# Effect of Magnetic Field in the Treatment of Textile Wastewater

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**Abstract.** In this study, effect of magnetic field on the activity of activated sludge in textile wastewater treatment was investigated. During the experiment, the magnetic field intensity and exposure time were changed within the ranges from 9 to 30 mT and 6 to 24 hours respectively. Activated sludge was exposed by magnetic field exhibited from NdFeB-type of permanent magnets. The exposure was aimed to improve the physical properties of the activated sludge used in treating wastewater. Hence, it was hypothesized that the magnetically exposed activated sludge is potential in enhancing the efficiency of wastewater treatment processes. The influence of magnetic field and exposure time on aggregation, settling velocity, COD and color removal were thoroughly investigated. Factorial Design and Response Surface Methodology (RSM) was applied for experimental design, analysis and optimization. Based on the results, magnetically-exposed activated sludge displayed certain trends showing that its properties were positively affected by magnetic field. At the optimum conditions of magnetic field of 19.5 mT magnetic field and 15 hrs exposure time, the maximum settling velocity and COD removal of 3.2 cm/s and 72.8%, respectively, were then obtained. However, the maximum aggregation of 85.6% was recorded at magnetic field of 19.5 mT and exposure time of 27.7 hrs. The highest color removal of 54.2% was obtained at lowest magnetic field and exposure time which were 9 mT and 6 hrs respectively.

## Introduction

Wastewater from dyeing and finishing processes, with a chemical oxygen demand (COD) concentration exceeding 1600mg/L and a strong dark color, is categorized as high strength wastewater [1]. It is a significant source of environmental pollution. The combinations of strong color and highly suspended solid content results in high turbidity of the waste effluent. Conventional method for dealing with textile wastewater consists of various combinations of biological, chemical and physical methods [2]. However, due to large variability of the composition of textile wastewaters, most of these traditional methods are becoming inadequate. Furthermore, treatment cost of textile wastewater effluents has been escalating rapidly, thus a search for more cost effective treatment is needed in order to overcome this problem [3].

Magnetic technology is a method for the magnetization of matters by the magnetic field. It is widely used for wastewater treatment and the effects of magnetic technology on activated sludge process have been studied by some authors [4,5]. These studied mainly focused on two aspects which are the effects of magnetic field on microbes and the effects of magnetic field on pollutants degradation [6,7]. Ji *et al*. [4] proved that magnetic field induction of 20 mT had a positive effect on bacterial growth in activated sludge. Rao *et al*. [5] reported that the influence of magnetic field enhanced the growth ratio of microbes while Jung *et al.* [6] showed that a magnetic field 450 mT increased the efficiency of phenol biodegradation by 30% compared with the control sample.

The aim of this study it to investigate the influence of magnetic field and exposure time on physical properties in terms of aggregation and settling velocity also removal performance of COD and color. The factorial design and central composite design (CCD) approaches were employed to quantitatively analyzed the effects of those factors, the interactions between them and to indicate any correlation between the factors and responses. This study is focused on the experimental works that has been done in Environmental Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM).

**Literature Review**

Throughout the years, several physical and chemical treatment processes have been used by numerous researches to remediate textile wastewater such as electro-coagulation, Fenton method and magnetic treatment. Increasing attention has been paid to reveal the theory and improve wastewater treatment by this external field. Magnetism is a unique physical property that independently facilitates applications such as water purification by affecting the physical properties of contaminants in water. In combination with other processes, it can improve the efficiency of purification technology [8]. Until recent, magnetic field has been implemented for several common wastewater treatment processes. For instance, magnetic field were applied for the removal of heavy metals [9], turbidity and suspended solids [10], organic compounds [4,7], nutrients consisting of nitrogen and phosphorus compound [11] and toxic chemical [6]. Generally, most of the treatment processes indicate improvement in their performances under specific magnetic conditions.

As stated by Tomska and Wolny [12], activity of the activated sludge was proven to be improved, thus enhanced as well the pollutant treatments in the wastewater under the appropriate magnetic field intensity. Usually, high strength in magnetic field intensity exhibited negative impact to the activated sludge. Studies by Ji *et al*. [4] and Yavuz & Çelebi [13] showed the same conclusion that the removal efficiency of organic matter was initially increased by strengthening the magnetic field intensity. Weak static magnetic field of 7 mT was also reported to significantly influence the formaldehyde (FA) biodegradation in synthetic wastewater. Decrease in FA concentration and COD were greater, by 30% and 26% respectively [7]. A mixed effect of the magnetic field on biodegradation of organic pollutants indicates that different bacteria which responsible in degradation process may have their unique level of magnetic susceptibility. These bacteria may act differently, either being inhibited or enhance, therefore similarly reflected to the wastewater treatment performance.

