

Advanced Materials Research QiR 15

The 15th International Conference on
Quality in Research (15th QiR 2017)

Edited by
Ardiyansyah Yatim



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Selected, peer reviewed paper from the
15th International Conference on
Quality in Research (QiR) 2017,
July 24-27, 2017, Bali, Indonesia

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Ardiyansyah Yatim

■ **Scientific.Net**

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Trans Tech Publications Ltd
Reinhardstrasse 18
8008 Zurich
Switzerland
<http://www.scientific.net>

Volume 929 of
Materials Science Forum
ISSN print 0255-5476
ISSN cd 1662-9760
ISSN web 1662-9752

Full text available online at <http://www.scientific.net>

Distributed worldwide by

Trans Tech Publications Ltd
Reinhardstrasse 18
8008 Zurich
Switzerland

Phone: +41 (44) 922 10 22
Fax: +41 (44) 922 10 33
e-mail: sales@scientific.net

Preface

On behalf of the organizing committee, it was a great pleasure for us to welcome you to the 15th International Conference on Quality in Research (QiR) 2017 to be held in Bali, Indonesia on July, 24–27, 2017. This biennial event was co-organized with the Faculty of Engineering Universitas Udayana and Politeknik Negeri Bali.

The main theme for the year conference is “Science, Technology and Innovation for Sustainable World”. Under this theme the conference focused on the innovative research and contribution in science and technology toward achieving sustainable world. In line with this theme, it is our utmost pleasure to present you with research papers in material-related field which were presented at QiR 2017 in the International Symposium on Materials, Metallurgy, and Chemical Engineering.

The QiR 2017 brought together national and international academicians, researchers, executives, government, industrial and business officials, practitioners and leaders to present and discuss a vast range of engineering, architectural designs and community development based on green and smart technology. QiR had been growing, since its first event two decades ago, into our flagship academic event with international reputation. This year, we received almost 1000 submissions from more than 26 countries. Along with our events in conjunction, more than 500 oral and poster presentations were scheduled with more than 700 participants gather in the event.

On behalf of QiR 2017 committee, we would like to thank all of our speakers, participants, contributors, partners and professional associations for their generous contributions. We also would like to acknowledge the support from our International Advisory Board members and distinguished reviewers. Last but not least, a special thanks to our local co-organizer, Universitas Udayana and Politeknik Negeri Bali.

We wish all of you a productive and rewarding conference, also a pleasant and memorable stay in Nusa Dua, Bali, Indonesia.

Thank you and we hope to see you in QiR 2019.

Ardiyansyah, PhD.
General Chair of QiR 2017 Organizing Committee

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Editors: **Ardiyansyah Yatim**

DOI: <https://doi.org/10.4028/b-8tb3dY>

THEMA: **TGM**

BISAC: **TEC021000**

Keywords: [Alloys](#), [Biotechnology](#), [Chemical Engineering](#), [Composites](#), [Materials Processing](#), [Metallurgy](#), [Metals](#), [Nanomaterials](#), [Polymers](#)

Details: **Selected, peer reviewed paper from the 15th International Conference on Quality in Research (QiR) 2017, July 24-27, 2017, Bali, Indonesia**

Pages: **266**

Year: **2018**

ISBN-13 (softcover): **9783035712667**

ISBN-13 (CD): **9783035722666**

ISBN-13 (eBook): **9783035732665**

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The Effects of Dielectric Fluid Viscosity on Chips Formation Rate and Electrode Wear Rate in Electrical Discharge Machining of SKD 61 Steel

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Keywords: EDM; Jatropha Curcas; Metal Removal; Tool Wear; Viscosity.

Abstract. Electrical Discharge Machining (EDM) is a machine for cutting workpieces with thermal energy derived from electrical spark from tool (cathode) to workpiece (anode). As EDM process requires a dielectric fluid in the cutting operation, the characteristics of the dielectric fluid play an essential role for obtaining excellent cutting. Jatropha curcas has been demonstrated for use as a dielectric fluid in EDM process. However, the drawback is that the Rate of Metal Removal (RMR) is lower than that of generally-used dielectric fluid in industry. We consider that the cause is a much higher viscosity of the jatropha curcas. This study was conducted to investigate the characteristics of a new dielectric fluid mixture of jatropha curcas and kerosene. Kerosene was used in the mixture to reduce the viscosity of the jatropha curcas since the kerosene has a much lower viscosity. The measurement of the viscosity of the fluid mixture was performed using an Ostwald viscosimeter. Evidently, when the jatropha curcas mixed with the kerosene the viscosity of the mixture is lower than that of the pure jatropha curcas. The effects of the viscosity of the fluid mixture were investigated by measuring the RMR and Tool Wear Rate (TWR). The RMR and TWR were determined by calculating the difference in the weight of the workpiece and the tool, respectively, before and after the cutting for a certain cutting interval. The measurements were carried out for eleven different concentration of the fluid mixture by varying the current of 15 and 21 Amp, with replication of 3 times. As the result, the energy released during the cutting process affects the values of TWR and RMR. It was also found that in contrast to the effect on TWR, the RMR was not influenced by the viscosity of the mixture.

Introduction

Jatropha curcas, as an esterification product, can be used as dielectric fluid because its breakdown voltage is higher than kerosene [1, 2]. However, its RMR is still low [3]. One of the probable culprit for this is the high viscosity of jatropha curcas. This condition will complicate the disposal of chips formed during the cutting process, which in turn the cutting process will be disrupted due to the short circuit. To overcome the problem, the tool should perform a pumping motion in the gap between the workpiece and the tool so that the non-productive time increases. Since the kerosene has higher fluidity, the jatropha curcas was mixed with kerosene (EDM-85) so that the mixture of has higher fluidity than that of pure jatropha curcas. The purpose of this study is to investigate the effects of the viscosity of the dielectric fluid mixture on Rate of Metal Removal (RMR) and Tool Wear Rate (TWR).

Methodology

The outline of the study is shown in the flow diagram in Figure 1. In this study, the EDM process mainly consists of a SKM ZNC SERIES T50 EDM machine, 10 mm diameter copper rod electrodes, and SKD 61 steel as the workpiece. Current used for the process were 15 and 21 Amp with pulse-on time and pulse off-time of 20 μ s each. Flushing was employed by an injection type.

The amount of chips formed and the wear of the electrode were determined by weighing the workpiece and electrode, respectively, before and after the cutting test, as well as recording the actual machining time. The dielectric fluid used was a mixture of jatropha curcas with kerosene (EDM-85). The chosen concentrations of jatropha curcas were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100%. Measurements of the viscosity were performed by using Ostwald viscosimeter. The data obtained from the measurement were the fall time. The fall time was affected by the viscosity of the tested fluid. High dilution will allow the fluid to flow, or *fall*, leaving the ball-shaped test glass. Jatropha curcas has a viscosity of 29.57 cSt [1], which is higher than the viscosity of kerosene (2.12 cSt). Therefore, the mixing of both fluids will produce a certain viscosity.

