An Experimental Study and Analysis of Different Dielectrics in Electrical Discharge Machining of Al 6063 Alloy

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ABSTRACT

Electrical discharge machining is a non-traditional machining processes in which it is based upon thermal and electrical energy source as an interval energy pulse discharge in-between the work piece and tool electrode so as to remove the material. A systematical investigation of melting and vaporising of aluminium to find the output responses such as Material removal rate (MRR), Electrode wear rate (R_a), and Surface finish (EWR) in EDM using two different dielectrics was conducted as experimental work. The working fluids are Polyethylene glycol (PEG 600) and kerosene. It is the hour of need to get the maximum MRR and surface finish with minimum EWR for any material. The paper focuses on the effect of polymer based dielectric machining the aluminium alloy EDM. The dielectrics enact a great role in production and its influence on environmental aspects should also be considered. These dielectric fluids are used in machining an aluminium alloy 6063 using copper electrode and they are compared for their MRR, EWR, and R_a. Taguchi method is used for analysing the results of two different dielectrics that carried with the help of Minitab software.

KEYWORDS: *Electrical discharge machining, Kerosene, Polyethylene glycol (PEG 600), Signal to noise ratio (S/N response factors), Aluminum alloy, Surface finish (R_a), Electrode wear rate (EWR), and Material removal rate (MRR).*

1. INTRODUCTION

EDM is a thermal eroding shaping process based by which the unwanted material from the parent material is detached by continuous non-mechanical thermoelectric discharges between work piece electrode and a tool

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electrode which causes periodic fusion and pulverization of material in tool electrode and work piece. To improve the material removal, EDM works in a non-conducting fluid namely, the dielectric fluid. While machining, the tool and work piece electrode are positioned that micro gap is maintained such that the gap is filled with dielectric fluid. Tsai *et al.,* 2001 defined that the principle of EDM is based on the transformation of electrical energy into thermal energy that happens due to distinct electrical liberation of spark discharges occurring in-between two electrodes [1].

The dielectric has insulating effect which is of primary importance to eradicate electrolysis process. Metal Erosion takes place in both electrodes. Machining takes place to a needed form which is a reciprocal to that of the tool, whenever spark that carried away to next narrowest gap after each discharge. So, the dielectric fluid play important functions in industries in every parts machined and also in range of productivity, costs and quality. Health, safety and environment should also be taken for consideration while using hydrocarbon oil. Zhang *et.al.,* (2011) disclosed that industries productivity and quality are pretentious by the dielectrics use; and showed that non-identical dielectric gives different surface with different characteristics [2].

The dielectric serves to cools both electrode with concentration of the discharge energy, and flushes away the products formed in machining gap. EDM is one of the mechanisms used in production of dies in which the formed die has good accuracy and precision due to there is calculated and measured physical touch between the work piece and tool and then no machine driven stress is exerted on machined product. If voltage is made to passover between the work piece and tool electrode, because of the formation of strong electrostatic field the breakdown of dielectric medium occurs and

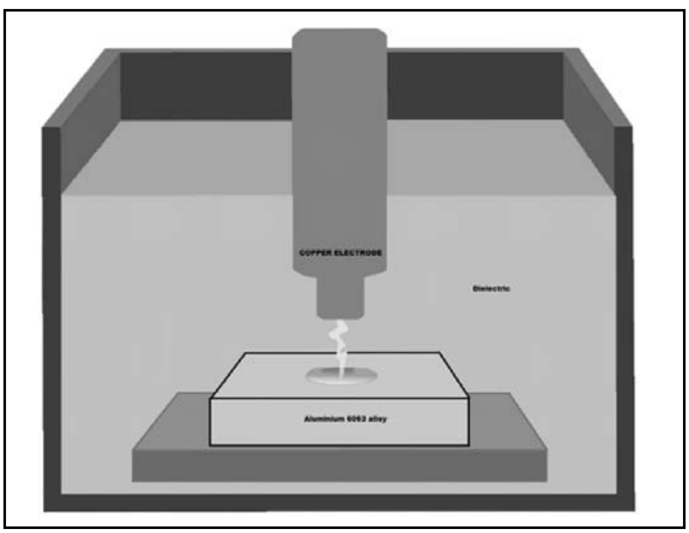

Fig. 1. The working principle of EDM

electrons will flow from the cathode toward the anode by the distance between them. In presence of the insulating medium, these electrons will flow towards opposite direction because of the magnitude and it will impinge on the dielectric molecules, and tend to break the atomic molecules into respective positive ions and electrons. Ionization path will be created because of the flow of secondary electrons and rise in the electric field intensity happens along the work surfaces and lead to multiplied number of electrons. In-between the spark gap, ionized column is generated, which lead to decrease the opposition movement of the fluid and stimulated electrical discharge in IEG. T. Muthuramalingam *et al.,*(2014) in their work clearly showed the impact of dielectrics on each and every process potential [3]. Various dielectrics have been used in diverse and modification of EDM. EDM performance is only based dielectric properties including both physical and chemical properties. M. Kiyak *et.al.,* (2007) in their work stated that pulsed current and time are influential major parameters are the reason for surface roughness of both work piece and electrode and revealed that in order to produce better surface finish, input parameters such as higher pause time, lower pulse time and comparatively lower current is needed [4].