**Material and Methods**

***Acclimatization of Activated Sludge***

Activated sludge, which was collected from the aeration unit of wastewater treatment (Indah Water Konsortium Sdn. Bhd) located in Taman Impian Emas, Johor was used in this study. For adaptation of the bacteria of activated sludge to the textile medium, activated sludge samples were acclimated in the medium whose composition was described in Table 1. Acclimatization was performed in glass flask with superficial air velocity (SAV) of 1.2 cm/s supplied for 24 hours.

Table 1: Medium composition for acclimatization stage

| **Day** | **Percentage (%)** | |
|---|---|---|
| | **Municipal Wastewater** | **Textile Wastewater** |
| 1 | 70 | 30 |
| 2 | 50 | 50 |
| 3 | 30 | 70 |
| 4 | 0 | 100 |

***Reactor Set-up***

The schematic representation of the reactor set-up is given in Figure 1. The Scott bottle for a working volume of 500 mL was used. Air was supplied by stone diffuser which connected to aquarium pump. The stone diffuser was located at the bottom of Schott bottle. Permanent magnet of sizes 50 x 50 mm was used in this experiment. The magnets (NdFeB-N24) manufactured by Ningbo Newland International Trade Co., Ltd, China were arranged at both side surfaces of the Scott bottle.

***Analytical Methods***

The experiment was investigated for physical characteristics and removal performances. The physical characteristic was analyzed in terms of aggregation and settling velocity. The removal performance analyzed includes the COD and color removal. All tests were conducted based on the Standard Methods for the Examination of Water and Wastewater - settling velocity with method 2710E. As for aggregation, the parameter was measured in terms of turbidity. A spectrophotometer (DR6000 HACH) was used for measuring COD. The color intensity was analyzed by calorimetric approach using a HACH spectrophotometer (DR/6000U) according to Procedure No. 1660.

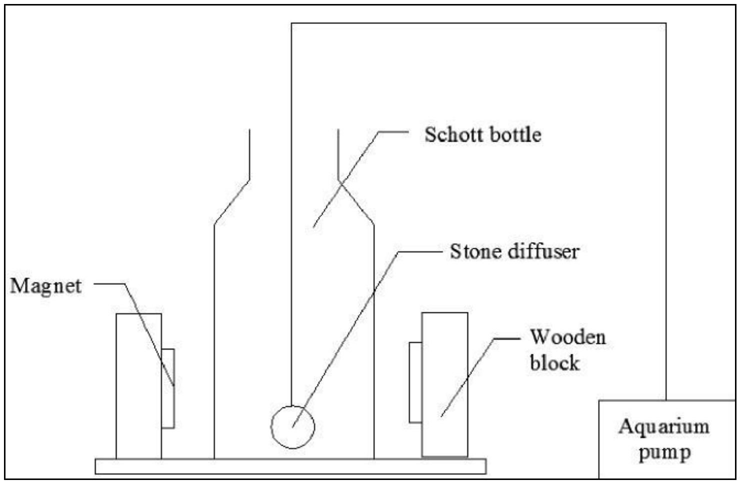

Figure 1: Schematic Layout of Experimental Set-up

***Experimental Procedure***

A volume of 50 mL activated sludge and 200 mL of raw textile wastewater were added into the 500 mL Schott bottle making the total volume of 250 mL with a total sludge concentration of 2000 mg/L. The raw textile wastewater samples were collected once a week from a textile wastewater plant (Ramatex Industry Sdn. Bhd) which is located at Sri Gading Industrial Park, Batu Pahat, Johor. The mixture of activated sludge was exposed to magnetic field ranges from 9 to 30 mT within exposure time of 6 to 24 hours. Throughout the experiments, the mixture was mixed under specific mixing intensity (1.2 cm/s of SAV). After the completion of each experiment, the mixture was allowed to idle for 10 minutes before the sample was collected for the measurement of aggregation, settling velocity, COD and color removal.

