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Effect of Dielectric Fluid in EDM: A Review

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Abstract – Electrical Discharge Machining (EDM) is widely used non-traditional process for the production of miniaturized products with high precision and accuracy. In this process material removal takes place by thermal erosion between workpiece and electrode both of which are dipped in dielectric fluid. Initially, high voltage is applied, when current pass through circuit, about 8000-10000 ^{0}C temperature is created causing to melt and vaporize the area of workpiece. In electrical discharge machining (EDM), the working fluid plays an important role affecting the different response variables such a material removal rate, surface finish, etc. The machining characteristics are greatly influenced by dielectric fluid used in EDM. Health, safety and environment are important factors, especially when hydrocarbon based dielectric fluids are used. Due to release of toxic emission products cause environmental impact, operator health issues due to release of toxic fumes, vapours and aerosols during the process, also fire hazards and electromagnetic radiations are harmful. Non-biodegradable wastes are generated. To rectify these problems, replacement of dielectric fluid is main concerns in EDM research. This paper presents literature review of different dielectric fluids used and their effects on different response variables and characteristics of machining. This paper suggests that vegetable oil may be an alternative.

Keywords – Electrical Discharge Machining, Dielectric Fluid, Hydrocarbon Oil, Vegetable Oil, Sustainability.

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1. INTRODUCTION

With the development of micro-electromechanical systems (MEMS) and devices, micromachining has gained much importance in manufacturing industry. Need for mass manufacturing of miniaturized product is growing. Miniaturized products from different super alloys are required for industries such as aerospace, automotive, biomedical and military applications, etc. Many non-traditional machining methods which are developed in recent years are able to meet these demands *[1].* Electrical Discharge Machining (EDM) is one of those non-traditional methods, which is able to machine miniaturized parts with precision and accuracy.

2. LITERATURE REVIEW

A. Electrical Discharge Machining (EDM)

Electrical discharge machining (EDM) is one of the most popular non-traditional material removal processes and has become a basic machining method for the manufacturing industries like aerospace, automotive, nuclear, medical and die-mould production.

In this process thermal energy is used to generate heat that melts and vaporizes the work piece by ionization within the dielectric medium. The electrical discharges generate impulsive pressure by dielectric explosion to remove the melted material. Thus, the amount of removed material can be effectively controlled to produce complex and precise machine components.

EDM processes are classified into die-sinking EDM and Wire- EDM. The electrode of die-sinking EDM has the reversed shape of the part to be machined, while Wire-EDM uses thin wire, ranging from 0.01 to 0.36 mm in diameter, as the electrode *[2].*

B. Mechanism of Material Removal

The mechanism of material removal in the EDM process can be explained with the help of figure 1. When small gap is maintained between electrode and workpiece, discharge built up and free positive ions and electrons are accelerated. They gain very high speed and rapidly form a conductive channel called plasma channel, as in figure 1(a). At this stage the current flow and the spark builds up between the electrodes resulting in a large number of collisions. Temperature within that plasma channel is about 8000-10000 ^{0}C which causes local and instantaneous melting of material at the surfaces as shown in figure

1(b). When the current is stopped, the sudden drop in temperature causes the bubble to burst expelling the melted material out of that channel as in figure 1(c). The eroded material then resolidifies in the dielectric in the form of small spheres and is evacuated by the dielectric *[3].*

Dielectric fluid plays very important role in electrical discharge machining. Different response parameters such as material removal rate (MRR), tool wear rate (TWR), surface roughness (SR), recast layer, hardness etc. are affected greatly by dielectric fluid used in EDM. Therefore, literature review is carried out with respect to the effect of dielectric fluid used on response parameters and tabulated in table 1.

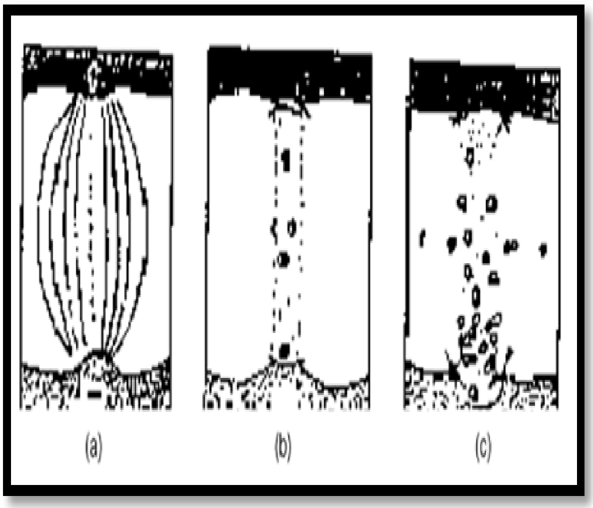

Fig. 1 Principle of EDM process (a) Plasma channel created (b) Melting of material (c) Burst bubble *[3]*