II. DIELECTRIC FLUID

The dielectrics play a very important role as dielectric fluid is made to flow to through the IEG to sweep eroded particles between the electrodes. Most common fluids used are EDM Oil, Petroleum-based hydrocarbon oil, distilled and deionised water. Usage of low viscosity fluids will improve machining and surface finishing. Replacement of dielectric is a major concern after using it in few cycles of machining. So, this makes researchers draw their attentiveness in examining and analyzing the dielectric in EDM process. Usage of dielectric cause skin irritation and bad smell surrounds the environment because of the continuous usage of the dielectric. Even though, many industries use kerosene as they produce the above effects while machining and creates carbon dispersion.

Sivapikarasam *et.al.,* (2011) discussed the environmental aspect of green EDM with the factors that influence dielectric consumption, submission to aerosol and process energy. Dielectric utilization leads to economical and environmental impact [5]. F.N. Leao *et.al.,* (2004) explored a review paper on dielectrics. Usage of Deionised/distilled water which is safe for the environment has the potential to be used as dielectric to attain higher MRR yet commercially used hydrocarbon oil is competent [6]. Norliana Mohd Abbas *et.al.,* (2007) scrutinized the favourable of EDM machining with deionised water [7]. M. Kunieda *et.al.,* (1997) initiated dry machining by supplying gas into IEG between the electrodes. The results showed continuous discharge and improvement the MRR [8]. Different dielectrics like Bio diesel were used in EDM by Mouliprasanth and Sadagopan P (2017) [10]. Sarabjeet *et.al.,* (2014) highlighted to use copper electrode than aluminium by the significant amount of metal transfer between both electrodes [11]. B. Kuriachen et.al (2016) recommended to use the powder concentration, with capacitance and voltage to get higher MRR and lower TWR [12]. Anil kumar et.al discussed Multiobjective parametric optimisation and identified notable parameters on process performance of EN-24 tool steel in presence of kerosene dielectric [13]. Sagar Patel et.al improved machining performance of inconel 718 using tool rotation with additive aluminium oxide in dielectric [14]. Rachin Goyal et.al assisted electric discharge machining with cryogenic addition to boost the machining capability and productivity of cryogenically cooled D2 tool steel with copper electrode with various parameters [15].

This research aim is to have an outlook on the usage of choice of other dielectric than that of hydrocarbon oils as dielectrics. So huge molecular structures organic compounds like polyethylene glycol (PEG 600) is used. It has excellent low moisture absorption and exceptional electrical properties. The dielectric strength of most insulating materials varies with temperature and humidity This paper objective is to experimentally examine the effects of PEG 600 and Kerosene with respect to MRR, EWR and R_a, so as to find the environmental friendly dielectric. The results of both dielectrics are compared and the process parameters are optimized.

III. MATERIAL AND METHODS

A. Materials

In this study, the materials selected are aluminium 6063 alloy of cylindrical rod of 28mm and length 15mm as a work piece (density 2700 kg/m^3) and it is hardened. The electrode used is pure cylindrical copper rod with a nominal diameter of 4mm. Aluminum has lowest resistivity and is lighter than copper.

B. EDM Machine

2000 Series Electronica- EMS brand of 5535-R50 ZNC machine is used and with the control of the machine as NC control in Z-direction. The machine polarity of the work piece is positive to that of tool is negative. Dielectric fluid used for the EDM machining is Polyethylene glycol (PEG 600) and kerosene.

C. Properties

TABLE 1. Aluminium alloy 6063 Mechanical Properties

Melting point	°C	660
Density	kg/m^3	2700
Percent Elongation	%	10-25
Yield strength	MPa	215-505
Poisson's ratio		0.33
Tensile strength	MPa	230-570
Elastic modulus	GPa	70-79

TABLE 2. Copper Electrode Properties

Physical Properties	Units	Value
Melting point	°c	1083
Coefficient of thermal expansion	×10° c^{-1}	6.6
Specific gravity at 20^{0}c	g/cm^3	8.9
Electrical resistivity	μΩ/cm	1.96
Specific heat	cal/g °c	0.092
Thermal conductivity	W/mK	268-389
Electrical conductivity	%	92

Table 3. Dielectric Properties.

Dielectrics	Viscosity (cst)	Flash point
Kerosene	1.3 @ 40°C	60°C
PEG 600	10.8 @ 100 °C	230°C (182-280°C)

The mechanical properties of aluminium 6063 alloy,

Table 4. Machining conditions

Machining Depth	3mm
Diameter of Work piece	28mm
Length of Work piece	15mm
Diameter of Electrode	4mm

copper tool and the used dielectric properties are shown in table 1, 2 and 3 respectively.

d. Machine conditions

E. Design of experiments

This paper utilises one of the oldest optimisation Taguchi method, to examine and analyse the characterisation of three most influential machining input parameters like, I_p, T_{on}, and T_{off} (those parameters only deal with current and voltage are chosen) on three important response factors, MRR, EWR, and R_a which is a effective optimisation tool to handle with responses that are affected by multi-response variables. Studying all the input and output process factors and their impacts in a single level experiment is impossible too. So, Taguchi technique is carried out since it overcomes all the drawbacks. Experimental machining parameters with their respective levels are shown in Table-4. As for the appropriate orthogonal arrays, degree of freedom of L9 array is calculated. There are totally six DOF for three input parameters, so Taguchi dependent L9 orthogonal array is adopted. Premilnary experiments were carried out to study the machining conditions and to find the parameters levels. So, in total nine experiments were performed to work on the results of output responses on input parameters in each dielectric.