**Results and Discussions**

***Physical Characteristics of Activated Sludge***

*Factorial Design Analysis of Coaggregation and Settling Velocity*. Table 2 shows the factorial design results that are presented in the form of analysis of variance (ANOVA) which gives a summary of the significance of the main and interaction effects by observation on the *P*-value. In this factorial design, all the figures shown were generated by MINITAB™.

Table 2: *P*-values of the estimated main and interaction effects (significant at α = 0.05)

| Effect | Aggregation | Significant | Settling Velocity | Significant |
|---|---|---|---|---|
| *Main* | | | | |
| Magnetic Field | 0.200 | No | 0.019 | Yes |
| Exposure Time | 0.005 | Yes | 0.008 | Yes |
| *2-way interaction* | | | | |
| Magnetic Field x Exposure Time | 0.691 | No | 0.081 | Yes |

It was observed that the increase in exposure time caused an increase in aggregation. The exposure time variables gave a +12.3 of estimated main effect onto the aggregation process. As stated by Liu *et al*. [14], the microbial aggregation process is faster at higher specific growth rates of microorganisms. Increase in the cell growth rate will lead to increase in cell biomass and the percentage of collision between the cells resulting in increase in the probability of cell aggregation. However, the interaction effect was observed to be not significant between magnetic field intensity and exposure time

The Pareto chart that shows the effects of magnetic field and exposure time on settling velocity of the experimental runs are given in Figure 2. The settling velocity increased as the magnetic field intensity was increased from 9 mT to 30 mT. Figure 3(a) show the main effect of magnetic field and exposure time for the experiment. The positive value of the estimated effect (+1.23) means that as the exposure time increased, the settling velocity of the activated sludge will also increase. Higher exposure time may help the growth of microbial population in flocculated form since the activated sludge needed sufficient air supply to develop a flocculent mass that settles rapidly.

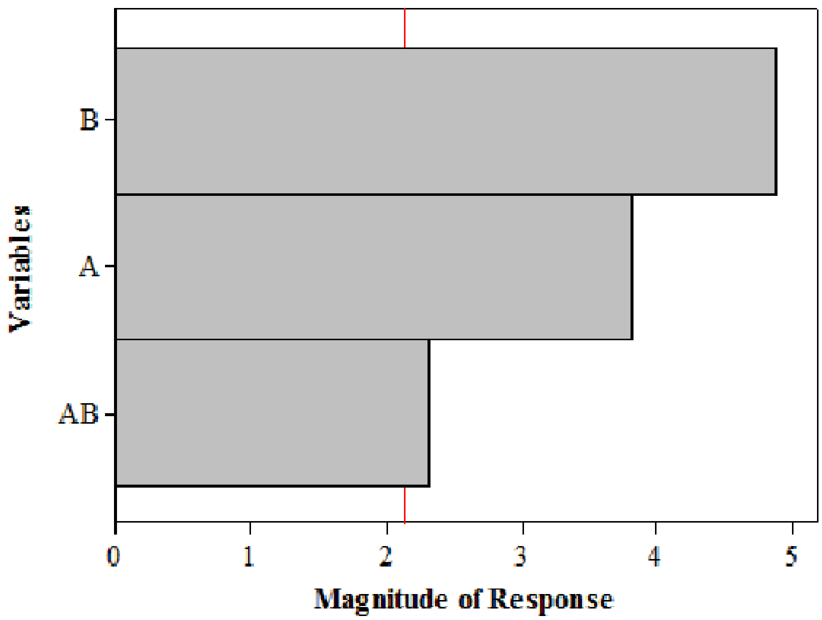


Figure 2: The Pareto chart of settling velocity (A: Magnetic Field; B: Exposure Time; α: 0.1)

The magnetic field intensity and exposure time show a significant interaction effect for settling velocity where the *P*-value is 0.081. At low magnetic field intensity, increase in exposure time resulted in increase in the settling velocity of the activated sludge by 77%. The rapid increase in settling velocity might occur with the help of magnetic field exposure that improve the ability of the destabilized particles to collide between each other to form larger particles. Due to the same reason, increase in exposure time from 6 hours to 24 hours has also caused a slight increase (37%) in the percentage of settling velocity at high magnetic field intensity. The interaction effect of the experiment is given in Figure 3(b).