Kibria et al. *[4]* addresses the issues of micro-EDM using different types of dielectrics and the influence of these dielectrics on the performance criteria. Figure 2 and 3 show the comparative plots of the MRR and TWR, respectively using different dielectrics for varying pulse-on-time (Ton). MRR is high with deionized water than kerosene for all considered settings during experimentation. When hydrocarbon oil was used, the decomposed carbon adhered to the surface of the electrode and titanium carbide (TiC) was formed on the workpiece surface. As the carbide has a higher melting point, the impulsive force during discharge is unstable, thus reducing the material removal rate. When distilled water was used, no carbon adhered to the surface of the electrode and titanium oxide (TiO_2) was formed on the workpiece surface. As the oxide has a lower melting point than the carbide, the impulsive force of discharge was much more stable and the material removal rate was higher.

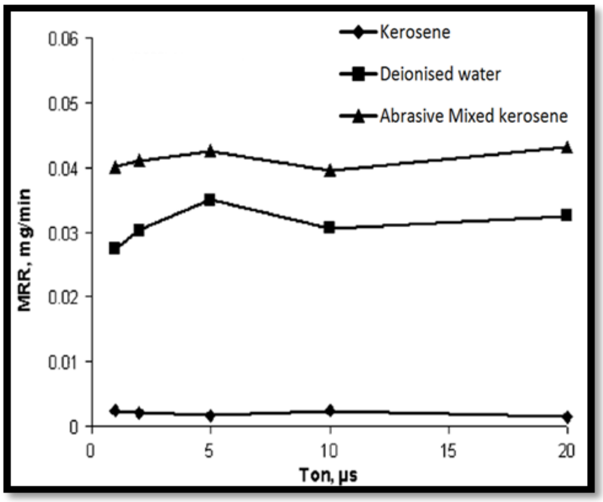

Fig. 2 Variation of material removal rate (MRR) with pulse duration (Ton) at fixed peak current (Ip) of 2A for different dielectrics *[4]*

Figure 3 reveals that TWR is high using deionized water compared to kerosene dielectric. Kerosene decomposes at elevated temperature and produces carbon particles that adhere to tool electrode surface. These carbon particles restrict the rapid wear of the tool. But deionized water does not produce any carbon during machining and thus no such protective carbon layer formed on the tool surface. But in contrast, more burning occurs in the discharge zone causing more tool wear with deionized water. When machining is done with boron carbide abrasive mixed to both dielectrics, the tool wear is less due to the presence of more number of carbon particles evolving from the decomposition of dielectrics as well as boron carbide abrasive in the machining zone *[4].*

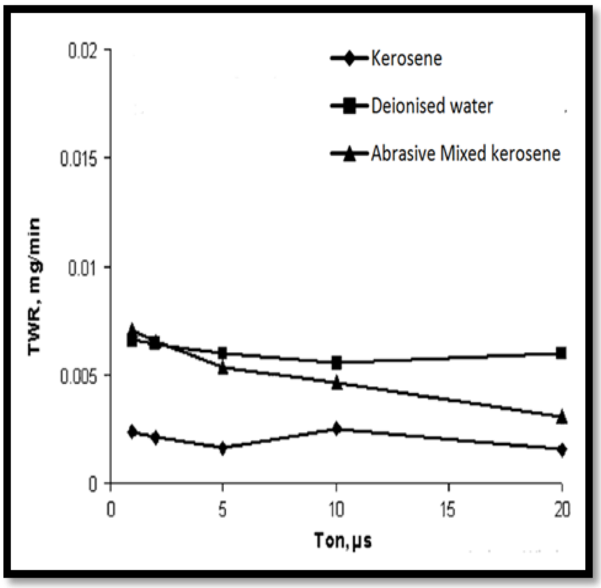

Fig. 3 Variation of tool wear rate (TWR) with pulse duration (Ton) at fixed peak current (Ip) of 2A for different dielectrics *[4]*

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Table 1 Literature Review [5-19]