Chosen input process parameters for machining aluminium 6063 alloy:

a) Pulse-off time [T_{off}]. b Pulse-on time [T_{on}], c) Peak current [I_p],

Chosen response functions for machining aluminium 6063 alloy are:

a) Electrode wear rate [EWR], b) Material removal rate [MRR], c) Surface roughness [R_a].

Table 5 shows the Number of levels of the parameters and machining conditions for Aluminium 6063 alloy selected.

In the present research work, Taguchi based an L9 orthogonal array is used. The degree of freedom is defined. An analytical and statistical ANOVA is operated to pinpoint the input process parameters that are statistically significant. With the results of ANOVA the optimal integral mix of the process parameters for machining aluminium is optimized. The experimental design arrangement for the machining using the L9 orthogonal array is shown in Table 6.

TABLE 5. Factors and Levels used as input Factors

S. No.	Factors		Levels		
		Unit	1	2	3
1	T_{ON}	μ_s	45	35	30
2	T_{OFF}	μ_s	9	8	7
3	I_p	Amp	8	7	6

TABLE 6. Design Matrix of Taguchi L9 Array

Level of Factors			
	C1	C2	C3
Exp. No.	T_{on}	T_{off}	I_p
1	45	9	8
2	45	8	7
3	45	7	6
4	35	9	7
5	35	8	6
6	35	7	8
7	30	9	6
8	30	8	8
9	30	7	7

F. Experimental procedure:

Experiments are carried out as per the machining conditions and L9 orthogonal array given in the Table 4, in an aluminium alloy 6063 of work piece of diameter 28mm. Separate tool is used for each and every experiment. The machining time is calculated with the help of stopwatch. Precisa 125 A SCS balance is used to calculate the MRR and EWR. The geometrical outputs of the electrode, after machining and before machining are weighed and measured. The "SJ 201" Mitutoyo Surftest instrument is used to measure surface roughness (R_a). The readings are taken at different positions for surface roughness. R_a is used as the surface roughness parameter. For each workpiece five measurements were taken on machined surface area and the average of all the five readings is taken as final surface roughness output response value. The machined sample using PEG 600 and Kerosene were shown in figure 2

G. Measurement Procedure:

1. MRR = $(W_{wb} – W_{wa})$ / t. (gm/min) 2.TWR = $(W_{tb} –W_{ta})$ / t. (gm/min)

Where,

W_{wb} = Work piece weight before machining

W_{wa} = Work piece weight after machining

W_{tb} = Tool weight before machining

W_{ta} = Tool weight after machining

T = Machining time

H. Quality characteristics*:*

Signal to noise ratio for output response values are processed based on two characteristics,

i. Larger is better characteristic

Data calculation for MRR, is taken as larger is better performance characteristic, are predicted as per formula i.

$$S/N = -10 \log \left(1/n \sum_{i=1}^{n} 1/y_i^2\right) \quad \text{(i)}$$

ii. Smaller is better characteristic

Data calculation for EWR and R_a, is taken as smaller is better performance characteristic, are predicted as per formula ii.

$$S/N = -10 \log \left(1/n \sum_{i=1}^{n} y_i^2\right) \quad \text{(ii)}$$

"y_i" indicates the observed experimentation value of "i^{th}" experiments carried.

"n" indicates number of continuous repetition of every experiments carried.

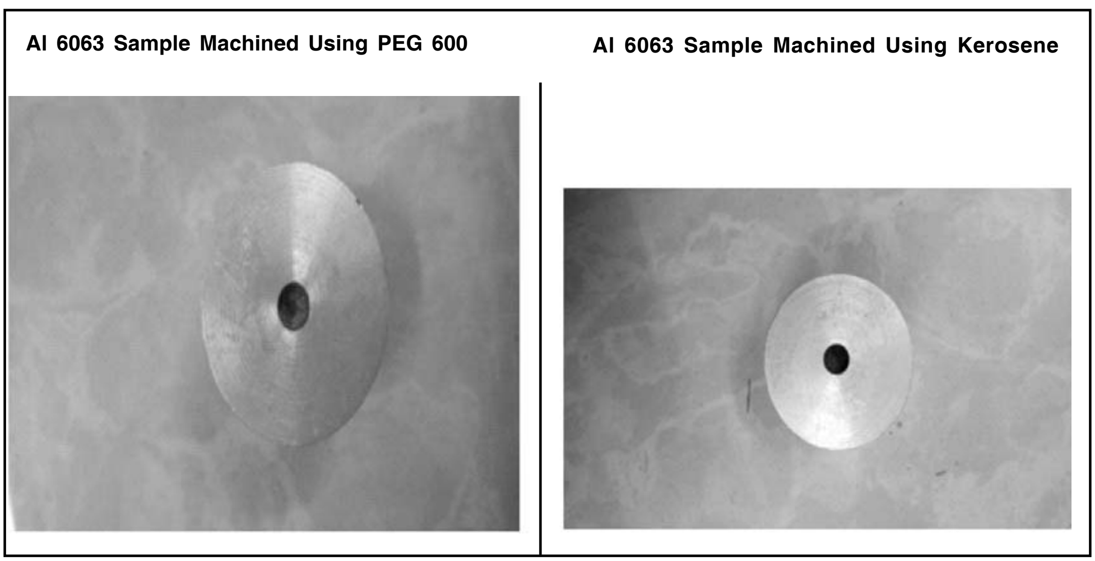

Fig. 2. Machined Sample using PEG 600 and Kerosene

TABLE 7. Results of MRR, EWR and R_a while using Polyethylene glycol (PEG 600) as dielectric fluid.