*Response Surface Analysis on Aggregation and Settling Velocity of Activated Sludge*. The results of analysis of variance (ANOVA) for the two responses are summarized in Table 3. There were statistically analyzed using full quadratic terms which include linear, square and interactional terms with the aid of Design Expert® (version 7.1.6). For the response of aggregation, *P*-values (0.0529) of the model terms that been listed in Table 3 indicates that the model was insignificant.

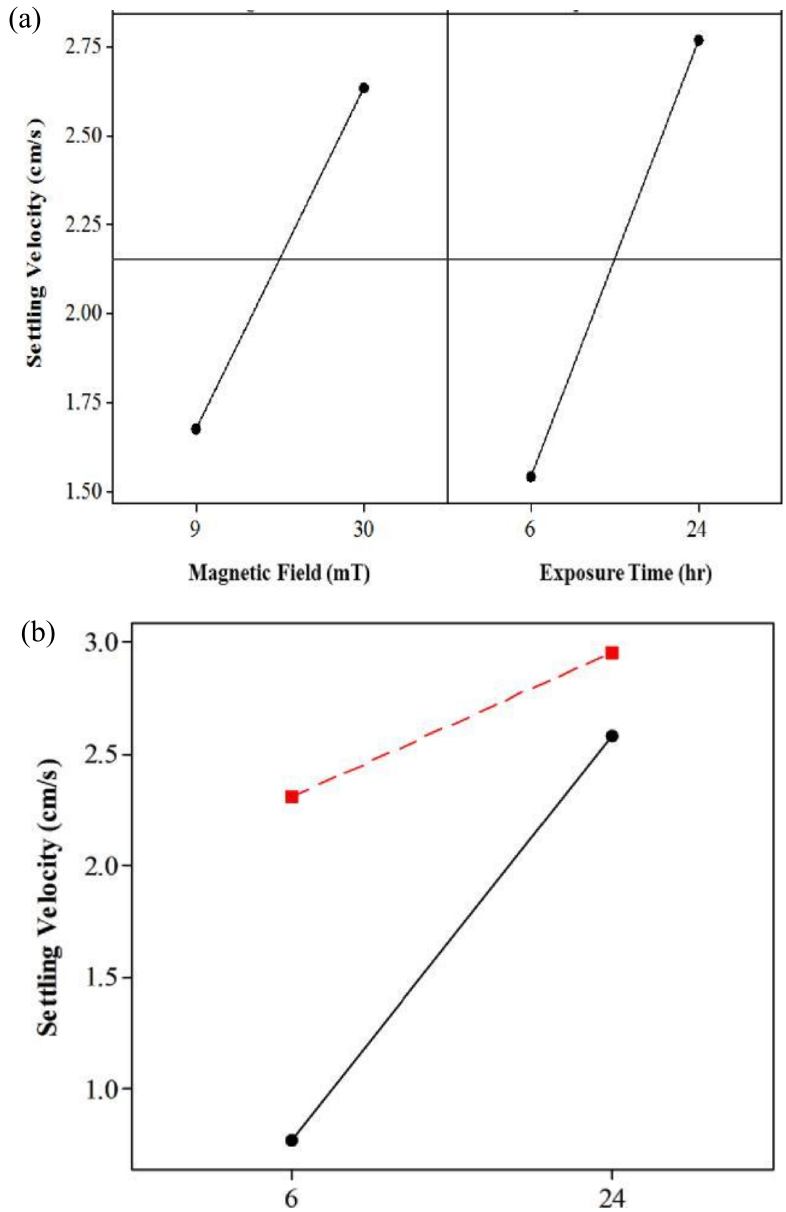


Figure 3: (a) Main effect plot of magnetic field and exposure time on settling velocity; (b) Interaction plot for the settling velocity

Table 3: *P*-values of response surface modeling analysis for aggregation and settling velocity of activated sludge

| **Term** | ***P*-values** | |
|---|---|---|
| | **Aggregation** | **Settling Velocity** |
| A: Magnetic field | 0.3911 | 0.1019 |
| B: Exposure time | 0.0562 | 0.0008 |
| $A^2$ | 0.9013 | 0.8181 |
| $B^2$ | 0.5787 | 0.0152 |
| AB | - | 0.1843 |
| R-squared | 44.45% | 87.29% |

