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Uses of Various Dielectrics in Electro Discharge Machining (EDM) – A Critical Review

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Abstract:- Electro discharge machining (EDM) is a non-conventional machining process, in this process does not require any mechanical contact between the electrode and the workpiece. Usually, the dielectric fluids are used to create a connection to the electrode and the workpiece. Generally, fluids (kerosene, EDM oil, gasoline, deionized water, etc.) and gases (oxygen, helium, etc.) are used as dielectric in the EDM process, which serves as electrical insulators and semiconductor between electrode and workpiece. Also, the fluids remove the dust particles from the machining surfaces of the workpiece. However, the liquid medium is widely used in the EDM process. On the other hand, the gaseous dielectric is also often used to fill in any specific need. Nowadays, mixed dielectric fluids are very commonly used for machining purposes, because of some lack of efficiency with plane dielectric fluid. In this study, it is shown the advantages of several dielectric mediums (liquid and gas) in the EDM process for different materials. Furthermore, it also reviewed how to improve output parameters with respect to input parameters with the help of various types of mixed dielectric fluids.

Keywords:- Electrical discharge machining, Dielectric fluids, Dielectric gases, Input parameters, Output parameters.

I. INTRODUCTION

In the year 1770, Joseph Priestley, the english physicist first discovered the erosive effect of the EDM process. After that, Russian scientists B.R Lazarenko and N. I Lazarenko in the year of 1940 discovered the EDM process [1]. After that, scientists from the Soviet Union developed the EDM machine in the year of 1967 [2]. EDM is not a traditional method [3], which is basically used for machininh of hard metals (like Ni based super alloys, Titanium, Hastelloy, etc.) and which would be very difficult to machine in the conventional method (like lathe, planning, etc.) [4][5]. Also, EDM works with electric conductive materials (like aluminum, copper, etc.), although the methods are proposed for ceramics [4]. However, EDM can be cut in pre-hardened steel with complicated shapes or cavities. Furthermore, machining performance of EDM is depends on diferent input parameters such as pulse time (on and off), current, voltage, etc. [6], also dielectric fluids (like kerosene, EDM oil, deionized water, etc.) are used. The responses are material removal rate (MRR), surface roughness (SR), tool wear rate (TWR), recast layer thickness (RLT), etc. As the dielectric medium, liquid (such as kerosene, EDM oil, vegetable oil, etc.) and gaseous (such as oxygen, helium, etc.) can be used [7]. If the liquid dielectric medium is used, then the EDM process is called wet EDM machining, and likewise gaseous substances are used as dielectric for dry EDM machining. It has been observed from the previous literature review that wet EDM is capable for giving batter MRR compared to dry EDM [8]. Mostly dielectric fluids (such as kerosene, EDM oil, jatropha curcas oil) are used for wet EDM machining. However, kerosene and deionized water are widely used in EDM process [9][10][11][12]. The present study reviewed the advantages dielectric medium (liquid and gas) and mixed dielectric fluids on responses with different materials. Also reviewed the improvement of responses on input parameters.

II. MAIN TEXT

Generally, Three Types Of EDM Are Used In Mordern Industries [13][14], These Are

- *Die sink EDM*
- *WEDM*
- *Micro EDM*

A. Types of EDM

➢ *Die Sink EDM:-*

Nowadays die sinking EDM is widely used in many sectors of modern industry [15]. Many works on this form of EDM are already underway [16][17][18][19]. Die sink EDM is also referred to as cavity-type EDM. The electrode and workpiece are submerged in the dielectric fluid when the machining operation is underway (Fig. 1). The workpiece and electrode both are connected to an appropriate power supply (DC). Dielectric fluids break down into positive and negative ions while the power supply is on. Metal ions are released from the workpiece during the process, and electrons are released from the electrode and created sparks between them. During the sparking, the temperature increased up to 8000°C-12000°C, for this reason, metals are eroded from the surfaces.