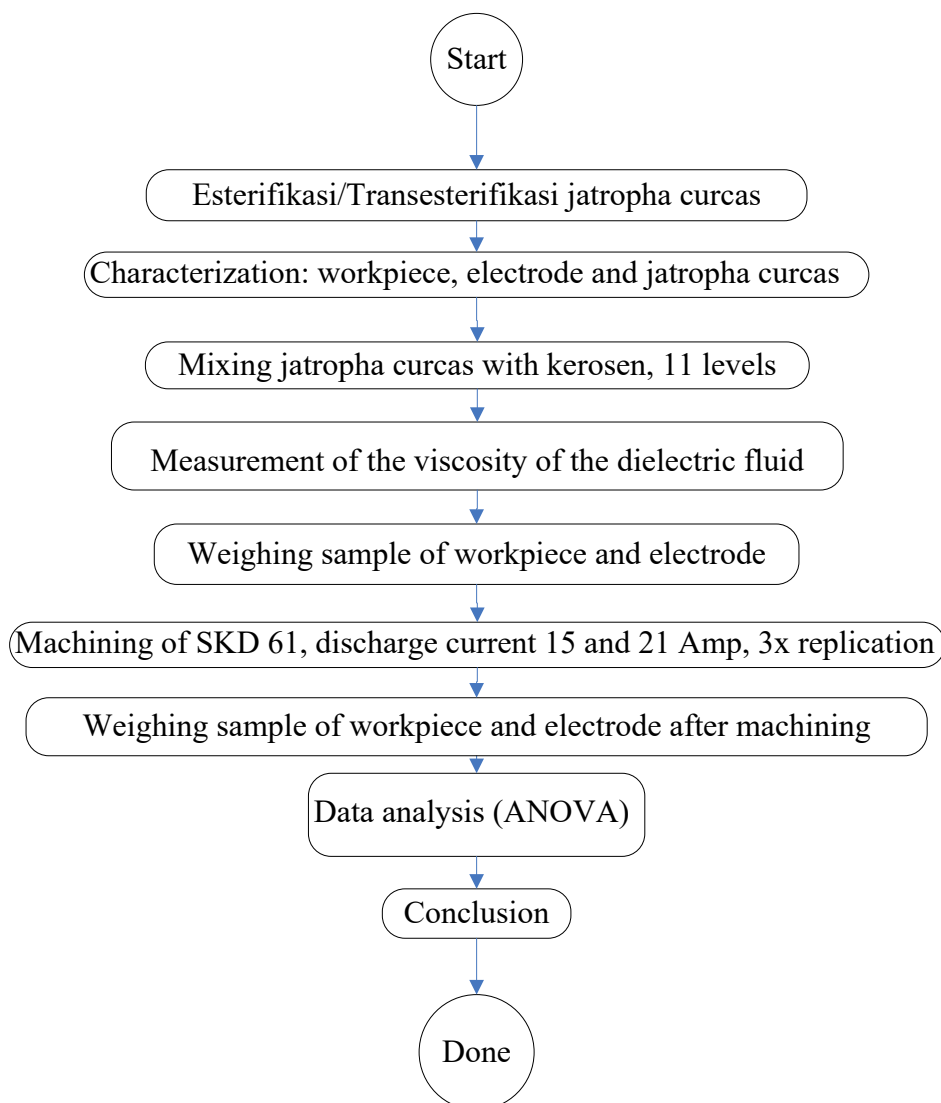


Figure 1. Flowchart of research work.

Workpiece in the form of rod steel with the diameter of 30 mm were cut into 66 samples with a thickness of 5 mm by using a flat grinding machine. For pairing the 66 samples of the workpiece, the 66 electrodes were cut from copper rods with the diameter of 10 mm and length of 15 mm.

Results and Discussion

Viscosity of Dielectric Fluid. One role of the dielectric fluid flow is to flush the debris away from the gap between the electrodes and the workpiece. From the fall time data, the viscosity of the dielectric mixture can be calculated by using Eq. (1)[5]. The calculation results are shown in Table 1. As shown in the table, when the concentration of jatropha curcas increases, the viscosity of the dielectric fluid also increases.

$$\eta_2 = \eta_1 \cdot \rho_2 / \rho_1 \cdot t_2 / t_1$$

(1)

where,

η : Viscosity [cPs]

t : Time [s]

ρ : Density [g/cm³]

Table 1. Viscosity of eleven dielectric fluid mixture measured with Ostwald viscosimeter.

Sample ID	Composition [%]		Time [s]	η [cPs]
	Jatropha curcas	Kerosene		
1	10	90	1.97	1.88
2	20	80	2.06	1.97
3	30	70	2.31	2.20
4	40	60	2.44	2.33
5	50	50	3.19	3.04
6	60	40	3.66	3.49
7	70	30	4.03	3.84
8	80	20	4.80	4.58
9	90	10	5.50	5.25
10	100	-	6.85	6.53
11	-	100	1.38	1.32

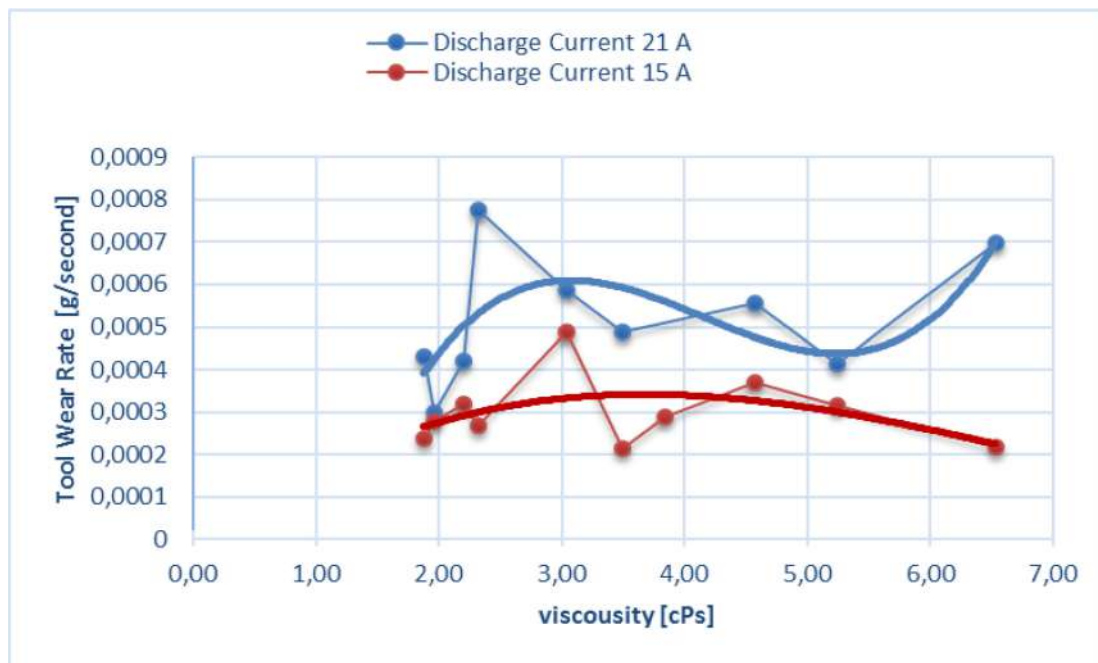


Figure 2. The plots of Tool Wear Rate (TWR) against the viscosity of the dielectric fluid mixture for the current of 15 dan 21 Amp.

Effect of Viscosity on TWR. Figure 2 shows the plots of TWR against viscosity for the current of 15 and 21 A. As shown in the figure, the TWR is higher for higher current. The trend for the TWR from the viscosity of 1.88 to 3.04 cPs (or concentration from 10 to 50%) on both current is equally increasing and then decreasing after the viscosity of 3.04 cPs. However, for 21 Amp current, the TWR increases beyond 80% concentration.