Statistical model as shown in Eq. (1) was developed to relate the magnetic field and exposure time to settling velocity.

$$\text{Settling Velocity} = + 2.75 + 0.22 \times A + 0.67 \times B - 0.25 \times AB -.0.030 \times A^2 - 0.40 \times B^2 \quad (1)$$

The response surface and contour plots based on the significant model are given in Figure 4. With respect to the effect of exposure time, at low magnetic field, increase in the exposure time has caused an increase in the settling velocity by 70%. The maximum settling velocity was 3.2 cm/s which seem to occur at the intermediate value of the low and high range of the magnetic field and exposure time. This trend could be reasoned due to the fact that greater intensity of magnetic field could be harmful to the microorganisms in the activated sludge, thus cause them to exhibit adverse effect in the settling process [13,15].

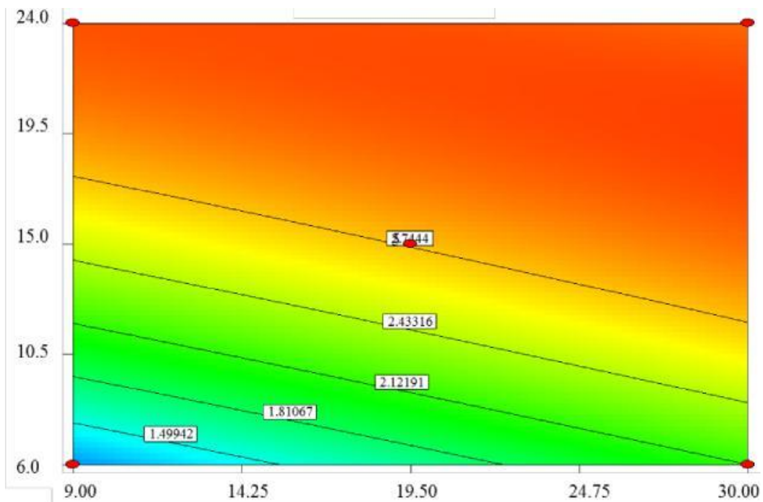


Figure 4: Contour plot representing the relationship between magnetic field and exposure time on settling velocity

***Removal Performance of Activated Sludge***

*Factorial Design Analysis of COD and Color Removal*. The summary table of the ANOVA that shows the main and two way interaction effects for COD and color removal are given in Table 4. The analyses show that at 90% confidence level (*P*-value less than 0.1), magnetic field and exposure time have significant main effect on COD removal. However, no interactive effect was found on COD removal. Figure 5 shows the Pareto chart generated by MINITAB$^{TM}$ for COD removal. The precise mechanism for COD removal by magnetization was still obscure [17]. Based on theories of energy changes in mass reaction as well as the kinetics of magnetic field [1821], the magnetizing mechanism for COD removal may be interpreted as: The organic molecules in wastewater would absorb the energy when the wastewater flowed through the magnetic field. Some energy enhance molecules were the induced to an excited state, which was unstable relative to the ground state, this increased the rate of chemical reactions for the degradation of organic substance in the magnetizing process [16].

When the exposure time increase, the percentage of COD removal decrease with the estimated effect of -4.55. The negative effect of substrate removal can be due to several reasons. As the exposure time increase, the biological activities of activated sludge might be affected and slowed down the growth rates of bacteria that contribute to COD removal. In other study, Iwasaka *et al.* [22] observed that the rate of yeast proliferation decreased after 16h of incubation under a high magnetic field compared to the control group. Figure 6 shows the main effect of magnetic field and exposure time.

Table 4: *P*-values of the estimated main and interaction effects of magnetic field and exposure time for the percentage of COD and color removal

| Effect | COD | Significant[a] | Color | Significant[a] |
|---|---|---|---|---|
| *Main* | | | | |
| Magnetic Field | 0.013 | Yes | 0.161 | No |
| Exposure Time | 0.007 | Yes | 0.004 | Yes |
| *2-way interaction* | | | | |
| Magnetic Field x Exposure Time | 0.427 | No | 0.105 | No |