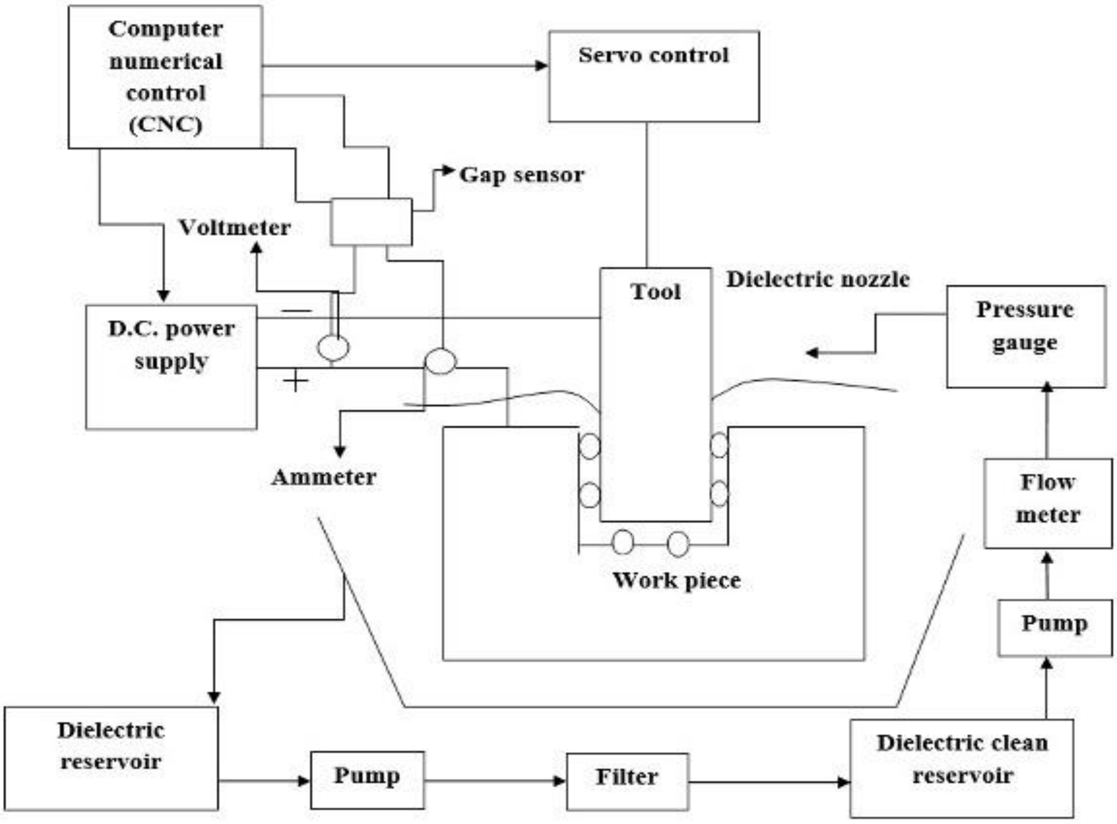

Fig 1 Block Diagram of Die Sink EDM

➢ *Wire Cut EDM (WEDM):-*

WEDM is commonly used for complex structure cutting [13][14][20][21]. WEDM is also known as spark EDM. A thin wire (such as copper, zinc, molybdenum, etc.) is broadly used as a cutting tool. The diameter of the wire varies 0.1-0.3 mm. In this process, a maximum 300 mm thick workpiece can be cut. In this method does not require high cutting forces to remove the material. Furthermore, WEDM process is burr-free and does not require any mechanical contact between the workpiece and the cutting tool. Generally, the WEDM system has five-axis motions i.e., x, y, z, u and v. The first two axes (x and y) practically used for the movement of machine bed. The z-axis is used for controlling the motion of the wire. Mainly the last two-axes (u and v) are used to create the taper shape. Fig. 2, shows the schematic representation of WEDM method.