With ANOVA method, the calculation and the interpretation are shown as follows,
ANOVA: Tool Wear Rate (TWR) versus Concentration JC-EDM; Current

Factor	Type	Levels	Values
Concentration JC:EDM	fixed	11	0; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100
Current	fixed	2	15; 21

Table 2. Analysis of Variance for TWR, using Adjusted SS for Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Concentration JC-EDM	10	0.0000061	0.0000061	0.0000006	3.32	0.003
Current	1	0.0000026	0.0000026	0.0000026	13.91	0.001
Concentration JC-EDM*Current	10	0.0000062	0.0000062	0.0000006	3.35	0.003
Error	44	0.0000081	0.0000081	0.0000002		
Total	65	0.0000229				
S = 0.000429058 R-Sq = 64.69% R-Sq(adj) = 47.83%						

Interpretation of the Output for the Factorial Design:

The output shows a description of the factors that there are 11 levels for the concentration factor of JC-EDM and 2 levels for the current factor. The level for the factor of JC-EDM concentration is 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and the level for the current factor is 15 and 21 Amp. As shown in Table 2, there are 2 factors and 1 interaction, so there are 3 hypotheses that must be formulated that is hypothesis test to determine: (i) the influence of JC-EDM concentration, (ii) the influence of the current, and (iii) the influence of interaction between JC-EDM concentration and the current.

Test for the hypothesis on the effect of concentration of JC-EDM on TWR.

Hypothesis

$H_0: \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11}$ (Concentration of JC-EDM does not affect the value of TWR)

H_1 : At least there is one pair of $\alpha_i \neq \alpha_j$ where $i \neq j$ (Concentration of JC-EDM affects the value of TWR)

From the output, the statistical test F results in the concentration of JC-EDM is 3.32 and p-value is 0.003. Therefore, the decision is to reject H_0 , i.e. JC-EDM concentration affects the value of TWR because p-value = 0.003 < $\alpha = 0.05$.

Test for the hypothesis on the effect of current on TWR.

Hypothesis

$H_0: \beta_1 = \beta_2$ (current does not affect the value of TWR).

$H_1: \beta_1 \neq \beta_2$ (current affects the value of TWR)

From the output, statistical test F for current is 13.91 with p-value = 0.001 < $\alpha = 0.05$. Therefore, the decision is to reject the initial hypothesis stating that current does not affect the value of TWR. So, the conclusion is that the current factor has a significant influence on the value of TWR.

Test for the hypothesis on the effect of interaction between factors on TWR.

Hypothesis

$H_0: (\alpha\beta)_{ij} = 0$ (Interaction between factors does not affect on the value of TWR).

$H_1: (\alpha\beta)_{ij} \neq 0$ (Interaction between factors affects on the value of TWR).

From the output, the statistical test F = 3.35 with p-value = 0.003 < $\alpha = 0.05$. The decision is to reject H_0 that the interaction between factors affects the value of TWR. Figure 3 shows the plot of the Main Factor which shows that 70% concentration of JC-EDM and 21 Amp current significantly influence the value of TWR.

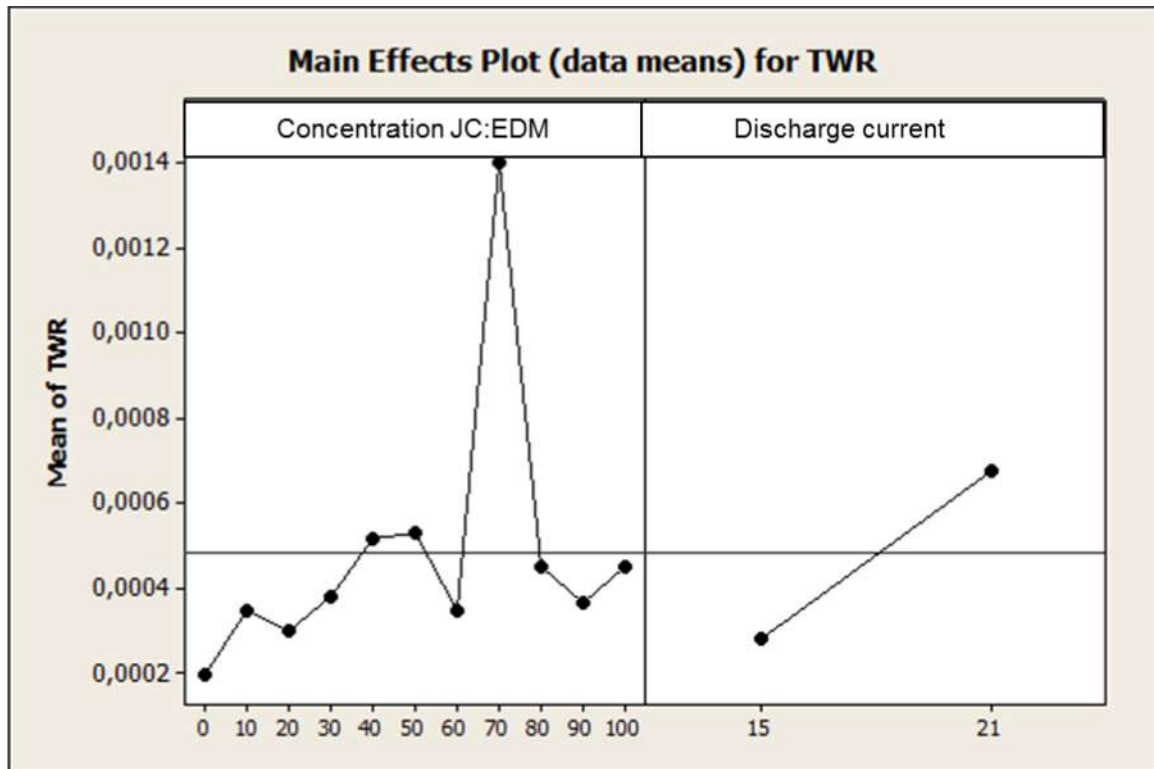


Figure 3. The plot of Main Factor.

Effect of Viscosity on RMR. Figure 4 shows the effect of the viscosity of the dielectric fluid on RMR. Previous studies [1, 3, 4] have also shown that the dominant factor on RMR is the current. The higher the current, the higher the RMR. This is because of the higher energy released for the melting of the material. As seen in Figure 4, for 20 Amp current the RMR increases until levelling off at 60% concentration. One interesting find is that for all concentrations the RMR is higher than that of EDM-85. On the contrary, for 15 Amp current, the RMR decreases with concentration. However, the RMR is higher than that of the treatment with pure kerosene for concentration up to 50%. Different characteristics for RMR change for both currents may be due to the spreading of energy to move the metal atoms contained in *jatropha curcas* becomes more evenly when the energy is increased.

