

EXPERIMENTAL RESEARCH OF ECOLOGICAL DIELECTRIC LIQUID IN ELECTRICAL DISCHARGE MACHINING

Marian-Ionuț Dragomir[1], Oana-Cornelia Popescu [2], Alexandra Banu[3], Liviu Daniel Ghiculescu[4]
[1] m.dragomir9618@gmail.com, Polytechnic University of Bucharest
[2] oanacorneliaaa@gmail.com , Polytechnic University of Bucharest
[3] alexandra.banu@upb.ro , Polytechnic University of Bucharest
[4]daniel.ghiculescu@upb.ro , Polytechnic University of Bucharest

ABSTRACT: Electrical Discharge Machining (EDM) processing takes place as a result of controlled electric discharges between the surface of the tool electrode and the surface of the machined part between which there is an electrically insulating working environment. The dielectric fluids used at EDM have a worrying impact on the environment and the human operator from two perspectives: the renewable source and the emission of volatile organic compounds (VOC's) that occurs during machining due to the resulting thermal effects. The classic dielectric fluid could be replaced with native vegetable oils. In the present paper, the possibility of replacing it with sunflower oil or rapeseed oil is studied, the research being oriented towards the study of their influence on the quality of the processing as well as on the emissions of volatile organic compounds. Preliminary results show that both ecologic oils can be potential alternatives as dielectric liquids.

KEYWORDS: EDM, dielectric, vegetable oil, ecology.

1. INTRODUCTION

EDM is the most used nonconventional technology that is part of the thermal erosion processing group because it uses the thermal energy to melt, vaporize and even boil the material of the processed part. This occurs as a result of controlled electrical discharges (with the formation of plasma channels) between the surface of the tool electrode and the surface of the machined part between which there is an electrically insulating working environment [1]. The most important applications of this process are found in the manufacture of dies, stamps, in the automotive, aerospace and surgical equipment. EDM has the capacity to use thermal energy to process high hardness conductive electrical components.

The productivity and quality of EDM depends on a large extent of both the electrical parameters used (ignition voltage, discharge current, pulse and pause time) as well as on the properties of the working gap, because the machining consists mainly in performing electrical discharges, and the fundamental quality of the working environment must be very high electrical resistance (the working fluid must be dielectric).

From the point of view of the impact on the environment, the dielectric fluids must be viewed from at least two perspectives: the renewable source and the emission of volatile organic compounds that occur during machining due to the resulting thermal effects. The dielectric fluid is imperative to have certain characteristics which include: high dielectric strength and rapid recovery after decomposition, effective extinguishing and washing capacity, not to be toxic and flammable at operating temperature, to be chemically passive in relation to the electrode material and part. Traditionally, the dielectric fluids used are hydrocarbon mixtures that undergo cracking processes (breakdown of molecules) with the formation of volatile organic compounds (VOCs) of which benzene and pyrene compounds have a high carcinogenic potential.

Given these issues over the last 50 years, a large number of studies have been developed at international level to replace hydrocarbons with other environmentally friendly dielectric media that have renewable sources and produce low emissions of polluting compounds.

Initially the research was carried out using water as a dielectric fluid, but over time studies with other liquids that can replace hydrocarbons are encountered.

Thus, in 1984 researchers Tariq Jilani and Pandey determined the performance of water as a dielectric liquid in EDM. They used distilled water, tap water and a mixture between the two 25% tap water and 75% distilled water. The best processing results were obtained with tap water. Using this liquid, the machining had the possibility to reach zero when removing a quantity of metal when copper electrodes with negative polarities were used [2].

In 1987 Koenig and Joerres carried out an experiment taking aqueous glycerine solution as an additive in water. They found that an aqueous solution of concentrated glycerine has an advantage compared to hydrocarbon dielectrics when working with long pulse lengths, high-frequency pulse factors and discharge currents, that is, with high open-circuit voltages in the field, defrosting and positive polarity of the tool electrode [3].

In 2006 Jayadas and Prabhakaran analysed and compared the cooling behaviour, thermal and oxidative stability of coconut oil with sesame oil, sunflower oil and mineral oil. Coconut oil has been found to improve tool life with superior surface finish for low-level processing [4].

Concerning the ecological dielectric fluids, special attention was paid to vegetable oils. These are triglycerides (glycerine unsaturated fatty acid esters). Among the most widespread unsaturated, fatty acids are those in the C18 group (18 C atoms in the molecule) with one, two or three double bonds. The presence of multiple bonds in the molecule decreases the resistance of the environment to oxidation at temperatures higher than 100 °C. The most stable vegetable oils are those that have a higher proportion of saturated vegetable fats, followed by fats based on oleic acid and the other more unsaturated acids. In choosing the type of oil for use in EDM processing, one of the criteria must be a degree of total unsaturation as low as possible.