Expt. No	MRR (gm/min)	EWR (gm/min)	R_a (μm)
1	0.03050	0.001850	7.020
2	0.03310	0.001640	6.410
3	0.03010	0.001810	4.100
4	0.02760	0.001710	4.900
5	0.02540	0.001650	4.210
6	0.02430	0.001400	6.230
7	0.01800	0.001100	4.040
8	0.02010	0.001670	5.520
9	0.01930	0.001410	5.400

TABLE 8. Results of MRR, EWR and R_a while using Kerosene as dielectric fluid.

Expt. No	MRR (gm/min)	EWR (gm/min)	R_a (μm)
1	0.02000	0.001900	7.000
2	0.02060	0.001840	6.960
3	0.01940	0.001890	6.850
4	0.01860	0.001790	6.900
5	0.01850	0.001750	6.150
6	0.01650	0.001690	6.960
7	0.01020	0.001200	6.000
8	0.01000	0.00180	7.100
9	0.01780	0.001510	6.860

IV. RESULTS AND DISCUSSION

In this EDM machining, different output response factors like MRR, EWR and R_a of the drilled blind holes is calculated and analyzed with ANOVA based on the signal to noise characteristic and observed data. With the generated results, S/N ratio values of response factors are arranged in Table 9.

1. POLYETHYLENE GLYCOL (PEG 600) RESULTS

PEG is made of long chains of carbons, an inexpensive polymer attached with hydrogen bonds. Dielectric strength of PEG differs in values with respect to the ratio of the material thickness and to the breakdown voltage. However, with the increase in temperature the chain soften and its crystallites followed by melting which consequently decreases its dielectric strength. A conducting path is formed through it whenever maximum voltage a material can withstand the breakdown voltage of PEG.

TABLE 9. Signal to noise ratio of PEG 600

Expt. No.	S/N RATIO FOR MRR	S/N RATIO FOR EWR	S/N RATIO FOR R_a
1	-30.31400	54.65660	-16.92670
2	-29.60340	55.70310	-16.13720
3	-30.42870	54.84640	-12.25570
4	-31.18180	55.34010	-13.80390
5	-31.90330	55.65030	-12.48560
6	-32.28790	57.07740	-15.88980
7	-34.89450	59.17210	-12.12760
8	-33.93610	55.54570	-14.83880
9	-34.28890	57.01560	-14.64790

Signal to noise ratio for output response factors when using polyethylene glycol (PEG 600) as dielectric is shown in Table 9.

A. Effect of input parameters on MRR

MRR increases, As temperature was increased due to ionization, the conductivity of dielectric became smaller and relatively high dielectric constants of the PEG were attributed to the end hydroxyl groups and the flexible oxyethylene chain of the molecule and in this case the dielectric constant was decreased not by a change in the molecular weight but by a decrease in the moisture content, and when PEG is mixed with distilled water, It is clear that a small amount of water affects the dielectric constant. So PEG added with distilled water is no preferable for machining Aluminium alloy.

Response table for MRR is shown in Table 10. For the calculation of S/N ratio, “Larger is better quality characteristic” is used.

TABLE 10. Response table for S/N ratio for MRR

Levels	Pulse on time (T_{ON})	Pulse off time (T_{OFF})	Peak current (I_P)
1	-34.37	-32.34	-32.41
2	-31.79	-31.81	-31.69
3	-30.12	-32.13	-32.18
Delta	4.26	0.52	0.72
Rank	1	3	2

Referring response Table 10, it is perceived that “T_{on}” ranks first which denotes that it has a maximum effect on MRR, “I_p” have significant effect and “T_{off}” which has minimal effect on MRR (Fig. 3).

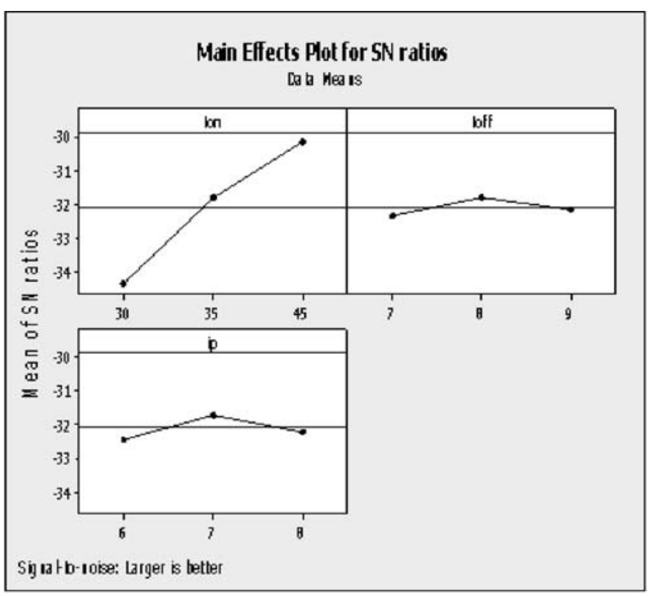

Fig. 3. S/N ratio curve for MRR with I_p, T_{on} and T_{off}

The regression analysis is handled to see the difference between the principle effects in every level of the numeral on the MRR, EWR and R_a shown in Table 11.