[a]significant at $\alpha = 0.05$

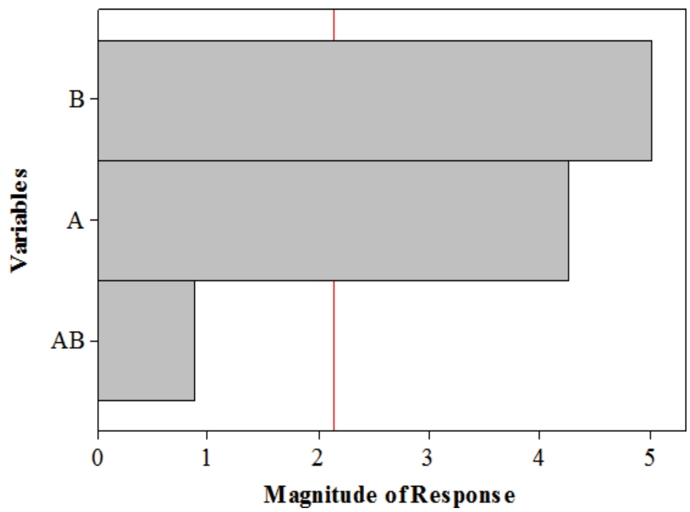


Figure 5: The Pareto chart of COD removal (A: Magnetic Field; B: Exposure Time; α: 0.1)

The same trend can be seen for color removal. The *P*-value for the effect of exposure time on color removal is less than 0.004 and show negative magnitude with an estimated effect of -14.25. It shows that the addition of exposure time has caused a reduction in the percentage of color removal. Increase in exposure time within the range of this experimental condition would reduce the microbial activities which include metabolisms and mobility of the microorganisms and lead to poor color removal.

*Response Surface Analysis on COD and Color Removal*. The results of analysis of variance (ANOVA) for the two responses are summarized in Table 5. There were statistically analyzed using full quadratic terms which include linear, square and interactional terms with the aid of Design Expert® (version 7.1.6).

Table 5: *P*-values of response surface modeling analysis for COD and color removal

| Term | *P*-values | |
|---|---|---|
| | COD | Color Removal |
| A: Magnetic field | 0.6460 | 0.9070 |
| B: Exposure time | 0.1121 | 0.0049 |
| $A^2$ | 0.1428 | 0.0162 |
| $B^2$ | 0.0028 | 0.2182 |
| AB | 0.9079 | 0.6506 |
| R-squared | 78.1% | 80.9% |

(a)

(b)