The present paper aims to preliminary study the possibility of replacing classical dielectrics based on hydrocarbons with two types of indigenous vegetable oils: sunflower oil or rapeseed oil.

2. EXPERIMENTAL DATA

Experimental data are represented by materials and characterization techniques and measurement of emissions.

2.1 Materials:

Three types of dielectric fluids were used: a traditional P3 liquid, sunflower oil and domestic rapeseed oil. The material processed by EDM was C45 steel.

The traditional dielectric liquid P3 is a hydrocarbon-based liquid having optimum physical-chemical properties that allow it to act as a dielectric material. The P3 liquid properties are presented in Table 1 [5].

Table 1. Properties of P3 liquid [5]

Properties		P3 liquid
Density at 15°C [kg/mm^3]		840
Ignition point [°C]		104
Amount of aromatic hydrocarbons [%]		22
Kinematic viscosity (m^{2}s^{-1})	at 37.8°C	(2.2…3) x 10^{-6}
	at 22°C	(2.2…4.5) x 10^{-6}
Mineral acidity and alkalinity		no

2.2 Characterization Techniques

The characterization techniques are divided into two categories: characterization of vegetable oils and the machinability of C45 at using the studied dielectrics.

2.2.1 Characterization of vegetable oils

In order to use these oils as dielectric media in the EDM processes, the ENGLER relative viscosity and the electrical conductivity were measured, two fundamental properties for their good behaviour.

The relative viscosity was determined using an Engler viscometer at temperatures of 40, 60 and 80^{o}C respectively and the electrical conductivity was determined by a MeterLab CDM210 conductometer.

2.2.2 Machinability of C45 steel

The using of the three dielectric media was studied on ELER01 Romanian EDM machine with massive electrode from copper with the following technological input and output parameters:

- The inputs are the parameters of the machining mode: polarity (Pol), ignition voltage (U), current step (I), pulse time (t_i), pause time (t_o), flushing pressure of the gap (p_{sp}).
- The outputs are the technological parameters: productivity (Vw), relative volumetric wear (θ), surface roughness (Ra) and the quality of the machined surface.

The EDM process can be represented as a block diagram with inputs and outputs as in Figure 1 [6].

The productivity (the volume of material removed in the unit of time) was determined gravimetrically by the initial and final mass of the workpiece with an analytical balance, OHAUS type with the precision of 10^{-4} g.

Figure 1. Generic EDM Process

Table 2. The chemical composition of vegetable oils

Oils	Saturated fatty acids, total %	Mono unsaturated acids%	Poli unsaturated acids %	Linoleic acids %	Linolenic acids %	Vitamins	
						B-caroten (mg)	E (mg)
Sunflower	1,4	22,5	51-58	51-58	0,4	0,04	56
Rapeseed	1,0	64,3	34	15-29	1,7	NC	50
Peanuts	18,0	48	34	34	-	0,1-0,5	34
Olive	18,0	71	4-12	-	-	NC	NC

2.3 Measurement of Emissions

The amount of emissions emitted for each type of machining was determined using Cub Ion device and the processing of the acquired data was done with the equipment's software.

3. EXPERIMENTAL RESULTS AND DISCUSS

3.1 Characterization of vegetable oils

The chemical composition of used vegetable oils is presented in Table 2 according to the literature data [7].

From analysing the data presented in Table 2, it can be observed that olive and peanut oils have the highest content in unsaturated fats, meaning that they are the most stable at oxidation. For economic efficiency reason, two indigenous oils were chosen: sunflower oil and rapeseed oil. Despite the fact that rapeseed oil has only 1% content in saturated fatty acids, it contains up to almost 65% oleic acid (mono unsaturated), compared to sunflower oil which has a much lower percentage of oleic acid and consequently a high content of polyunsaturated acids.

- The viscosity of the two oils

For good machinability, the dielectric fluid must have a low viscosity to allow it to circulate in the work gaps, so as to achieve the removal of the collected material. The viscosity of a fluid is its resistance to the displacement of one of its layers relative to another layer. The ENGLER relative viscosity values of the oils were determined at three temperature values: 40, 60 and 80 ° C. These are presented in Table 3.

The relative viscosity corresponding to the 40ºC temperature is 1.87, meaning that rapeseed oil is almost twice as viscous as water, while sunflower oil (used in the experiments) is 1.5 times. It should be noticed that by increasing the temperature to 80 ºC the viscosity decreases, practically reaching a value, in the case of sunflower oil, equal to water. Rapeseed oil remains at 80ºC slightly more viscous than water.

