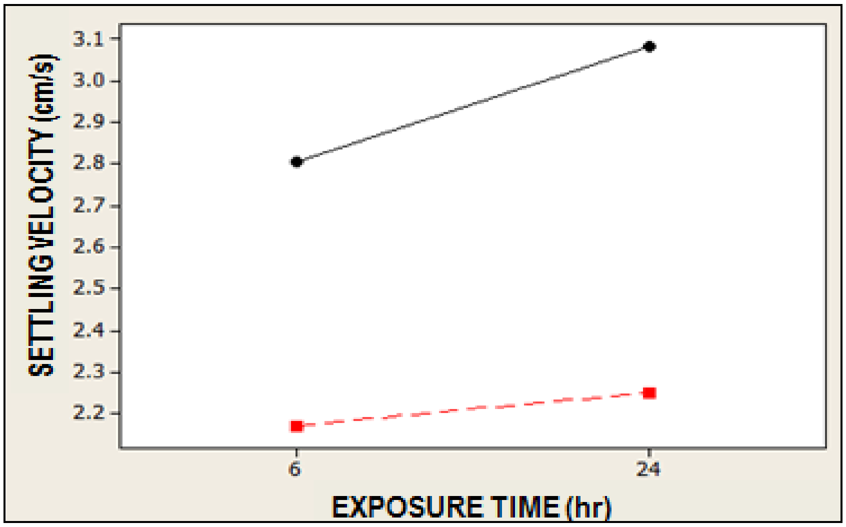

Figure 10: Interaction effects of magnetic field and exposure time on settling velocity (—●— Low range magnetic field of 9 mT; ■ High range magnetic field of 30 mT)

Factorial Design Analysis: Chemical Oxygen Demand (COD) Removal

Main Effect. Figure 11 illustrates the main effect of magnetic field and exposure time on COD. Based on the figure, the magnetic intensity increased from 9 to 30 mT caused increasing of COD by 34%. Similar observation was obtained by the variable of exposure time as it prolonged from 6 to 24 hours, the biomass concentration were rose up by 12%.Tomska and Wolny also achieved similar trend of observation whereby an increase of magnetic field of 40% led to higher of COD removal.

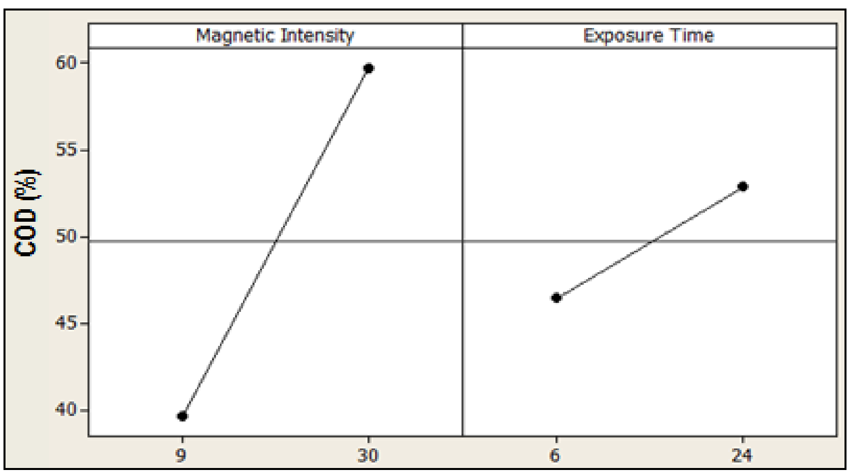

Figure 11: Main effects of magnetic field and exposure time on COD

Interaction Effect. Figure 12 shows interaction effects of magnetic field and exposure time on COD. Based on the figure, different intensity of magnetic field exhibited different effect towards COD as the exposure time increases from 6 to 24 hours.The higher magnetic field of 30 mT resulted in lower of COD from 66 to 53% by 20% .In contrast, the low magnetic field of 9 mT led to rose up of COD from 24 to 52% by 54%.

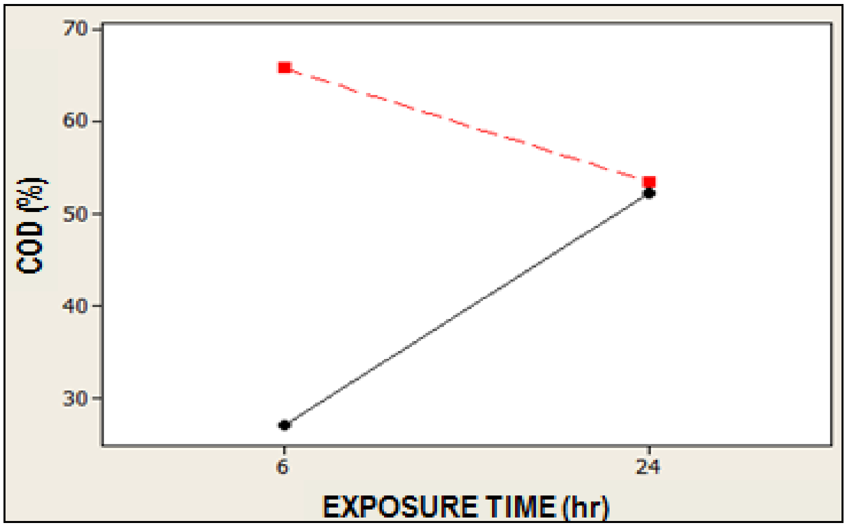

Figure 12: Interaction effects of magnetic field and exposure time on COD removal (—●— Low range magnetic field of 9 mT; ■ High range magnetic field of 30 mT)