TABLE 11. Statistical regression analysis for MRR Vs $T_{ON,}$ T_{OFF} and I_P

Predictor	Coefficient	SE Coefficient	T	p
Constant	-0.007670	0.010660	-0.720	0.5040
T_{on}	0.00076950	0.00011940	6.440	0.0010
T_{off}	0.00040000	0.00091200	0.440	0.6790
I_p	0.00023330	0.00091200	0.260	0.8080

S = 0.002233850 R-Sq = 89.3% R-Sq (adj) = 82.9%

The regression equation is

$$MRR = - 0.00770 + 0.0007700\, T_{on} + 0.0004000\, T_{off} + 0.0002330\, I_{p.}$$

TABLE 12. Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	p
T_{on}	2	27.60400	27.60400	13.80200	98.000	0.0100
T_{off}	2	0.41310	0.41310	0.20650	1.470	0.4050
I_p	2	0.80560	0.80560	0.40280	2.860	0.2590
Residual Error	2	0.28170	0.28170	0.14080		
Total	8	29.10430				

B. Effect of input parameters on EWR

Although no insulation for the electrode was used, the stray capacitance was minimized by proper shielding of the tank. At room temperature, no dielectric dispersion was found in the present experimental range. The apparent increase in dielectric constant due to the electrode polarization took place this is due to ionic impurities present. The electrode polarization plays a major role in magnitude of the dielectric and caused decrease in proportion which reduces the conductivity of the sample. The interesting feature is conductivity of the sample in the liquid state of PEG for fixing the polarization for both the electrodes and dielectric constants and also caused the usage of RC circuit for machining. The lower conductivity of the dielectric, the polarization will be less and smaller the EWR. The higher conductivity of the dielectric, the polarization was the larger and larger the EWR.

Response table for EWR is shown in Table 13. For the calculation of S/N ratio, “Smaller is better quality characteristic” is used.

TABLE 13. Response table for S/N ratio for EWR

Levels	Pulse on time (T_{ON})	Pulse off time (T_{OFF})	Peak current (I_P)
1	57.24	56.31	56.56
2	56.02	55.63	56.02
3	55.07	56.39	55.76
Delta	2.18	0.76	0.80
Rank	1	3	2

Referring Response Table 13, it is perceived that "T_{on}" ranks first which denotes that it has a maximum effect on EWR; "I_p" has significant effect and "T_{off}" which has minimal effect on EWR (Fig. 4).

The regression analysis is handled to see the difference between principle effects in every level of the numeral on the MRR, EWR and R_a shown in Table 14.

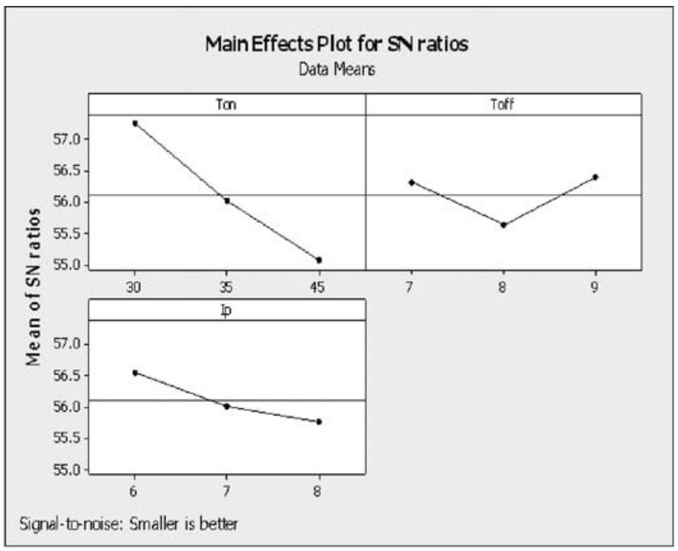

Fig. 4. S/N ratio curve for EWR with I_p, T_{on}, and T_{off}.

TABLE 14. Statistical regression analysis for EWR Vs $T_{ON,}$ T_{OFF} and I_P

Predictor	Coefficient	SE Coefficient	T	p
Constant	0.0002320	0.0010220	0.230	0.8290
T_{on}	0.000023900	0.000011440	2.090	0.0910
T_{off}	0.000006670	0.000087390	0.080	0.9420
I_p	0.000060000	0.000087390	0.690	0.5230

S = 0.0002140490   R-Sq = 49.2%   R-Sq (Sq) = 18.7%

The regression equation is

$$EWR = 0.000230 + 0.0000240\,T_{on} + 0.0000070\,T_{off} + 0.0000600 I_p$$

TABLE 15. Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	p
T_{on}	2	7.13690	7.13690	3.56840	1.030	0.4940
T_{off}	2	1.04080	1.04080	0.52040	0.150	0.8700
I_p	2	0.98980	0.98980	0.49490	0.140	0.8760
Residual Error	2	6.96250	6.96250	3.48130		
Total	8	16.13000				

C. Effect of input parameters on R_a.

R_a has its reasonable play on the dielectric as the used PEG has higher molecular-weight and lower dielectric constant. Since PEG has no end hydroxyl groups, the formation of HC compounds is reduced and the contribution of the dipole moment of the polymer chain to the dielectric constant is evident as it has the high dielectric constant. In a dielectric, atoms and molecules are bounded with electrons and whenever electric current is applied there is a high resistance, which denotes that it has zero or near zero electrical conductivity. Breakdown occurs, when the voltage is applied so the present electric field liberates the electrons. If the given electric field is strong enough, the free electrons gets stimulated and release other electrons to get collide with neutral atoms or molecules. The release of the electrons may change the dielectric into a conductor with positive charge. The dielectric strength gets increased when voltage is given until that the dielectric can hold it before breaking down, so more useful is the dielectric as an insulator. Although the surface roughness is measured, the surface morphology and integrity should be studied in detail in conformation of the dielectric.