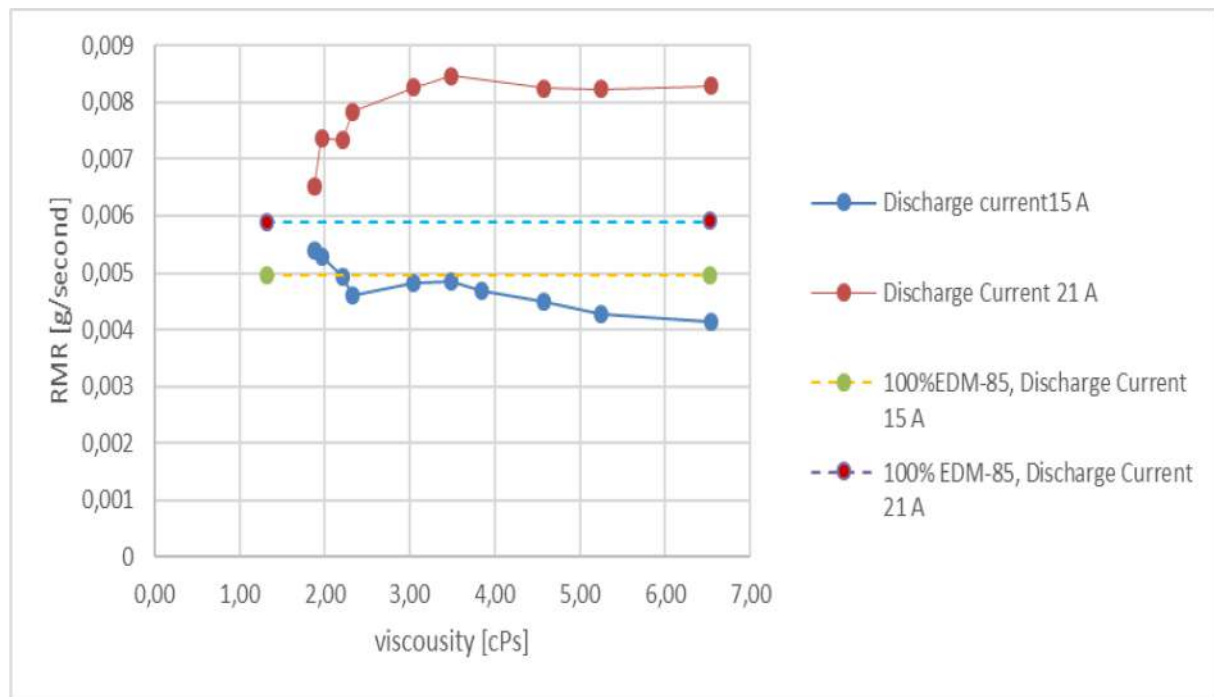


Figure 4. The plots of Rate of Metal Removal (RMR) against the viscosity of the dielectric fluid mixture for the current of 15 dan 21 Amp.

For statistical analysis, with ANOVA method, the calculation and interpretation are as follows,

Factor	Type	Levels	Values
Concentration JC-EDM	fixed	11	0; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100
Current	fixed	2	15; 21

Table 3. Analysis of Variance for RMR, using Adjusted SS for Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Concentration JC-EDM	10	0.0001287	0.0001287	0.0000129	1.26	0.284
Current	1	0.0002303	0.0002303	0.0002303	22.50	0.000
Concentration C-EDM*Current	10	0.0001453	0.0001453	0.0000145	1.42	0.204
Error	44	0.0004505	0.0004505	0.0000102		
Total	65	0.0009549				
S = 0.00319964 R-Sq = 52.82% R-Sq(adj) = 30.31%						

Interpretation of the Output for the Factorial Design:

The output shows a description of the factor that there are 11 levels for the concentration factor of JC-EDM and 2 levels for the current factor. The level for the factor of JC-EDM concentration is 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and the level for the current factor is 15 and 21 Amp. As shown in Table 3, there are 2 factors and 1 interaction, so there are 3 hypotheses that must be formulated that is hypothesis test to determine: (i) the influence of JC-EDM concentration, (ii) the influence of the current, and (iii) the influence of interaction between JC-EDM concentration and the current.

Test for the hypothesis on the effect of concentration of JC-EDM on RMR.

Hypothesis

$H_0: \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11}$ (Concentration of JC-EDM does not affect the value of RMR).

H_1 : At least there is one pair of $\alpha_i \neq \alpha_j$ where $i \neq j$ (Concentration of JC-EDM affects the value of RMR)).

From the output, the statistical test F results in the concentration of JC-EDM is 1.26 and p-value is 0.284. Therefore, the decision is to accept H_0 , i.e. JC-EDM concentration does not affect the value of RMR because $p\text{-value} = 0.284 > \alpha = 0.05$.

Test for the hypothesis on the effect of current on RMR.

Hypothesis

H_0 : $\beta_1 = \beta_2$ (current does not affect the value of RMR).

H_1 : $\beta_1 \neq \beta_2$ (current affects the value of RMR)

From the output, statistical test F for current is 22.5 with $p\text{-value} = 0.00 < \alpha = 0.05$. Therefore, the decision is to reject the initial hypothesis stating that current does not affect the value of RMR. So, the conclusion is that the current factor has a significant influence on the value of RMR.

Test for the hypothesis on the effect of interaction between factors on RMR.

Hypothesis

H_0 : $(\alpha\beta)_{ij} = 0$ (Interaction between factors does not affect on the value of RMR).

H_1 : $(\alpha\beta)_{ij} \neq 0$ (Interaction between factors affects on the value of TWR).

From the output, the statistical test $F = 1.42$ with $p\text{-value} = 0.204 > \alpha = 0.05$. The decision is to accept H_0 that the interaction between factors does not affect the value of RMR. In addition, the concentration of 70% JC-EDM or the viscosity of 3.84 cPs for 21 Amp current has a significant effect on the RMR, as shown in Figure 5.

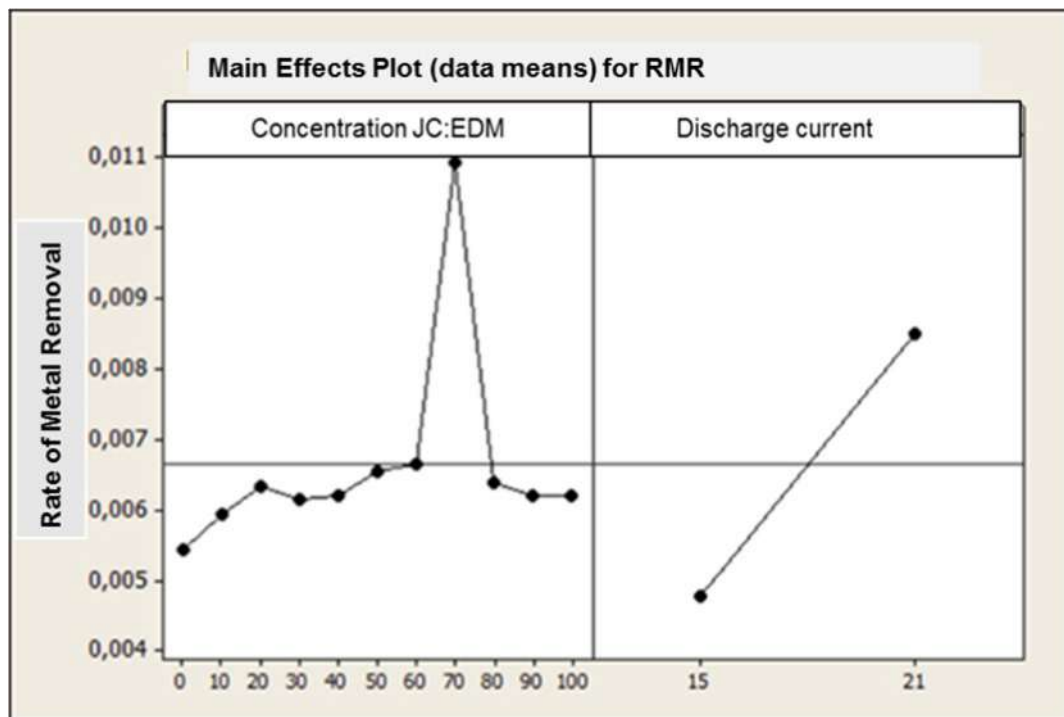


Figure 5. The Plots of RMR against concentration and current.