Central Composite Design (CCD)Analysis

The results of the CCD analysis and analysis of variance (ANOVA) are shown in Table 3 and Table 4, respectively. The analysis for al responses were carried out using quadratic terms except for aggregation which using 2FI terms.

Table 3: Experimental results for CCD analysis

Run	Magnetic Intensity (mT)	Exposure Time (hr)	Biomass Concentration (mg/L)	Aggregation (%)	Settling Velocity (cm/s)	COD (%)
1	9.0	6.0	1221	66.60	2.89	26.4
2	9.0	6.0	1224	65.40	2.72	27.9
3	30.0	6.0	1010	49.98	2.11	65.6
4	30.0	6.0	1014	50.27	2.23	66.1
5	9.0	24.0	897	62.11	3.04	53.2
6	9.0	24.0	901	61.70	3.12	51.4
7	30.0	24.0	510	60.59	2.24	59.1
8	30.0	24.0	486	61.90	2.26	58.3
9	4.65	15.0	1326	60.30	3.29	42.2
10	4.65	15.0	1410	60.80	3.37	43.7
11	34.35	15.0	1154	61.80	2.39	70.1
12	34.35	15.0	1169	58.10	2.45	72.8
13	19.50	2.27	1001	57.63	1.82	30.1
14	19.50	2.27	944	57.34	1.71	31.4
15	19.50	27.73	760	61.90	2.96	47.9
16	19.50	27.73	810	63.20	2.01	49.1
17	19.50	15.0	2650	52.92	2.67	31.2
18	19.50	15.0	2201	60.65	2.54	30.8
19	19.50	15.0	2300	55.16	2.56	27.0
20	19.50	15.0	2998	59.40	2.34	35.6
21	19.50	15.0	2213	56.67	2.39	26.3

Table 4: *P*-values for the ANOVA analysis

Term	Biomass Concentration	Aggregation	Settling Velocity	COD
A: Magnetic Field	0.0539	0.0086	<0.0001	<0.0001
B: Exposure Time	0.0221	0.0267	0.0062	<0.0001
A²	<0.0001	-	0.0078	<0.0001
B²	<0.0001	-	0.0243	<0.0001
AB	0.5423	0.0019	0.5330	<0.0001
Lack of Fit (LOF)	0.2062	0.0126	0.4222	0.0891
R-Squared value	92.9%	83.4%	62.4%	97.8%

Biomass Concentration. The model terms show that the biomass concentration is significant. The linear terms and squares terms of magnetic field and exposure time were significant. Lack of Fit is not significant. R-squared valued for the biomass concentration is 92.9%. All the three sources above are satisfied thus, this response is valid. But, the model terms for interaction term between magnetic field and exposure time are not significant.

Aggregation. The model terms show that the aggregation is significant. Lack of Fit is significant which is not good. But, it is justified by diagnostic. The values still within the range for the graph predicted versus actual. R-squared valued for the aggregation is 83.4%. The model terms between magnetic field and exposure timeare significant.Figure 13 indicates contour graph and 3D response surface plots that generated by Design Expert® for aggregation. Based on Figure 13, high magnetic field from 14.25 to 30 mT, the aggregation starts to slightly decreased. Similar observation were obtained by the high exposure time from 6 to 15 hours, aggregation were reduced.

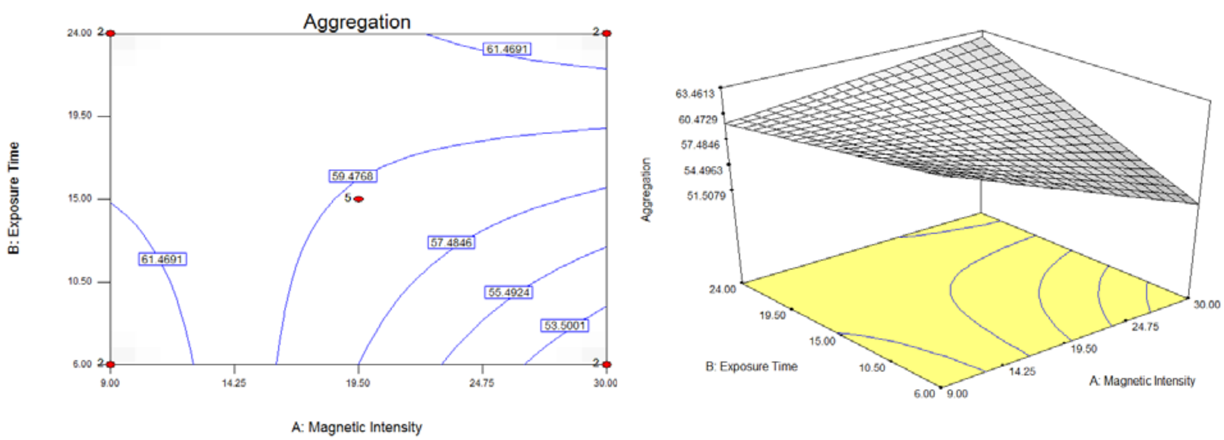

Figure 13: Contour graph and 3D response surface plots for response of aggregation