Ref.	Dielectric Fluid and Process Parameters	Research findings
Chen et al. [5]	Kerosene, Distilled Water Voltage=150V, Discharge Current=3-24A Pulse Duration=10-200μs Working Time=20min	MRR is greater and TWR is lower when distilled water is used compared to kerosene. Carbide is formed on the workpiece surface when using kerosene while oxide is formed on the workpiece surface when using distilled water. Distilled water is decomposed into hydrogen and oxygen, the released oxygen in distilled water accounts for the increase in the discharge stability, resulting in a greater material removal rate. With kerosene as dielectric fluid, stuck carbon to the electrode reduces the discharge efficiency and thus affecting the TWR while in contrast distilled water has less TWR. Debris size is more in distilled water and micro-cracks are observed.
Yu et al. [6]	Oxygen, EDM oil Voltage=260V, Discharge current=100A, Pulse Duration=30 μs, Discharge interval= 5μs	Work removal rate of dry EDM milling is about six times larger than that of oil EDM milling. In dry EDM, when oxygen is supplied as working fluid, oxidation reaction occurs. This helps to increase the work removal volume under the same discharge energy. As dry EDM is free from vaporization of liquid working fluid when electrical discharge occurs, physical damage of the tool electrode caused by reactive force is small causing lower electrode tool wear. Dry EDM milling shows higher machining speed oil EDM milling. In comparing dry EDM with oil die sinking EDM for machining the same shape using cemented carbide, oil die sinking EDM shows shorter machining time. But as oil die sinking requires time for producing electrodes, dry EDM should be more useful in actual production.
Leao and Pashby [7]	Plain water, Distilled water, Water with organic compound, Gaseous fluid	Hydrocarbon oils are more efficient than deionised/distilled water in die sink applications. Some authors have studied the feasibility of adding organic compounds to deionised water and obtained a performance higher than that of hydrocarbon oils for roughing and finishing operations. Some commercial water-based fluids have performance similar or higher than that of hydrocarbon oils. A specific product may provide material removal rates 2–3 times higher than that achieved with hydrocarbon oil and lower cost per part. Surface roughness produced with deionised water is generally lower than that of hydrocarbon oils. Parts machined with hydrocarbon have an increase in the carbon content. In contrast, parts machined with water have a decrease in the concentration of carbon. As a result, the microhardness of the white layer is generally higher when hydrocarbon oil is used as the dielectric. Higher concentration of micro-cracks is produced with water-based dielectrics as opposed to hydrocarbon oils.
Bai and Koo [8]	Kerosene, Distilled water Discharge current=10A Pulse duration=600μs Duty factor=0.33 Working time= 360s	When kerosene is used as a dielectric, the carbon decomposed from kerosene adheres on the machining surface and then mixed into the molten surface of the workpiece during the EDA process. Also, kerosene is flammable and the gaseous chemicals produced from kerosene are poisonous. The distilled water is non-flammable and harmless. As oxygen is decomposed when distilled water reacts with workpiece and electrode during machining forming oxides and dispersed on the surface layer of the workpiece. This in turns increases surface hardness and corrosion resistance. The maximum hardness of part with water exceeds that of Kerosene because the resolidification rate of molten substrate in distilled water exceeds that in kerosene. However, the Kerosene specimen has the finest surface morphology, the thickest alloyed layer, and the slowest oxidation rate.
Kibria et al. [9]	Kerosene, Deionised water, Boron powder mixed kerosene, Boron powder mixed deionised water	Material removal rate is high with deionized water dielectric compared to pure kerosene. This is due to formation of titanium oxide (TiO_2) layer on workpiece surface when deionized water is used, which melts in lower discharge energy compared to melting of titanium carbide (TiC) formed in case of kerosene. TWR is more with deionised water than kerosene as adhere carbon to electrode restricts the wear. White layer or recast layer formed is less during machining with deionized water compared to pure kerosene. The topography of inner-machined surface is smooth when employing pure deionized water compared to kerosene. Performance of boron powder mixed fluid is better in all aspects due to efficient distribution of discharge.
Zhang et al. [10]	Oxygen, Air, Deionised Water, Kerosene, Water in oil (W/O) emulsion Pulse duration= 52,105,210,420,840 μs	In kerosene, less volume of material was melted compared to other dielectrics. The removal efficiency was higher in liquid dielectrics than that in gaseous dielectrics; higher at short pulse duration than that at long pulse duration. In water in oil (W/O) emulsion, high pressure can sustain for a much longer time than that in kerosene and de-ionized water due to the extremely high viscosity of the W/O emulsion. The higher material removal efficiency in liquid dielectrics, especially in W/O emulsion, was due to the higher pressure above the discharge point.
Chakraborty et al. [11]	Kerosene, Pure water, Water with additives, Oil with additives, Gaseous fluid	Hydrocarbon oils results better in die sink application, but machining in distilled water also resulted in a higher MRR and a lower wear ratio than hydrocarbon oils when a high pulse energy range was used. With distilled water, the machining accuracy is poor but the surface finish is better. The best machining rates have been achieved with the tap water. Surface roughness produced with deionised water is generally lower than that with hydrocarbon oils. Deionised water with organic compounds has an advantage over hydrocarbon dielectrics in terms of MRR. PMEDM can also improve machining efficiency in roughing operations by reducing insulating strength and thus increases the spark gap between the tool and the work piece. EDM process becomes more stable and improves MRR and SQ also. Electric discharge machining can also be achieved with gaseous dielectrics such as air and oxygen. It is found that gaseous dielectric can provide higher material removal rates than that with hydrocarbon oil.
Uhlmann et al. [12]	Water, oxygen, Argon Capacitance=10,15 nF Pulse duration= 1.5,4.2,4.7μs Pulse interval=64.8,75μs Charging current=3,1.2A Open voltage=100,200V	Roughing process with oxygen was much faster than the other two dielectric fluids and also presented a satisfactory bore quality. With deionized water presented higher erosion time, lower electrode relative wear and smaller recast and white layers. Those are important outputs desired for a finishing process. The dry-EDM with argon had the higher erosion time; it enables the erosion bore holes with small recast and white layers and sharp edges. An advantage is the extreme low electrode relative wear, which is influenced by the inert gas properties of argon.
Singh and Sharmac[13]	Graphite powder mixed EDM oil, Distilled water, Kerosene Pulse duration=15,50,100μs Current= 3,6,9A Flushing press=0.2,0.4,0.6 kg/cm^2	MRR and TWR both are more with distilled water. Powder mixed fluid provide more efficient machining. Aerosol concentration and dielectric consumption are two genuine main concerns; a significant need to introduce new dielectric fluid substitutions, given that dielectric fluid is a major factor responsible for the environmental concerns identified in this study.
Nevagi et al. [14]	EDM oil Current=10,20A Dielectric flow rate=2750, 3100 ml/min Pulse ON time=5, 30 μs	MRR increases with current due to increase in the number of electrons bombarding the workpiece material. These electrons release heat energy which melts and vaporize the workpiece. The increase in pulse ON time decreases MRR due to decrease in intensity of spark with increase in pulse ON time. Increase in the current increases the TWR is due to increase in the number of sparks between tool and workpiece.
Jagtap and Dabade [15]	EDM oil, Dry EDM with air	MRR increases with pulse ON time as spark stays for longer time and thus removes material. As there is no current flow during pulse OFF time, there is no spark and no material removal. Machining voltage, capacitance and current are the significant parameters affecting surface finish. Larger capacitance and voltage result in deeper crater and thus rough surface. Polarity also affects the surface finish as cathode erosion rate is lower than anode erosion rate. Dry WEDM without airflow has lower MRR than dry WEDM with airflow. This is due to low viscosity of air, which results in smaller explosive force and less MRR for each spark. By introducing air flow the debris can be removed effectively.
Kao et al. [16]	Deionised water, Air, Water+Air Water flow rate= 5,8,15,21,35,50,75 ml/min	The wet EDM has a significantly higher MRR than that of the dry EDM. At low pulse intervals, frequent EDM pulses generate concentrated heat and lead to wire breakage. The minimum value of pulse interval that can be reached at high level of T_{ON} without wire breakage is greatly dependent on the dielectric fluid used. The near dry EDM has a consistently higher MRR than that of dry EDM for all TON and TOFF. However, the wire breakage, due to the lower capability of water–air mixture TOFF relieve the concentrated heat from the wire electrode, still limits the MRR in near dry EDM at low TOFF. Nevertheless, near dry EDM shows two advantages. First, there is no short circuit limit at the lower boundary. Second, in the region of very low-energy input, the MRR in near dry EDM is higher than that of the wet EDM. A much higher flow rate is required to increase the MRR because the nozzle is set near the discharge gap and thus not all water droplets are successfully delivered into the gap. The gap distance of wet EDM is wider than that of near dry EDM. This is likely caused by the lower viscosity of the water–air mixture. Similarly, in near dry EDM, higher water flow rate generates larger gap distance. No debris deposition is observed for near dry EDM. This occurs because water–air mixture has a better flushing capability than the air jet in dry EDM.
Dhakar et al. [17]	Water+air, Glycerin+air, EDM oil+air Current= 9,12,15A Duty factor=0.7,0.75,0.8 Flushing Pressure= 40,60,80 psi	Glycerin-air dielectric medium produces more molten metal in molten puddle in comparison with other combinations of dielectric mediums. In this case, increased distance between tool and workpiece provides efficient flushing at IEG. The EDM oil-air dielectric medium provided slightly higher MRR than water-air dielectric at lower and higher discharge energies. EDM oil-air mixture generates more thermal energy at IEG than water-air mixture because EDM oil being a hydrocarbon based oil decomposes during near-dry EDM. Thus, it creates an exothermic reaction with oxygen present in air. It results in generating more heat energy at IEG than water-air mixture. The tool wear rate was almost zero in near-dry EDM. The EDM oil-air gives rough surface as compared to water-air dielectric medium. Whereas, opposite trend was observed with glycerin-air dielectric medium. Glycerin-air mixture produces higher heat energy than other dielectric mediums. It may occur due to the explosive reaction of glycerin when it decomposes with a spark. It was observed that recast layer were produced by water-air and EDM oil-air but glycerin-air dielectric medium did not produce any measurable recast layer.