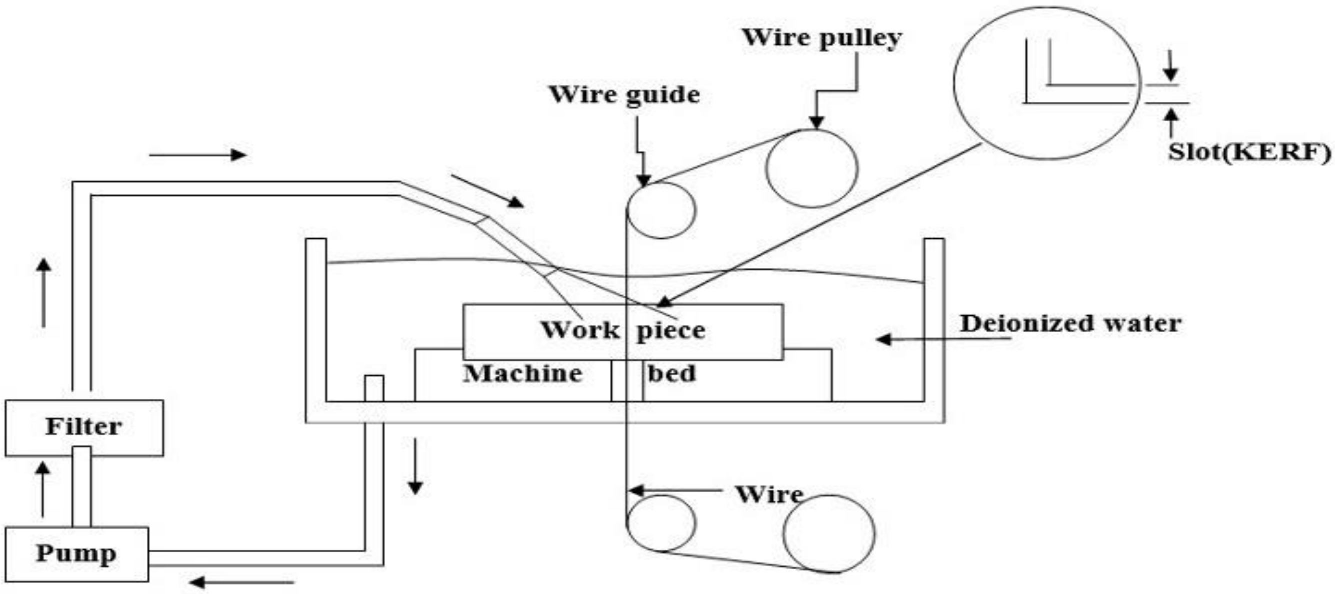

Fig 2 Block Diagram of WEDM

➢ *Micro(µ)- EDM*

Micro (µ)-EDM has been able to be used to generate complex microstructures [22][23]. It can cut different types of small shapes (diameter less than 200µm) [24]. It also machined micro-cavities (stress-free) on electrically conductive and semiconducting materials. In µ-EDM, the anode is connected to the workpiece and the electrode is connected to the cathode. Dielectric fluids are used between the workpiece and electrode, as a result, sparks are created. The µ-EDM can be divided into four groups (µ-die sink EDM, µ-EDM drilling, µ-milling EDM & µ-wire EDM milling), based on the types of tools and kinematics of tools. Fig. 3 shows the schematic representation of the µ-EDM method.