Figure 6 shows an interaction plots between the contributing factors. With ANOVA, the influence of each magnitude of the current can be determined.

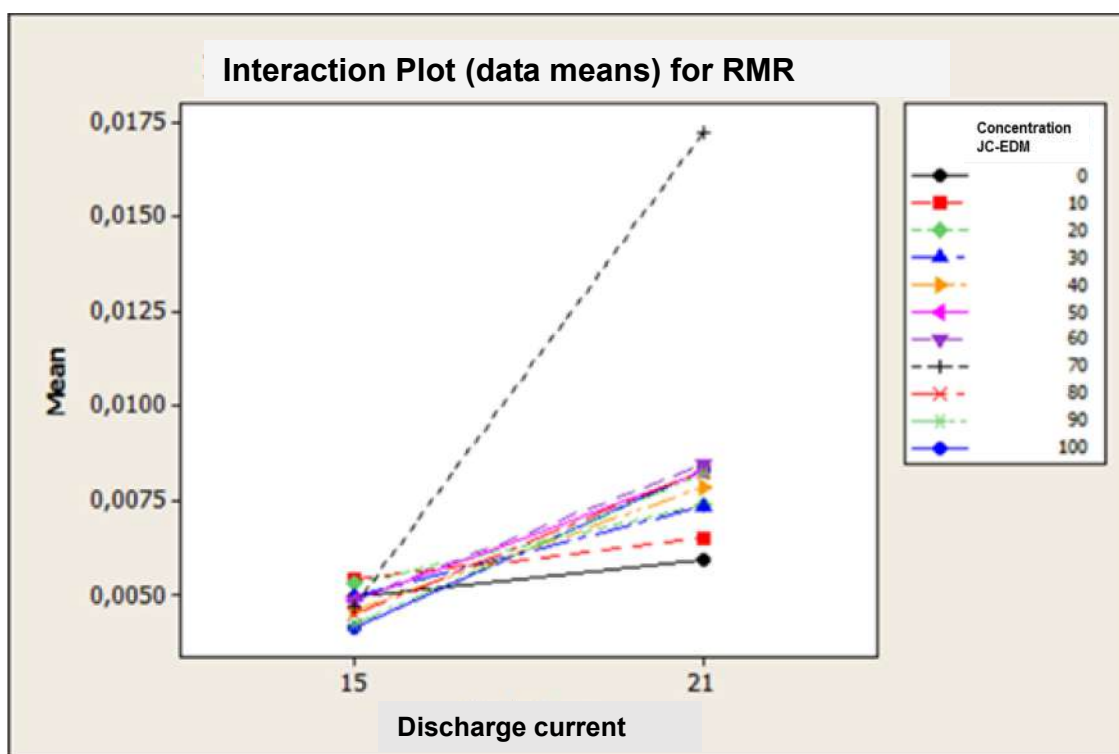


Figure 6. Plots of interaction between factors.

One-way ANOVA:

Table 4. ANOVA analysis of concentration effect on RMR with 15 Amp current.

Source	DF	SS	MS	F	P
Concentration JC-EDM	10	0.0000047	0.0000005	4.58	0.001
Error	22	0.0000023	0.0000001		
Total	32	0.0000070			
S = 0.0003205 R-Sq = 67.55% R-Sq(adj) = 52.81%					

Table 5. ANOVA analysis of concentration effect on RMR with 21 Amp current

Source	DF	SS	MS	F	P
Concentration JC-EDM	10	0.0002693	0.0000269	1.32	0.279
Error	22	0.0004482	0.0000204		
Total	32	0.0007175			
S = 0.004514 R-Sq = 37.54% R-Sq(adj) = 9.15%					

Interpretation of the output of the interaction plots between the factors in Table 4 and Table 5 above is:

- For 15 Amp current, there is a significant difference between the concentrations of JC-EDM to the RMR where $p\text{-value} < \alpha$
- For 21 Amp current, there is no significant difference between JC-EDM concentrations of JC-EDM to the RMR where $p\text{-value} > \alpha$
- The average value of RMR for 21 Amp current is higher than that of 15 Amp current.

In addition, the TWR at various concentrations when compared to the RMR, ranged from 4% to 10% with an average of 6% and 7% for 15 and 21 Amp current, respectively. Thus the higher the current level will increase the wear rate of the tool. This is also in accordance with previous studies [1,3] that the higher the current used, the heat generated in the tool is also increased which in turn will facilitate the displacement of the atoms.

Conclusions

In this study, the mixture of jatropha curcas and kerosene with various concentration were used successfully as the dielectric fluid in EDM process for cutting SKD 61 steel. The effects of the viscosity of the mixture were investigated for two different current of 15 and 21 Amp. The following points are drawn in this study :

1. The viscosity of the dielectric fluid mixture affects the value of TWR when the current used is small.
2. The viscosity of the dielectric fluid mixture does not affect the value of RMR.
3. The value of TWR and RMR depends on the energy released. Higher current results in higher TWR and RMR.
4. The EDM cutting process works normally at various viscosity of the dielectric fluid mixture, which is indicated by the much lower percentage of TWR than RMR. For the current of 15 and 21 Amp, the average value of TWR is 6% and 7% of RMR, respectively.

Acknowledgement

The authors would like to acknowledge the Faculty of Industrial Technology, Universitas Trisakti which has funded this research for the fiscal year of 2015/2016.

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The Effects of Dielectric Fluid Viscosity on Chips Formation Rate and Electrode Wear Rate in Electrical Discharge Machining of SKD 61 Steel

by Joko Riyono FTI

Submission date: 07-Nov-2025 08:50AM (UTC+0700)

Submission ID: 2806106161

File name: 18_MCF.pdf (2.47M)

Word count: 3164

Character count: 15318

The Effects of Dielectric Fluid Viscosity on Chips Formation Rate and Electrode Wear Rate in Electrical Discharge Machining of SKD 61 Steel

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Keywords: EDM; Jatropa Curcas; Metal Removal; Tool Wear; Viscosity.

Abstract. Electrical Discharge Machining (EDM) is a machine for cutting workpieces with thermal energy derived from electrical spark from tool (cathode) to workpiece (anode). As EDM process requires a dielectric fluid in the cutting operation, the characteristics of the dielectric fluid play an essential role for obtaining excellent cutting. Jatropa curcas has been demonstrated for use as a dielectric fluid in EDM process. However, the drawback is that the Rate of Metal Removal (RMR) is lower than that of generally-used dielectric fluid in industry. We consider that the cause is a much higher viscosity of the jatropa curcas. This study was conducted to investigate the characteristics of a new dielectric fluid mixture of jatropa curcas and kerosene. Kerosene was used in the mixture to reduce the viscosity of the jatropa curcas since the kerosene has a much lower viscosity. The measurement of the viscosity of the fluid mixture was performed using an Ostwald viscometer. Evidently, when the jatropa curcas mixed with the kerosene the viscosity of the mixture is lower than that of the pure jatropa curcas. The effects of the viscosity of the fluid mixture were investigated by measuring the RMR and Tool Wear Rate (TWR). The RMR and TWR were determined by calculating the difference in the weight of the workpiece and the tool, respectively, before and after the cutting for a certain cutting interval. The measurements were carried out for eleven different concentration of the fluid mixture by varying the current of 15 and 21 Amp, with replication of 3 times. As the result, the energy released during the cutting process affects the values of TWR and RMR. It was also found that in contrast to the effect on TWR, the RMR was not influenced by the viscosity of the mixture.