Table 3. Viscosity

Oils	Temperature ^{0}C	Time (s)	^{0}E
Rapeseed-oil	40	94	1,87
	60	68	1,37
	80	56	1,07
Sunflower-oil	40	78	1,5
	60	60	1,15
	80	49	0.94

This leads us to the conclusion that sunflower oil is more suitable for machining.

From this point of view, it is ensured the interstitial flow and the evacuation of the collected material. This has also been verified during physical machining.

- The electrical conductivity of the oils

The electrical conductivity values measured in the laboratory are presented in Table 4.

Table 4. Conductivity

Environment	Conductivity (μS/cm)
Distilled water	183,3
Sunflower oil	142,2
Rapeseed oil	148,4

It was found that both oils have an electrical conduction close to that of distilled water.

It should be noted that the electrical conductivity of distilled water was measured from an open container in direct contact with the air.

Various researchers had carried out research work to assess the influence of different dielectric fluids on performance of EDM parameters such as material removal rate, electrode wear, surface roughness, overcut, white layer thickness, surface hardness, etc. Water can be used as substitute to hydrocarbon oil in EDM machining. It is more economic, safe and with less negative influence on environment and health when speaking about EDM machining [8].

After analysing the results presented in Tables 3 and 4, it is found that vegetable oils can also play the role of dielectric fluid.

Table 5. Calculation of productivity

Environment	Initial mass m_i (g)	Final mass m_f (g)	Processing time (min)	Volume of material taken Vp (mm^3)	Productivity Vw (mm^3/min)
P3	249.68	247.71	8	252.5641	31.57
Sunflower oil	246.77	244.83	8	248.7179	31.09
Rapeseed oil	225.84	223.93	8	244.8718	30.61

3.2 Machinability

3.2.1 The machinability of C45 steel

EDM machining was performed with a massive copper electrode that was connected to the negative pole of the current source constituting the cathode, and the piece to the positive pole constituting the anode.

For studying the machinability, the machine was set-up with the following values: intensity 24 A, pulse time 2s, pause time 1s, washing pressure 1bar.

The machining was carried out in three dielectric liquids: vegetable oils and the currently used liquid. Considering that rapeseed oil is twice as viscous as water at 40°C, for machining it was necessary to increase the liquid's pressure with a hydraulic pump.

The productivity was determined gravimetrically by weighing the piece before and after processing. The gravimetric results productivity are presented in Table 5.

Analysing the data from Table 4 it was found that the best machinability is found in the dielectric liquid used in the laboratory (P3) followed by the sunflower oil and then the rapeseed oil. It is worth mentioning that there are not very big differences in terms of machinability, so there are the premises for replacing the classic dielectric with an oil, the final choice being made on the basis of volatile organic compounds.

3.2.2 Determination of volatile organic compounds

During EDM machining with C45 steel electrode with both oils, the concentration's values of the volatile organic compounds emitted were recorded. The values processing was performed with the software of the IonCub device and materialized in the diagrams presented in Figure 2. The Cub is a personal portable gas detector that detects a pre-selected range of Volatile Organic Compounds (VOC's) which can be dangerous from both poisoning and explosive perspective. The Cub uses a Photoionisation Detector (PID) to measure gas concentrations. The Cub is used to check for conformity of short term exposure limits and time weighted averages that are specific for particular hazardous environments.

Interpreting the values shown in the graph above, it can be seen that one of the vegetable oils used (the rapeseed oil) had a relatively low emission level compared to the sunflower oil. The classical P3 dielectric liquid presents very high values of emissions of volatile organic compounds, this aspect being noticed also during the visual processing and also olfactory.