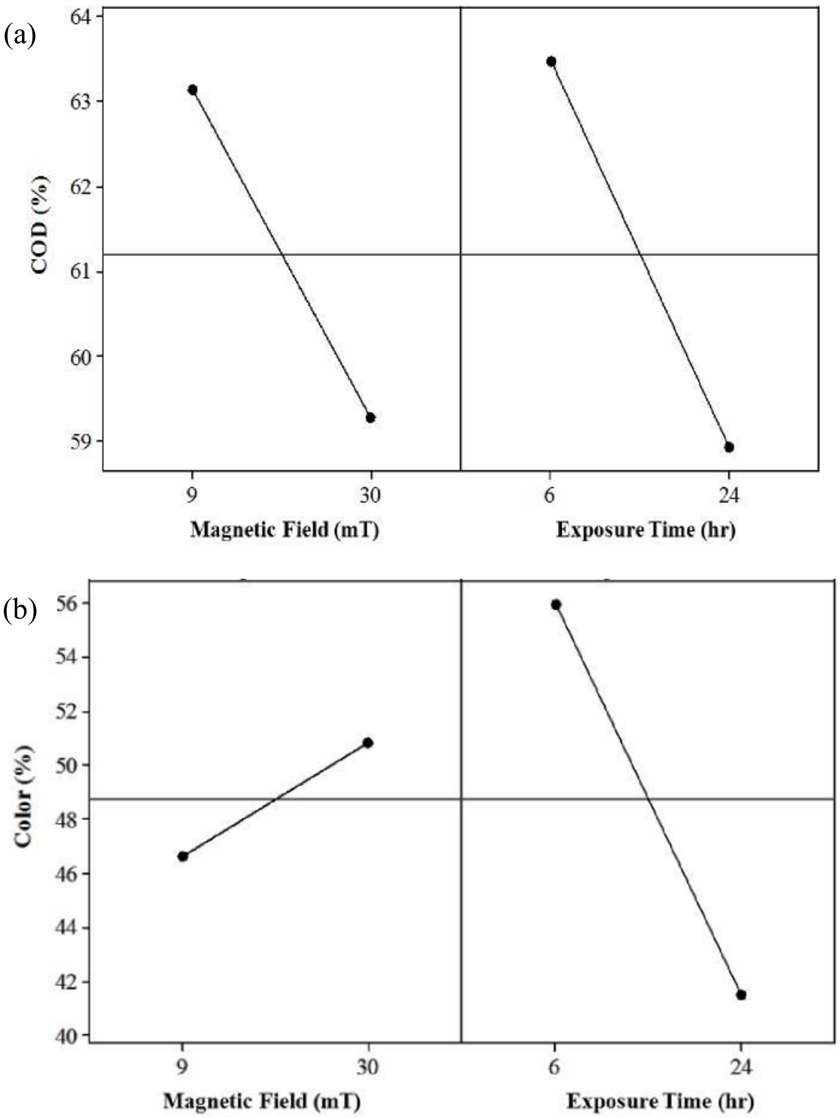


Figure 6: (a) Main effect plot of magnetic field and exposure time on COD removal (b) Main effect plot of magnetic field and exposure time on color removal

The best statistical model for the COD removal based on the experimental condition in this study is given in Eq. (2).

$$\text{COD removal} = + 69.22 - 0.92 \times A - 3.48 \times B - 0.32 \times AB - 3.39 \times A^2 - 9.24 \times B^2 \quad (2)$$

As shown in Table 3, the only interaction was between magnetic field and exposure time. Although the interaction between those variables is insignificant (*P*-value of 0.9079), but their only existence as the only interaction model term on the COD removal makes it allowable to be further discussed. Figure 7 illustrate the relationship between the magnetic field and exposure time. In the figure, the concave shape of the surface plot explained that the maximum COD removal was achieved between the low and high range of the variables. The highest percentage removal of COD was observed at magnetic field and exposure time of 19.5 mT, and 15.0 hour, respectively with 72.8%. The figure suggested that as the magnetic field increases, the percentage of COD removal decrease. With respect to the effect of exposure time at low magnetic field, increase in exposure time has caused a reduction in the COD removal from 64.7% to 59.7%. At high magnetic field, increase in the exposure time also caused a slight reduction in the COD removal by 6%.

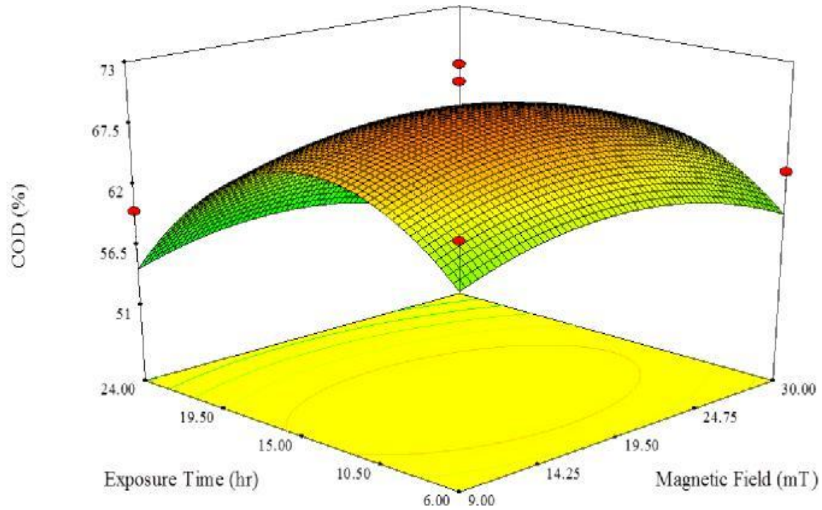


Figure 7: Three-dimensional response surface plot of the magnetic field and biomass concentration on COD removal

Statistical model as shown in Eq. (3) was also developed to relate the magnetic field and exposure time to color removal. With regard to the effect of exposure time, the variable shows a significant effect for color removal of the experimental condition for quadratic term. The R-squared values for the model was in the acceptable ranges (74 - 86%).

$$\text{Color (\%)} = +37.1 + 0.28 \times A - 9.21 \times B + 7.69 \times A^2 - 3.31 \times B^2 \quad (3)$$

The predicted versus actual plot for the color removal are shown in Figure 8. The observed points of the plots reveal that the actual values can be considered distributed relatively near to the straight line for the color removal. The predicted and actual values obtained from this experiment are considered to be fit.