Introduction

Jatropa curcas, as an esterification product, can be used as dielectric fluid because its breakdown voltage is higher than kerosene [1, 2]. However, its RMR is still low [3]. One of the probable culprit for this is the high viscosity of jatropa curcas. This condition will complicate the disposal of chips formed during the cutting process, which in turn the cutting process will be disrupted due to the short circuit. To overcome the problem, the tool should perform a pumping motion in the gap between the workpiece and the tool so that the non-productive time increases. Since the kerosene has higher fluidity, the jatropa curcas was mixed with kerosene (EDM-85) so that the mixture of has higher fluidity than that of pure jatropa curcas. The purpose of this study is to investigate the effects of the viscosity of the dielectric fluid mixture on Rate of Metal Removal (RMR) and Tool Wear Rate (TWR).

Methodology

The outline of the study is shown in the flow diagram in Figure 1. In this study, the EDM process mainly consists of a SKM ZNC SERIES T50 EDM machine, 10 mm diameter copper rod electrodes, and SKD 61 steel as the workpiece. Current used for the process were 15 and 21 Amp with pulse-on time and pulse off-time of 20 μ s each. Flushing was employed by an injection type.

The amount of chips formed and the wear of the electrode were determined by weighing the workpiece and electrode, respectively, before and after the cutting test, as well as recording the actual machining time. The dielectric fluid used was a mixture of jatropha curcas with kerosene (EDM-85). The chosen concentrations of jatropha curcas were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100%. Measurements of the viscosity were performed by using Ostwald viscosimeter. The data obtained from the measurement were the fall time. The fall time was affected by the viscosity of the tested fluid. High dilution will allow the fluid to flow, or *fall*, leaving the ball-shaped test glass. Jatropha curcas has a viscosity of 29.57 cSt [1], which is higher than the viscosity of kerosene (2.12 cSt). Therefore, the mixing of both fluids will produce a certain viscosity.

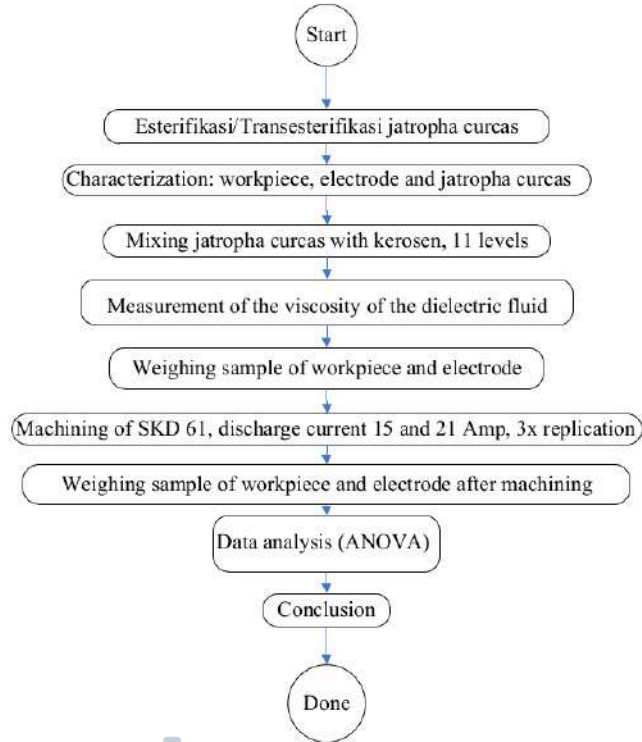


Figure 1. Flowchart of research work.

Workpiece in the form of rod steel with the diameter of 30 mm were cut into 66 samples with a thickness of 5 mm by using a flat grinding machine. For pairing the 66 samples of the workpiece, the 66 electrodes were cut from copper rods with the diameter of 10 mm and length of 15 mm.

Results and Discussion

Viscosity of Dielectric Fluid. One role of the dielectric fluid flow is to flush the debris away from the gap between the electrodes and the workpiece. From the fall time data, the viscosity of the dielectric mixture can be calculated by using Eq. (1)[5]. The calculation results are shown in Table 1. As shown in the table, when the concentration of jatropha curcas increases, the viscosity of the dielectric fluid also increases.

$$\eta_2 = \eta_1 \cdot \rho_2 / \rho_1 \cdot t_2 / t_1$$

(1)

where,

η : Viscosity [cPs]

t : Time [s]

ρ : Density [g/cm³]

Table 1. Viscosity of eleven dielectric fluid mixture measured with Ostwald viscosimeter.

Sample ID	Composition [%]		Time [s]	η [cPs]
	Jatropha curcas	Kerosene		
1	10	90	1.97	1.88
2	20	80	2.06	1.97
3	30	70	2.31	2.20
4	40	60	2.44	2.33
5	50	50	3.19	3.04
6	60	40	3.66	3.49
7	70	30	4.03	3.84
8	80	20	4.80	4.58
9	90	10	5.50	5.25
10	100	-	6.85	6.53
11	-	100	1.38	1.32

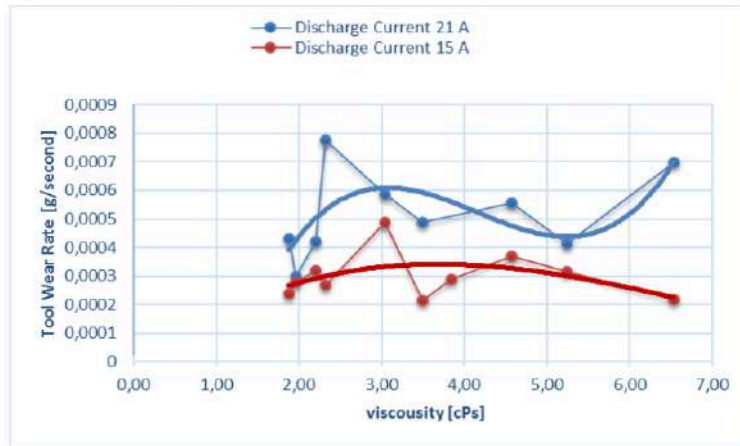


Figure 2. The plots of Tool Wear Rate (TWR) against the viscosity of the dielectric fluid mixture for the current of 15 dan 21 Amp.

Effect of Viscosity on TWR. Figure 2 shows the plots of TWR against viscosity for the current of 15 and 21 A. As shown in the figure, the TWR is higher for higher current. The trend for the TWR from the viscosity of 1.88 to 3.04 cPs (or concentration from 10 to 50%) on both current is equally increasing and then decreasing after the viscosity of 3.04 cPs. However, for 21 Amp current, the TWR increases beyond 80% concentration.