Response table for R_a is shown in Table-16. For the calculation of S/N ratio, "Smaller is better quality characteristic" is used.

Referring Response Table 16, it is perceived that "I_p" ranks first which denotes that it has a maximum effect on R_a, "T_{on}" have significant effect and "T_{off}" which has minimal effect on R_a (Fig. 5).

TABLE 16. Response table for S/N ratio for R_a

Levels	Pulse on time (T_{ON})	Pulse off time (T_{OFF})	Peak current (I_P)
1	-13.87	-14.26	-12.29
2	-14.06	-14.49	-14.86
3	-15.11	-14.29	-15.89
Delta	1.24	0.22	3.60
Rank	2	3	1

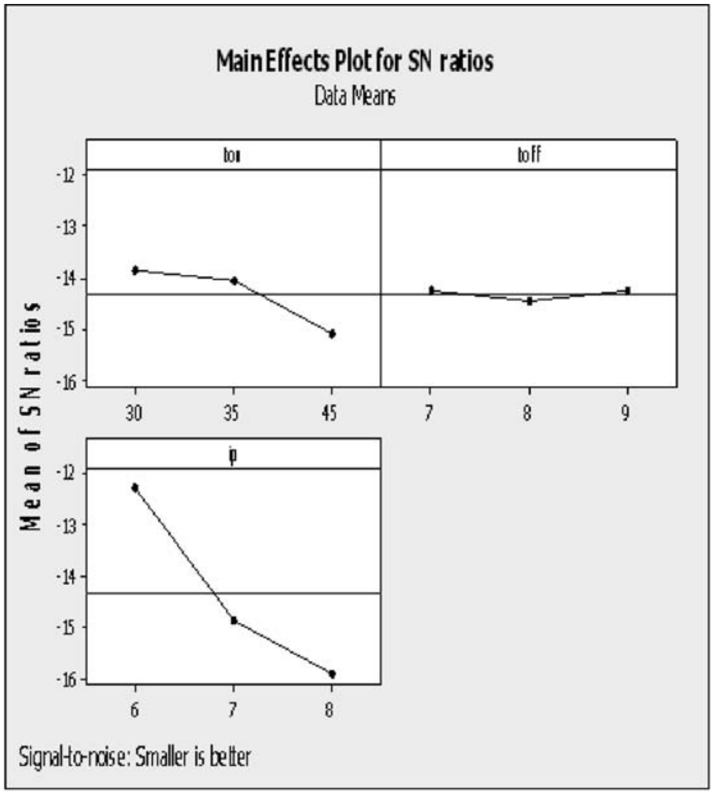

Fig. 5. S/N ratio curve for R_a with I_p, T_{on}, and T_{off}.

The regression analysis is handled to see the difference between principle effects in every level of the numeral on the MRR, EWR and R_a shown in Table 17.

TABLE 17. Statistical regression analysis for R_a Vs $T_{ON,}$ T_{OFF} and I_P

Predictor	Coefficient	SE Coefficient	T	p
Constant	-4.6600	2.5030	- 1.860	0.1220
T_{on}	0.05938	0.028030	2.120	0.0880
T_{off}	0.03830	0.21410	0.180	0.8650
I_p	1.07000	0.21410	5.000	0.0040

S = 0.5244560   R-Sq = 85.5%   R-Sq (adj) = 76.8%

The regression equation is

$R_a = - 4.660 + 0.05940\ T_{on} + 0.0380\ T_{off} + 1.070\ I_p$

TABLE 18. Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	p
T_{on}	2	2.65660	2.65660	1.32830	1.160	0.4630
T_{off}	2	0.09050	0.09050	0.04530	0.040	0.9620
I_p	2	20.59400	20.59400	10.29700	8.990	0.1000
Residual Error	2	2.28990	2.28990	1.14490		
Total	8	25.63110				

2. KEROSENE RESULTS

A. Effect of input parameters on MRR

Response table for MRR is shown in Table 19. For the calculation of S/N ratio, "Larger is better quality characteristic" is used.

Signal to noise ratio for various response factors when using kerosene as dielectric is shown in Table 19.

Referring Response Table 20, it is perceived that "T_{on}" ranks first which denotes that it has a

TABLE 19. Signal to noise ratio of kerosene

Expt. No.	S/N RATIO FOR MRR	S/N RATIO FOR EWR	S/N RATIO FOR R_a
1	-33.97940	54.42490	-16.90200
2	-33.72270	54.70360	-16.85220
3	-34.24400	54.47080	-16.71380
4	-34.60970	54.94290	-16.77700
5	-34.65660	55.13920	-15.77750
6	-34.65030	55.44230	-16.85220
7	-39.82800	58.41640	-15.56300
8	-40.00000	54.89450	-17.02520
9	-34.99160	56.42050	-16.72650

TABLE 20. Response table for S/N ratio for MRR

Levels	Pulse on time (T_{ON})	Pulse off time (T_{OFF})	Peak current (I_P)
1	-38.27	-34.96	-36.24
2	-34.97	-36.13	-34.44
3	-33.98	-36.14	-36.54
Delta	4.29	1.18	2.10
Rank	1	3	2