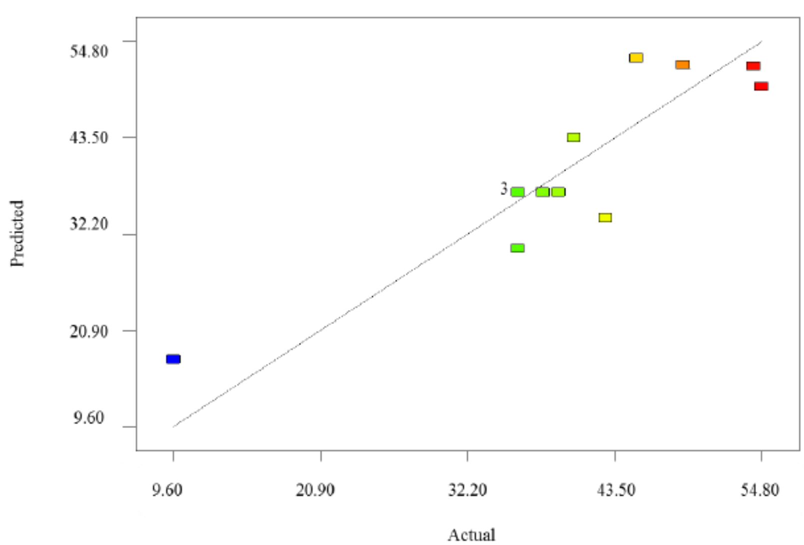


Figure 8: Predicted versus actual data for color removal

Based on Table 2, only linear terms of exposure time is significant. Figure 9 particularly illustrate the relationship between the interactional terms on the color removal of activated sludge. The maximum percentage of color removal was 54.2% that occur when magnetic field intensity and exposure time were at 9.0 mT and 6 hours respectively. At low magnetic field intensity, increase in the exposure time has cause reduction on the color removal. At the lowest exposure time (6 hr), the percentage of color removal was about 54.2%. The percentage of color removal slightly decreased to 48.8% when the exposure time was 15 hr before reducing again to 36.1% when the exposure time increase to the highest value (24 hr). The highest percentage of color removal was 54.8% that occurred at magnetic field and exposure time of 9 mT and 6.0 hr, respectively.

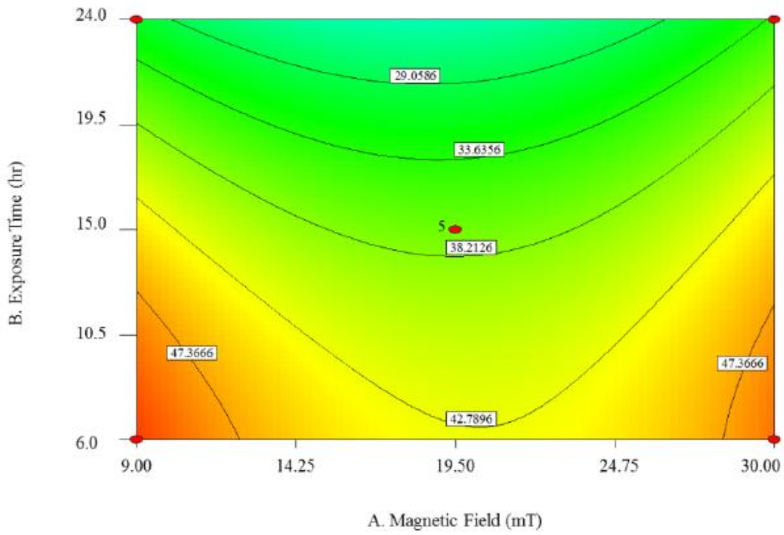


Figure 9: Contour plot representing the relationship between magnetic field and exposure time on color removal

## Conclusions

Overall, the element analysis suggested that the applied magnetic field could enhance the settling property of the activated sludge through the improvement on its aggregation capability. These indicate that the magnetic field is reliable for accelerating sludge settleability. The same results were obtained for COD and color removal, where magnetically-exposed activated sludge displayed certain trends showing that its properties were positively affected by magnetic field, thus potential to enhance the performance efficiency of the wastewater treatment systems.

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