Valaki and Rathod [18]	Kerosene, Waste Vegetable Oil (WVO) Current=3,6,9,12,15,18A Gap Voltage=30,40,50,60,70,80V Pulse duration=21,50,100,200,400µs Pulse interval=6,11,20,30,40,75µs	The comparative results obtained in this research show that from the operational feasibility point of view, WVO dielectrics can be used as an alternative to hydrocarbon-based dielectric fluid, i.e. kerosene. Trends of response parameters, i.e. MRR, EWR and TWR, obtained using WVO indicate similarity with results of kerosene. Because of higher BD voltage, oxygen content, viscosity and thermal conductivity of WVO, ionisation state of dielectric in the discharge gap sustained for a longer time resulting in improved melting and evaporation phenomenon. Hence, higher MRR is obtained for WVO than kerosene. Higher viscosity confines the plasma channel and higher thermal conductivity ensures better heat transfer and electron movement toward the electrode side, which eventually increased EWR in case of WVO. Thus WVO can be a cleaner, greener and safer solution for improving sustainability of EDM process. In addition, WVO-based dielectric fluid improves environmental friendliness, operational safety and personal health issues of the process.
Valaki et al. [19]	Kerosene, Jatropha oil Current=3,6,9,12,15,18A Gap Voltage=30,40,50,60,70,80V Pulse duration=21,50,100,200,400µs Pulse interval=6,11,20,30,40,75µs	Results show that trends obtained with jatropha oil are same as that of kerosene. It resulted in higher MRR, lower SR and higher SH. Higher Breakdown voltage of Jatropha increased spark energy density, higher average temperature due to higher oxygen content causes improved melting and vaporization; efficient flushing due to higher density and better energy due to higher viscosity produced higher MRR for Jatropha. Higher thermal conductivity and lower specific heat causes better heat transfer to the surrounding dielectric media to produce shallower craters and thus lower SR. Results obtained in this research proves that Jatropha oil is operationally feasible and better dielectric than kerosene for EDM process. It can be a cleaner, greener and safer solution for improving sustainability of EDM process.