With ANOVA method, the calculation and the interpretation are shown as follows,
ANOVA: Tool Wear Rate (TWR) versus Concentration JC-EDM; Current

Factor	Type	Levels	Values
Concentration JC:EDM	fixed	11	0; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100
Current	fixed	2	15; 21

Table 2. Analysis of Variance for TWR, using Adjusted SS for Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Concentration JC-EDM	10	0.0000061	0.0000061	0.0000006	3.32	0.003
Current	1	0.0000026	0.0000026	0.0000026	13.91	0.001
Concentration JC-EDM*Current	10	0.0000062	0.0000062	0.0000006	3.35	0.003
Error	44	0.0000081	0.0000081	0.0000002		
Total	65	0.0000229				

S = 0.000429058 R-Sq = 64.69% R-Sq(adj) = 47.83%

Interpretation of the Output for the Factorial Design:

The output shows a description of the factors that there are 11 levels for the concentration factor of JC-EDM and 2 levels for the current factor. The level for the factor of JC-EDM concentration is 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and the level for the current factor is 15 and 21 Amp. As shown in Table 2, there are 2 factors and 1 interaction, so there are 3 hypotheses that must be formulated that is hypothesis test to determine: (i) the influence of JC-EDM concentration, (ii) the influence of the current, and (iii) the influence of interaction between JC-EDM concentration and the current.

Test for the hypothesis on the effect of concentration of JC-EDM on TWR.

Hypothesis

$H_0: \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11}$ (Concentration of JC-EDM does not affect the value of TWR)

H_1 : At least there is one pair of $\alpha_i \neq \alpha_j$ where $i \neq j$ (Concentration of JC-EDM affects the value of TWR)

From the output, the statistical test F results in the concentration of JC-EDM is 3.32 and p-value is 0.003. Therefore, the decision is to reject H_0 , i.e. JC-EDM concentration affects the value of TWR because $p\text{-value} = 0.003 < \alpha = 0.05$.

Test for the hypothesis on the effect of current on TWR.

Hypothesis

$H_0: \beta_1 = \beta_2$ (current does not affect the value of TWR).

$H_1: \beta_1 \neq \beta_2$ (current affects the value of TWR)

From the output, statistical test F for current is 13.91 with $p\text{-value} = 0.001 < \alpha = 0.05$. Therefore, the decision is to reject the initial hypothesis stating that current does not affect the value of TWR. So, the conclusion is that the current factor has a significant influence on the value of TWR.

Test for the hypothesis on the effect of interaction between factors on TWR.

Hypothesis

$H_0: (\alpha\beta)_{ij} = 0$ (Interaction between factors does not affect on the value of TWR).

$H_1: (\alpha\beta)_{ij} \neq 0$ (Interaction between factors affects on the value of TWR).

From the output, the statistical test F = 3.35 with $p\text{-value} = 0.003 < \alpha = 0.05$. The decision is to reject H_0 that the interaction between factors affects the value of TWR. Figure 3 shows the plot of the Main Factor which shows that 70% concentration of JC-EDM and 21 Amp current significantly influence the value of TWR.

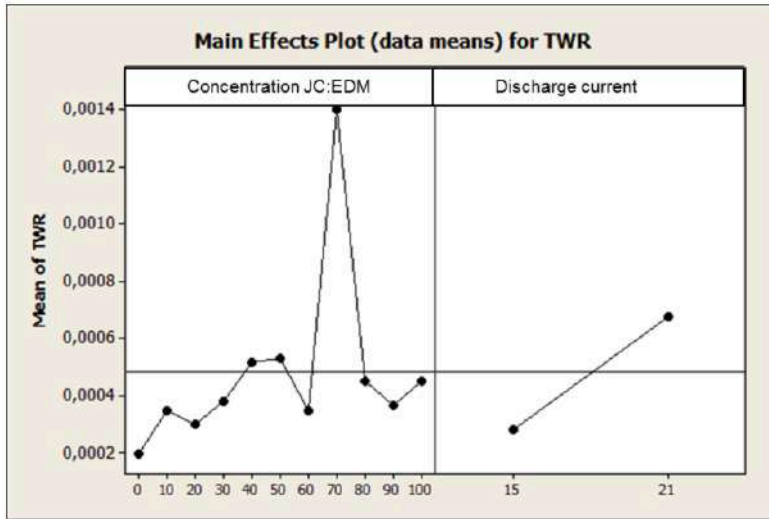


Figure 3. The plot of Main Factor.

Effect of Viscosity on RMR. Figure 4 shows the effect of the viscosity of the dielectric fluid on RMR. Previous studies [1, 3, 4] have also shown that the dominant factor on RMR is the current. The higher the current, the higher the RMR. This is because of the higher energy released for the melting of the material. As seen in Figure 4, for 20 Amp current the RMR increases until levelling off at 60% concentration. One interesting find is that for all concentrations the RMR is higher than that of EDM-85. On the contrary, for 15 Amp current, the RMR decreases with concentration. However, the RMR is higher than that of the treatment with pure kerosene for concentration up to 50%. Different characteristics for RMR change for both currents may be due to the spreading of energy to move the metal atoms contained in *jatropha curcas* becomes more evenly when the energy is increased.

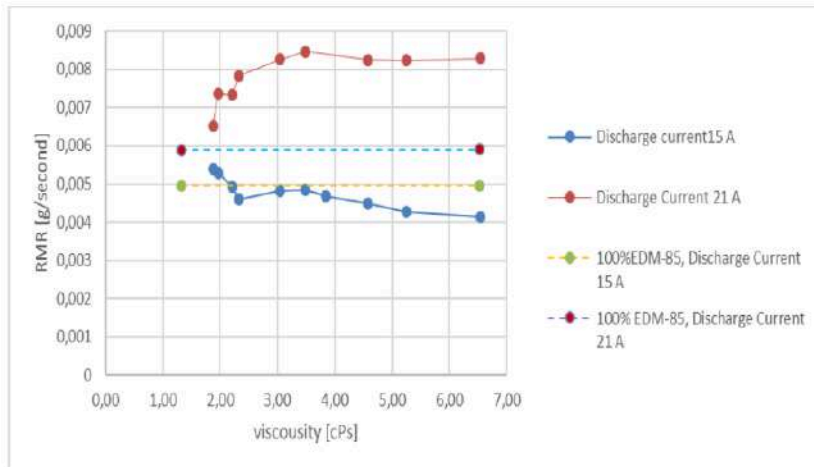


Figure 4. The plots of Rate of Metal Removal (RMR) against the viscosity of the dielectric fluid mixture for the current of 15 dan 21 Amp.

For statistical analysis, with ANOVA method, the calculation and interpretation are as follows,

Factor	Type	Levels	Values
Concentration JC-EDM	fixed	11	0; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100
Current	fixed	2	15; 21

Table 3. Analysis of Variance for RMR, using Adjusted SS for Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Concentration JC-EDM	10	0.0001287	0.0001287	0.0000129	1.26	0.284
Current	1	0.0002303	0.0002303	0.0002303	22.50	0.000
Concentration C-EDM*Current	10	0.0001453	0.0001453	0.0000145	1.42	0.204
Error	44	0.0004505	0.0004505	0.0000102		
Total	65	0.0009549				

S = 0.00319964 R-Sq = 52.82% R-Sq(adj) = 30.31%

Interpretation of the Output for the Factorial Design:

The output shows a description of the factor that there are 11 levels for the concentration factor of JC-EDM and 2 levels for the current factor. The level for the factor of JC-EDM concentration is 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and the level for the current factor is 15 and 21 Amp. As shown in Table 3, there are 2 factors and 1 interaction, so there are 3 hypotheses that must be formulated that is hypothesis test to determine: (i) the influence of JC-EDM concentration, (ii) the influence of the current, and (iii) the influence of interaction between JC-EDM concentration and the current.