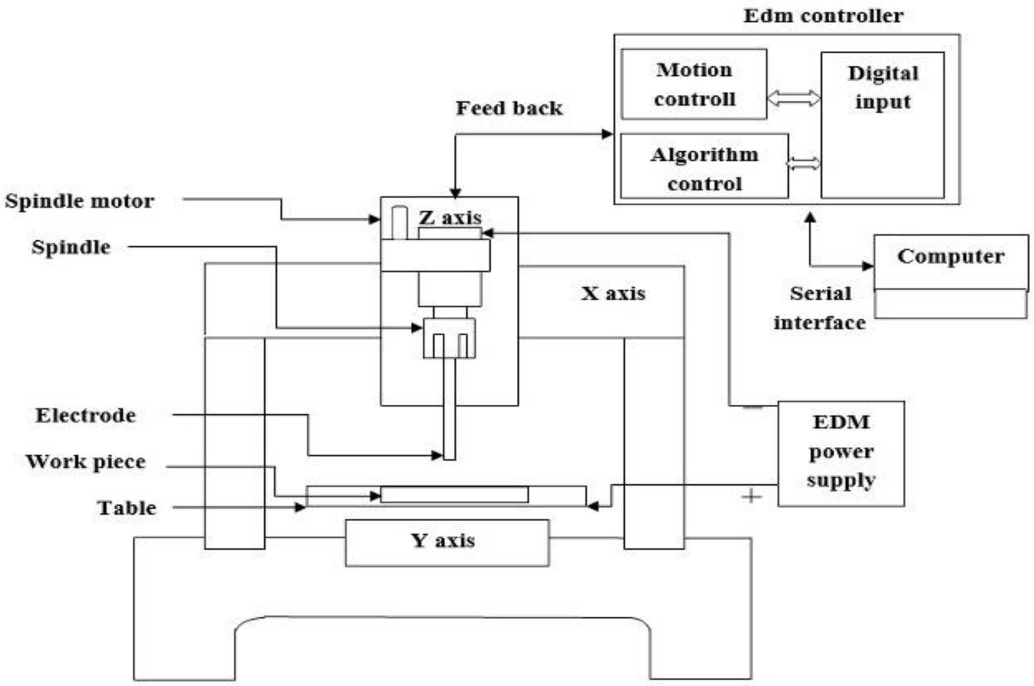

Fig 3 Block Diagram of µ-EDM

B. Important parameters of the EDM process

EDM process typically depends on many input and output parameters. Fig. 4 displays different types of EDM parameters. Input parameters have to be selected for starting EDM machining to get better outcomes. The sub-sections are accompanied by a brief overview of the most relevant input parameters and output parameters used in the EDM process.

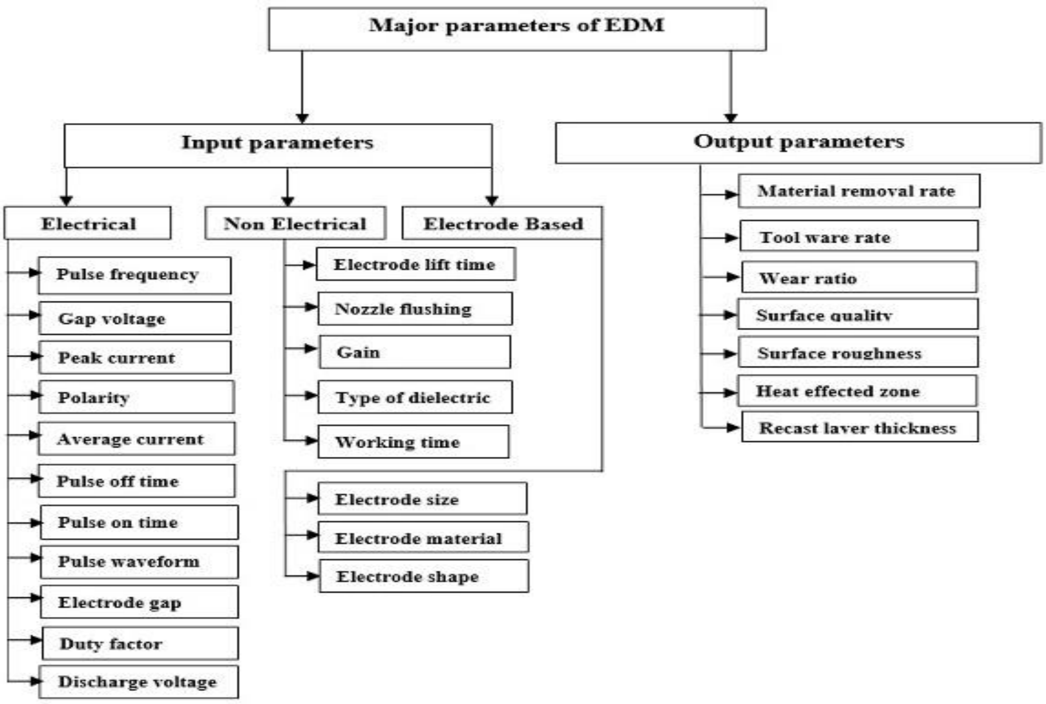

Fig 4 Major parameters of EDM process

➢ *Input Parameters*

- *The Input Parameters are Described below:-*

✓ Pulse on time **(t_{on}):** Pulse on time (t_{on}) is the total duration of discharge time between the tool and workpiece. A longer t_{on} will rise the discharge energy. Its measuring unit is a microsecond (μs).
✓ Pulse-off time **(t_{off}):** Pulse-off time (t_{off}) is the non-discharge time between the tool and the workpiece. Its measureing unit is microsecond (μs)
✓ Voltage (V): During machining, discharge voltage (V) is influenced by the dielectric strength. A larger V will rise the discharge energy
✓ Current (I): It is the measurement of the quantity of electrical charges flowing between the electrode and workpiece and its measuring unit is amp (A).
✓ Discharge Energy (D): When the material is removed then electrical energy is available between the tool and the workpiece. It can be measured with the help of the following Eq. (1) [25] and its measuring unit is Joule (J).

Discharge Energy(D)

$$\int_0^{t_d} \mathrm{v} \times \mathrm{i} \times \mathrm{dt} \cong \mathrm{v} \times \mathrm{i} \times \mathrm{t}_d \qquad (1)$$

Where t_d is discharge time, i is discharge current, and v is discharge voltage.