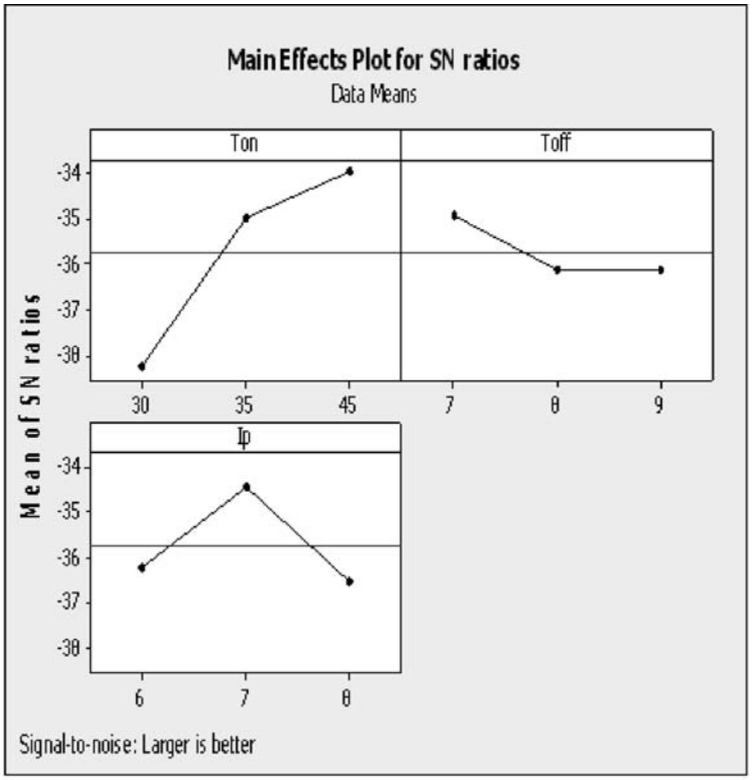

Fig. 6. S/N ratio curve for MRR with I_p, T_{on} and T_{off}

maximum effect on MRR, "I_p" have significant effect and "T_{off}" which has minimal effect on MRR (Fig. 6).

The regression analysis is handled to see the difference between principle effects in every level of the numeral on the MRR, EWR and R_a shown in Table 21.

TABLE 21. Statistical regression analysis for MRR Vs $T_{ON,}$ T_{OFF} and I_P

Predictor	Coefficient	SE Coefficient	T	p
onstant	0.008760	0.015550	0.560	0.5980
T_{on}	0.00044950	0.00017450	2.580	0.0500
T_{off}	-0.0008170	0.0013330	-0.610	0.5670
I_p	-0.0002670	0.0013330	-0.200	0.8490

S = 0.003264620 R-Sq = 58.5% R-Sq (adj) = 33.6%

The regression equation is

$$MRR = 0.00880 + 0.0004500\, T_{on} - 0.000820\, T_{off} - 0.000270\, I_p$$

TABLE 22. Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	p
T_{on}	2	30.2910	30.2910	15.1460	4.660	0.1770
T_{off}	2	2.7420	2.742	1.3710	0.420	0.7030
I_p	2	7.7540	7.7540	3.8770	1.190	0.4560
Residual Error	2	6.5000	6.5000	3.2500		
Total	8	47.286				

B. Effect of input parameters on EWR

Response table for EWR is shown in Table 23. For the calculation of S/N ratio, "Smaller is better quality characteristic" is used.

Referring Table-23, it is perceived that "T_{on}" ranks first which denotes that it has a maximum effect on EWR, "I_p" has significant effect and "T_{off}" has minimal effect on EWR (Fig. 7).

TABLE 23. Response table for S/N ratio for EWR

Levels	Pulse on time (T_{ON})	Pulse off time (T_{OFF})	Peak current (I_P)
1	56.58	55.44	56.01
2	55.17	54.91	55.36
3	54.53	55.93	54.92
Delta	2.04	1.02	1.09
Rank	1	3	2

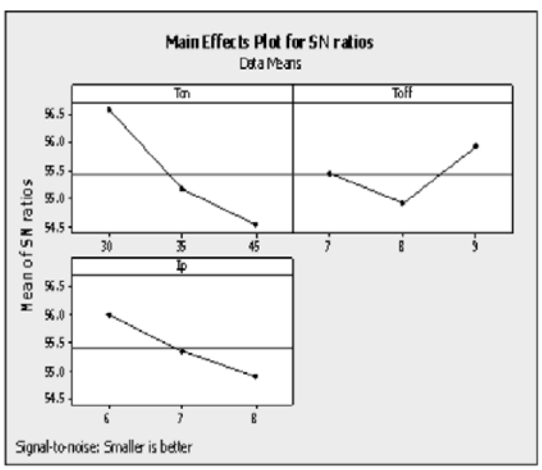

Fig. 7. S/N ratio curve for EWR with I_p, T_{on}, and T_{off}

The regression analysis is handled to see the difference between principle effects in every level of the numeral on the MRR, EWR and R_a shown in Table 24

TABLE 24. Statistical regression analysis for EWR Vs T_{ON}, T_{OFF} and I_P

Predictor	Coefficient	SE Coefficient	T	p
Constant	0.00048070	0.00084280	0.570	0.5930
T_{on}	0.000023240	0.000009440	2.460	0.0570
T_{off}	-0.000033330	0.000072080	-0.460	0.6630
I_p	0.000091670	0.000072080	1.270	0.2590

S = 0.0001765610 R-Sq = 61.2% R-Sq (adj) = 38.0%

The regression equation is

$$EWR = 0.0004810 + 0.0000230T_{on} - 0.0000330\,T_{off} + 0.0000920\,I_p$$

TABLE 25. Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	p
T_{on}	2	6.5560	6.5560	3.27810	2.140	0.3180
T_{off}	2	1.5480	1.5480	0.77420	0.510	0.6640
I_p	2	1.8000	1.8000	0.90000	0.590	0.6300
Residual Error	2	3.0610	3.0610	1.53060		
Total	8	12.9660				

C. Effect of input parameters on R_a

Response table for R_a is shown in Table 25. For the calculation of S/N ratio, “Smaller is better quality characteristic” is used.