Test for the hypothesis on the effect of concentration of JC-EDM on RMR.

Hypothesis

H₀: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11}$ (Concentration of JC-EDM does not affect the value of RMR).

H_1 : At least there is one pair of $\alpha_i \neq \alpha_j$ where $i \neq j$ (Concentration of JC-EDM affects the value of RMR)).

From the output, the statistical test F results in the concentration of JC-EDM is 1.26 and p-value is 0.284. Therefore, the decision is to accept H_0 , i.e. JC-EDM concentration does not affect the value of RMR because $p\text{-value} = 0.284 > \alpha = 0.05$.

Test for the hypothesis on the effect of current on RMR.

Hypothesis

$H_0: \beta_1 = \beta_2$ (current does not affect the value of RMR).

$H_1: \beta_1 \neq \beta_2$ (current affects the value of RMR)

From the output, statistical test F for current is 22.5 with $p\text{-value} = 0.00 < \alpha = 0.05$. Therefore, the decision is to reject the initial hypothesis stating that current does not affect the value of RMR. So, the conclusion is that the current factor has a significant influence on the value of RMR.

Test for the hypothesis on the effect of interaction between factors on RMR.

Hypothesis

$H_0: (\alpha\beta)_{ij} = 0$ (Interaction between factors does not affect on the value of RMR).

$H_1: (\alpha\beta)_{ij} \neq 0$ (Interaction between factors affects on the value of TWR).

From the output, the statistical test $F = 1.42$ with $p\text{-value} = 0.204 > \alpha = 0.05$. The decision is to accept H_0 that the interaction between factors does not affect the value of RMR. In addition, the concentration of 70% JC-EDM or the viscosity of 3.84 cPs for 21 Amp current has a significant effect on the RMR, as shown in Figure 5.

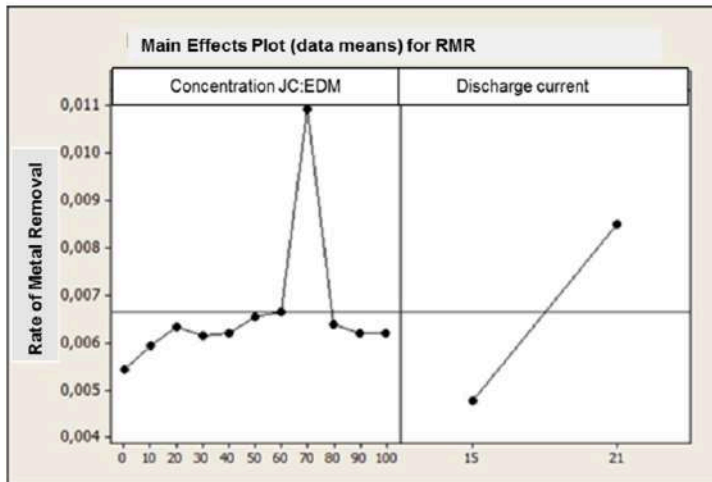


Figure 5. The Plots of RMR against concentration and current.

Figure 6 shows an interaction plots between the contributing factors. With ANOVA, the influence of each magnitude of the current can be determined.

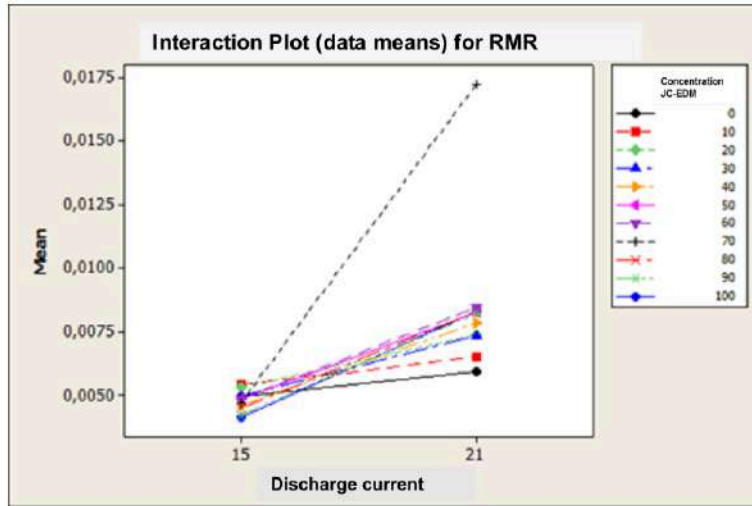


Figure 6. Plots of interaction between factors.

One-way ANOVA:

Table 4. ANOVA analysis of concentration effect on RMR with 15 Amp current.

Source	DF	SS	MS	F	P
Concentration JC-EDM	10	0.0000047	0.0000005	4.58	0.001
Error	22	0.0000023	0.0000001		
Total	32	0.0000070			

S = 0.0003205 R-Sq = 67.55% R-Sq(adj) = 52.81%

Table 5. ANOVA analysis of concentration effect on RMR with 21 Amp current

Source	DF	SS	MS	F	P
Concentration JC-EDM	10	0.0002693	0.0000269	1.32	0.279
Error	22	0.0004482	0.0000204		
Total	32	0.0007175			

S = 0.004514 R-Sq = 37.54% R-Sq(adj) = 9.15%

Interpretation of the output of the interaction plots between the factors in Table 4 and Table 5 above is:

- For 15 Amp current, there is a significant difference between the concentrations of JC-EDM to the RMR where $p\text{-value} < \alpha$
- For 21 Amp current, there is no significant difference between JC-EDM concentrations of JC-EDM to the RMR where $p\text{-value} > \alpha$
- The average value of RMR for 21 Amp current is higher than that of 15 Amp current.

In addition, the TWR at various concentrations when compared to the RMR, ranged from 4% to 10% with an average of 6% and 7% for 15 and 21 Amp current, respectively. Thus the higher the current level will increase the wear rate of the tool. This is also in accordance with previous studies [1,3] that the higher the current used, the heat generated in the tool is also increased which in turn will facilitate the displacement of the atoms.

Conclusions

In this study, the mixture of jatropha curcas and kerosene with various concentration were used successfully as the dielectric fluid in EDM process for cutting SKD 61 steel. The effects of the viscosity of the mixture were investigated for two different current of 15 and 21 Amp. The following points are drawn in this study :

1. The viscosity of the dielectric fluid mixture affects the value of TWR when the current used is small.
2. The viscosity of the dielectric fluid mixture does not affect the value of RMR.
3. The value of TWR and RMR depends on the energy released. Higher current results in higher TWR and RMR.
4. The EDM cutting process works normally at various viscosity of the dielectric fluid mixture, which is indicated by the much lower percentage of TWR than RMR. For the current of 15 and 21 Amp, the average value of TWR is 6% and 7% of RMR, respectively.

Acknowledgement

The authors would like to acknowledge the Faculty of Industrial Technology, Universitas Trisakti which has funded this research for the fiscal year of 2015/2016.

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