3. CONCLUSIONS

Work has been carried out on effect of different dielectric fluids used in EDM. Some of them are regarding literature survey on effects of dielectric fluid while others have carried out experiments with different dielectric fluids.

Hydrocarbon oil gives better results in die sinking EDM but hazardous fumes from oil affects environment and health of the operator. Some experiments were performed with water based fluids like distilled or deionised water, tap water etc. It resulted in better MRR, less TWR and better surface finish but recast layer and micro-cracks are produced.

Feasibility of adding powder additives to dielectric fluid were studied. Such a dielectric fluid with powder additives provided better results in all aspects than original fluid. But to obtain better results it is necessary to provide ultrasonic vibrations, therefore system becomes bulky and add cost also. At the same time it gives rise to more aerosol emissions which are harmful to the environment as well as health of the operator.

Experiments with vegetable oil resulted in better performance than conventional fluids. As vegetable oils are biodegradable, neither they harm environment nor health of the operator and thus may be an alternative solution to conventional dielectric fluids. But further study is necessary in this regard.

REFERENCES

[1] B. Kuriachen, K. P. Somashekhar and J. Mathew, “Multiresponse optimization of micro-wire electrical discharge machining process”, Int. J. Adv. Manufacturing Technology, 2015, volume 76, pp 91-104.