Referring Response Table-26, It is perceived that “I_p” ranks first which denotes that it has a maximum effect on R_a, “T_{on}” have significant effect and “T_{off}” which has minimal effect on R_a. (Fig. 8).

TABLE 26. Response table for S/N ratio for R_a

Levels	Pulse on time (T_{ON})	Pulse off time (T_{OFF})	Peak current (I_P)
1	-16.44	-16.76	-16.02
2	-16.47	-16.55	-16.79
3	-16.82	-16.41	-16.93
Delta	0.38	0.35	0.91
Rank	2	3	1

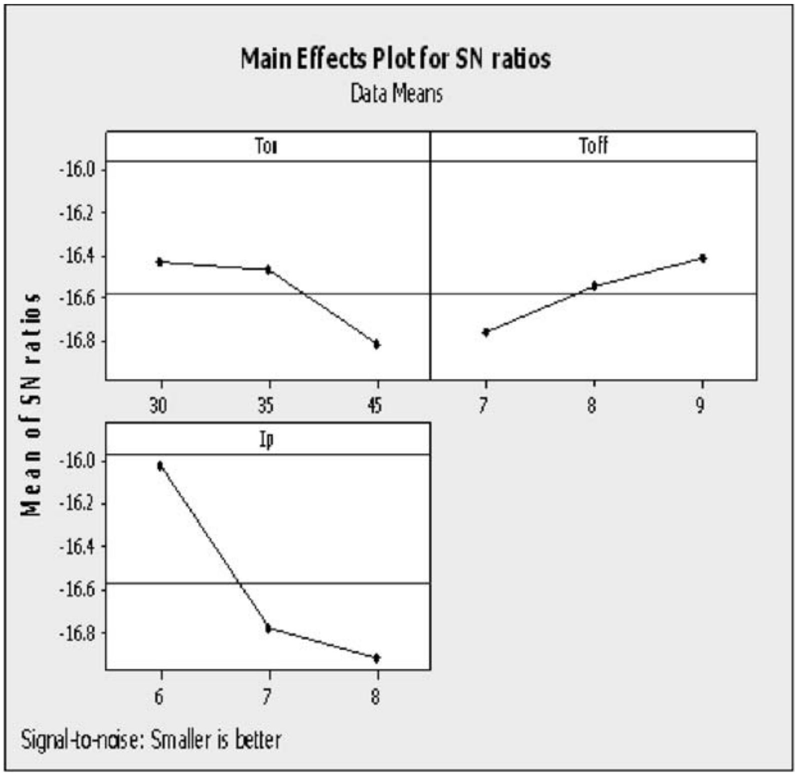

Fig. 8. S/N ratio curve for R_a with I_p, T_{on}, and T_{off}.

The regression analysis is handled to see the difference between principle effects in every level of the numeral on the MRR, EWR and R_a shown in Table 27.

TABLE 27. Statistical regression analysis for R_a Vs $T_{ON,}$ T_{OFF} and I_P

Predictor	Coefficient	SE Coefficient	T	p
Constant	4.6430	1.1580	4.010	0.0100
T_{on}	0.020000	0.012960	1.540	0.1840
T_{off}	-0.128330	0.099010	-1.300	0.2520
I_p	0.343330	0.099010	3.470	0.0180

S = 0.2425350 R-Sq = 76.3% R-Sq (adj) = 62.1%

The regression equation is

$$R_a = 4.640 + 0.02000\ T_{on} - 0.1280\ T_{off} + 0.3430\ I_p$$

TABLE 28. Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	p
T_{on}	2	0.27390	0.27390	0.136940	0.880	0.5330
T_{off}	2	0.18670	0.18670	0.093370	0.600	0.6260
I_p	2	1.43340	1.43340	0.716720	4.590	0.1790
Residual Error	2	0.31220	0.31220	0.156120		
Total	8	2.20630				

V. CONCLUSIONS

1. PEG (600) can be used as dielectric for machining Aluminium alloy in EDM. It gives high MRR and less EWR when compared to debris developing dielectric kerosene Polyethylene glycol PEG (600) gives less smoke and less odour and icreases productivity.
2. The material removal rate (MRR) is primarily affected by pulse on time (T_{on}) then peak current (I_p) has considerable effect on MRR. The pulse off time effect (T_{off}) is negligible.
3. The electrode wear (EWR) is primarily affected by pulse on time (T_{on}) then peak current (I_p) has considerable effect on EWR. The pulse off time effect (T_{off}) is negligible.
4. The surface roughness is primarily affected by peak current (I_p) then discharge on time (T_{on}) has Considerable effect on R_a. The discharge current effect (T_{off}) is negligible.

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