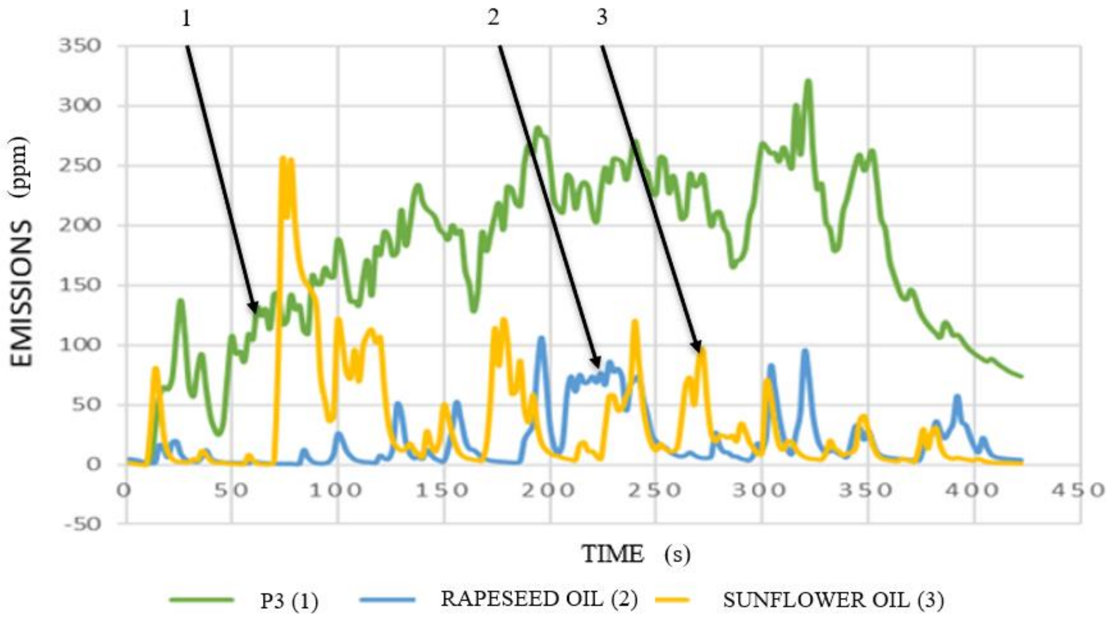

Figure 2. Emissions of volatile organic compound during machining

Another solution with low pollution emission resulted from EDM process consists in using a mix of two different densities of n-paraffin dielectric liquids, one that appropriate for roughing (at large working gap) and another one for finishing (small working gap) [9].

4. CONCLUSIONS

Based on the experimental data resulted from this research, the following conclusions were formulated:

- Selecting the dielectric fluid for EDM is an important task, as it has a special effect on the performance of the machining, the economy and the impact of the process on the environment.

- For more than 50 years, different researchers have been working to replace dielectric fluid based on hydrocarbon mixtures. They present a dangerous action, especially as they form volatile organic compounds with a high carcinogenic potential.

- The present paper aims to study the possibility of replacing the dielectric with two indigenous vegetable oils, sunflower oil and rapeseed oil, orienting research towards the influence of the proposed dielectric on the quality of machining as well as on the emissions of volatile organic compounds. To be used in the EDM process, the two vegetable oils were subjected to the ENGLER relative viscosity determination test, resulting that the sunflower oil is more suitable for processing, ensuring interstitial flow and allowing the evacuation of the removed material, also verified during machining. From the point of view of electrical conductivity, sunflower oil and rapeseed oil have values close to those of distilled water, which is being used in certain researches as dielectric liquid, which strengthens the use of these two types of oils as dielectric liquids.

- The machining was carried out with the same parameters for the two types of oils but also for the generic P3 oil, the machining rate having distinct values with no big differences. Therefore, from this point of view, the classic dielectric liquid based on hydrocarbons can be replaced with one of the two oils.

- The emissions of the registered volatile organic compounds have distinct values, so that the rapeseed oil produces less pollution than the sunflower oil.

- For future experimental research we will focus more on machining performances, in order to be able to ascertain whether from this point of view, the using these dielectric oils is reliable.

5. REFERENCES

1. Ghiculescu, D. *Computer aided Engineering and Machining in Nonconventional Processes*, (in Romanian), Printech, Bucharest, (2013).
2. S. Tariq Jilani, P.C. Pandey, Experimental investigations into the performance of water as dielectric in EDM, International Journal of Machine Tool Design and Research 24 (1984).
3. Koenig, W., Joerres, L., An aqueous solutions of organic compounds as dielectric for EDM sinking, *CIRP Annals—Manufacturing Technology*, Vol. 36, pp. 105–109, (1987).
4. Jayadas, N.H., Prabhakaran Nair K. (2006), Coconut oil as base oil for industrial lubricants—evaluation and modification of thermal, oxidative and low temperature properties, Tribology. Intl, 39, pp. 873–878.
5. Ghiculescu, D. și Marinescu, A., Performances obtained with local air purification system with active coal at EDM, *Revista de Ecologie Industrială*, nr.10, pp.12; (2000).
6. Ghiculescu, D., Nonconventional machining (in Romanian), Printech, Bucharest, (2004).
7. Dorobanțu, P., Scientific Works – Vol. 51, Agronomy series , pp. 391-396, (2008).
8. Sanghani, C.R, Acharya, G.D, Trends in Mechanical Engineering & Technology, Effect of Various Dielectric Fluids on Performance of EDM: A Review, volume 6 (issue 1), (2016).
9. Ghiculescu et al., *Dielectric liquids for electrical discharge machining*, Romanian Patent, RO-113.955, (1998).