✓ Electrode Polarity: The connection between workpiece and electrode is either positive (+) or negative (-), is called polarity which is based on the necessity of work.
✓ Discharge gap distance: This is the maximum distance between the anode and cathode. It is affected by voltage and dielectric strength.
✓ **Dielectric:** The dielectric makes sparks and acts as a semiconductor that can be produced electrical discharges. Even the dielectric cools the tool and workpiece and removes the debris from the cutting surface. The dielectric may be in liquid or gaseous form.
✓ Flushing method: Flushing is the method of cleansing material debris during machining time and provides fresh dielectric fluid inside the discharge gap

➢ *Response or Output Parameters*
Various responses are described below.

- Material removal rate (MRR): The volumetric removal of material per unit of time can be described as material removal rate (MRR). MRR is closely related to dielectric fluid [12][26]. The MRR calculation can be taken by the following Eq. (2) [27].

$$\mathrm{MRR}=\frac{\text{volume of the material removal}}{\text{time of machining}}=\frac{w_{sb}-w_{sa}}{\rho \times t_m} \qquad (2)$$

Where w_{sb} denotes the workpiece weight before machining and w_{sa} is the workpiece weight after machining. ρ is the density of the workpiece and t_m is the machining time.

- Tool wear rate (TWR): The errotion of cutting tools (due to machining of the EDM process) is called tool wear rate (TWR). TWR is calculated using Eq. (3) [27].

$$\mathrm{TW}=\frac{\text{volumetric removal of the tool weight}}{\text{total machining time}}=\frac{w_{tb}-w_{ta}}{\rho \times t_m} \qquad (3)$$

Where w_{tb} =weight of tool before machining and w_{ta} = weight of the tool after machining. ρ=density of the tool and t_m =machining time.

- Wire Wear ratio (WWR): The wire wear ratio (WWR) is defined as the wire weight loss to the wire's initial weight (IWW) and after the final weight (WWL). The help of the following Eq. (4) WWR can be calculated [28].

$$\mathrm{WWR}=\frac{\mathrm{WWL}}{\mathrm{IWW}} \qquad (4)$$

- Surface quality (SQ): The specimen's surface quality (SQ) is one of the desired responses required after EDM machining. SQ is dependent on the texture and the undulation of the surfaces of workpiece. SQ is also called workpiece topographic property. The SQ depends on the types of dielectric fluid used for the EDM process [29][30].
- Surface roughness (SR): Surface roughness (SR) is a deviation from its ideal form along the direction of the normal vector of an actual surface. If such deviations are large, the surface will be rough; if it is minor, the surface will be smooth [18][31].
- Heat-affected zone (HAZ): The heat-affected zone (HAZ) means, the area of the workpiece that is affected due to the heat generated during the time of machining [32][33].
- Recast layer thickness (RLT): A sudden rise in localized heat in the time machining melts the cutting surfaces to an extent followed by rapid quenching due to the presence of dielectric fluid. The uncleaned debrish produces a layer that resembles the cast state and is known as RLT [17][34]

C. Dielectric Medium

For EDM purposes two types of the dielectric medium may be used. One type is liquid, and another type is gaseous. The dielectric acts as a semiconductor and insulator between the tool and the workpiece to promote a stable and controlled spark gap when ionization occurred. In the machining operation, it also eliminates the dust content from the cutting surface. Therefore, the basic functions of dielectric fluids are insulation, ionization, cooling, and waste particle removal [35]. Mostly dielectric is used as a liquid medium and it has certain properties, i.e., high flash point, low viscosity, light-colored, and rust-resistant. It increases the life of the tools, improves efficiency, and enhances surface texture consistency.

➢ *Some Dielectric Fluids are Described below –*

Kerosene is readily available, and it is a very economical oil compared to other dielectric oils, [36]. Kerosene is also named paraffin or coal oil. The key properties of kerosene are, it has no cetane number, less lubricity, large delays in the ignition. The kerosene flashpoint lies between 37°C to 65°C, and its auto-ignition is 220°C. Kerosene is a mixture of hydrocarbons (ranging from 6 to 16), with several carbon particles and it becomes a very natural dielectric fluid for the aforementioned properties [11][12]. Previous researchers used kerosene as a dielectric fluid in their experiment with various work materials, and sometimes kerosene, combined with some powder, emulsion, and surfactant shown in Table 1 and Table 2 shows the uses of kerosene with mixed powder and emulsion for the EDM process.