[2] “Chapter 1-Introduction to EDM”, http://shodhganga.inflibnet.ac.in/bitstream/10603/9876/6/06_chapter%201.pdf, Last visited on 30th December, 2016 at 12:53PM.

[3] S. Kuriakose, K. Mohan and M.S. Shunmugam, “Data mining applied to wire-EDM process”, Journal of Materials Processing Technology, 2003, volume 142, pp 182–189.

[4] G. Kibria & B. R. Sarkar, B. B. Pradhan and B. Bhattacharyya, “Comparative study of different dielectrics for micro-EDM performance during microhole machining of Ti-6Al-4V alloy”, Int. J. Adv. Manuf. Technology, 2010, volume 48, pp 557-570.

[5] S.L. Chen, B.H. Yan and F.Y. Huang, “Influence of kerosene and distilled water as dielectrics on the electric discharge machining characteristics of Ti-6A1-4V”, Journal of Materials Processing Technology, 1999, volume 87, pp 107-111.

[6] Z. Yu, T. Jun and K. Masanori, “Dry electrical discharge machining of cemented carbide”, Journal of Materials Processing Technology, 2004, volume 49, pp 353-357.

[7] F. N. Leao and I. R. Pashby, “A review on the use of environmentally-friendly dielectric fluids in electrical discharge machining”, Journal of Materials Processing Technology, 2004, volume 149, pp 341-346.

[8] C. Y. Bai and C. H. Koo, “Effects of kerosene or distilled water as dielectric on electrical discharge alloying of super alloy Haynes 230 with Al–Mo composite electrode”, Surface & Coatings Technology, 2006, volume 200, pp 4127-4135.

[9] G. Kibria, B. R. Sarkar, B. B. Pradhan and B. Bhattacharyya, “Comparative study of different dielectrics for micro-EDM performance during microhole machining of Ti-6Al-4V alloy”, International Journal of Advance Manufacturing Technology, 2010, volume 48, pp 557-570.

[10] Y. Zhang, Y. Liu, Y. Shen, R. Ji, Z. Li and C. Zheng, “Investigation on the influence of the dielectrics on the material removal characteristics of EDM”, Journal of Materials Processing Technology, 2014, volume 214, pp 1052-1061.

[11] S. Chakraborty, V. Dey and S.K. Ghosh, “A review on the use of dielectric fluids and their effects in electrical discharge machining

characteristics", Precision Engineering, 2015, volume 40, pp1-6

[12] E. Uhlmann, T. M. Schimmelpfennig, I. Perfilov, J. Streckenbach and L. Schweitzer, "Comparative Analysis of Dry-EDM and Conventional EDM for the Manufacturing of Micro holes in Si3N4-TiN", CIRP Conference on Electro Physical and Chemical Machining, 2016, volume 42, pp 173-178.

[13] J. Singh and R. K. Sharma, "Assessing the effects of different dielectrics on environmentally conscious powder-mixed EDM of difficult to machine material (WC-Co)", Front. Mech. Engg., 2016, pp 1-14.

[14] V. L. Jagtap and U. A. Dabade, "Effect of process parameters during electrical discharge machining of Inconel-718", Proceeding of National Conference on Recent Advances in Manufacturing, 2010, pp 139-142.

[15] S. P. Negavi, S. S. Kamat and U. A. Dabade, "A review of Wire EDM process", Proceeding of National Conference on Recent Advances in Manufacturing, 2010, pp 133-138.

[16] C.C. Kao, J. Tao and Albert J. Shih, "Near dry electrical discharge machining", International Journal of Machine Tools & Manufacture, 2007, volume 47, pp 2273-2281.

[17] K. Dhakar, A. Dvivedi and A. Dhiman, "Experimental investigation on effects of dielectric mediums in near-dry electric discharge Machining", Journal of Mechanical Science and Technology, 2016, volume 30(5), pp 2179-2185.

[18] J. B. Valaki and P. P. Rathod, "Assessment of operational feasibility of waste vegetable oil based bio-dielectric fluid for sustainable electric discharge machining (EDM)", Int. J. Adv. Manuf. Technology, 2015, pp 1-10.

[19] J. B. Valaki, P. P. Rathod and C.D. Sankhavara, "Investigations on technical feasibility of Jatropha curcas oil based bio dielectric fluid for sustainable electric discharge machining (EDM)", Journal of Manufacturing Processes, 2016, volume 22, pp 151-160.

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