Settling Velocity. The model terms show that the settling velocity is significant. The linear terms and squares term of magnetic field and exposure time were significant. Lack of Fit is not significant. R-squared valued for the settling velocity is 62.4%. All the three sources above are satisfied thus, this response is valid. But, the model terms for interaction between magnetic field and exposure time are not significant.

Chemical Oxygen Demand (COD) Removal. The model terms show that the COD is significant. The linear terms and squares term of magnetic field and exposure time were significant. Lack of Fit is not significant. R-squared valued for the COD is 97.8%. The model terms between magnetic field and exposure time are significant. Figure 14 shows contour graph and 3D response surface plots that generated by Design Expert® for COD. Based on the Figure 14, high magnetic field from 9 to

30 mT led to the increase of COD removal. Similar observation were also obtained by high exposure time from 6 to 24 hours whereby the removal of COD was also increased.

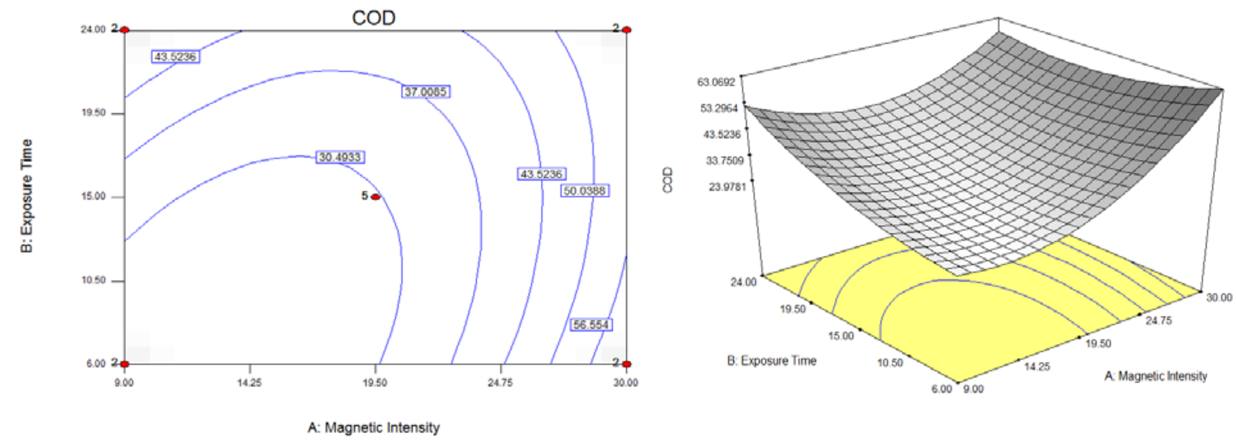

Figure 14: Contour graph and 3D response surface plots for response of COD removal

Experimental Condition Optimization

Based on the CCD analysis, all responses, the predicted optimized conditions occurred at magnetic field intensity of 30 mT and 9.7 hours of exposure time achieved the maximum of biomass concentration, aggregation, settling velocity and COD removal was 1532.9 mg/L, 53.8%, 2.23 cm/s and 54.7%, respectively

Conclusions

1. For the magnetic field, an increased in the magnetic intensity from 9 to 30 mT resulted in linear significance decrease of all responses except COD removal. Only parameter of COD removal was having the significant positive increment as the magnetic field increased throughout the range.
2. For the exposure time, prolonged hours from 6 to 24 hours resulted in linear increment of aggregation, settling velocity and COD removal. Contrary for biomass concentration, increased in exposure time led to the linear decreased of biomass concentration.
3. For the interaction terms between magnetic field and exposure time, all responses indicated significance observation except settling velocity whereby no converge between the two factors were obtained.
4. Analysis of CCD for all responses showed that all the linear terms, square terms of magnetic field and exposure time were significant. As for the interaction terms between the magnetic field and exposure time, only responses of aggregation and COD removal were observed and significant.
5. Under the optimal condition of 30mT of magnetic field and 9.7 hours of exposure time has achieved the maximum of biomass concentration, aggregation, settling velocity and COD removal was 1532.9 mg/L, 53.8%, 2.23 cm/s and 54.7%, respectively.
6. Overall, the element analysis suggested that to applymagnetic field could enhanced the physical properties of activated sludge to further improve the biodegradation of COD in POME.

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