Table 1 Use of Kerosene as a Dielectric Fluid on EDM

Author and Year	Material	Electrode	Finding
Jeswani (1981) [37]	High carbon steel	Copper	It is showed when the pulse energy range is high (72–288 MJ) then MRR is also high.
Chen et. al. (1999) [38]	Ti–6A1–4V	Copper	It is found that after machining, the crack density is lower and the depth of the white layer is thicker. But a carbide is formed on the surfaces of the workpiece.
Bai and Koo (2006) [39]	Super alloy Haynes 230	Al–Mo composite (85% Al,15% Mo)	It is shown that the maximum hardness value is 1086 HK. When used positive polarity then SR (2.62 μm) gives a better result.
Wu et. al. (2009) [40]	SKD 61steel	Copper	It is discovered the SR is improved by 60%.
Bhattacharya et. al.(2013) [41]	H11, HCHCr, AISI 1045	Graphite, W-Cu, Brass	It is observed that I and T_{on} are the main input parameters for finding MRR.
Mehta, (2015) [12]	Inconel 718	Copper	In this study, it is shown that the percentage of the difference between the actual value and predicted value of MRR lies between 0.38 - 2.38%.
Valaki et. al.(2016) [42]	P20+ plastic mold steel	Copper	It is found that the values of MRR (29.21 mm^3/min) is maxed when I value is 18 A, T_{on} value is 200 μs, T_{off} value is 20 μs, V value is 50V. But SR (4.89 μm) is min when I value is 3 A, T_{on} value is 200 μs, T_{off} value is 20 μs, V value is 50 V. MH is (339 HV) max when the I value is 9 A, T_{on} value is 11 μs, T_{off} value is 20 μs, V value is 50 V.
Singh and Sharma (2016) [43]	Cobalt-bonded tungsten carbide	Copper	It is observed that the values of MRR are improved and TWR values are also improved.
Niamat et. al. (2017) [27]	Al 6061 T6 alloy	Copper	It is discovered that the value of MRR is maximum, (302.47 mm^3/min) when increased I (12 A) and T_{on} (45 μs), TWR is minimum (0.56 mm^3/min) when I value is 6 A, T_{on} is 45 μs respectively. when T_{on} and I value increased then shows more cracks and micro holes.
Li et. al. (2018) [44]	Inconel 738	Hollow brass	In this study, it is shown that the machining time is much longer and a thin recast layer (4.8 μm) is formed.
Pellegrini and Ravasio (2020) [45]	AISI 319L and Ti-6Al-4V	Tungsten carbide (WC) and brass,	It is shown that kerosene with a WC electrode is not suitable for corresponding to the brass electrode and kerosene is created pollution effects that are not suitable for nature.
Ishfaq et. al. (2020) [46]	Ti-6Al-4V	copper, brass, aluminum	It is found maximum MRR (4.62 mm^3/min) in kerosene is obtained with the aluminum electrode.
Ming et. al. (2022) [47]	SKD 11	W, Cu, Cu-W, graphite	It is observed MRR is 15 % higher than vegetable oil.

Table 2 Use of Kerosene With Mixed of Powder/Emulsion/Surfactant on EDM

Author and Year	Material	Mixing agent	Electrode	Finding
Jeswani (1981) [37]	Mild steel	Graphite powder	Copper	It is shown that when the ionization and deionization are changed the liquid then created more spark discharges per unit of time. Then MRR is increased by 60% and TWR is increased by 15%.
Pecas and Henriques (2003) [15]	AISI H13	Silicon powder	Copper	In this study, it is observed that the polishing time has a greater effect on decreasing the SR.
Kansal et. al. (2005) [6]	HCHCr die steel	Graphite powder	Copper	Here shows the improvement of MRR (40%) and reduction of TWR (50%) and SR (38%) values.

Wu et. al. (2009) [40]	SKD 61steel	Surfactant	Copper	In this study, it is shown that the thin recast layer produced using dielectric fluids and MRR is 40% improved.
Liu et. al.(2010) [48]	AISI 1045	Emulsion (distilled water + emulsified oil + machine oil)	Red copper	In this literature, it is shown that some deep craters and micro-cracks are formed on the surfaces of workpieces.
Bhaumik and Maity (2017) [49]	AISI 304	SiC powder	Tungsten carbide	It discovered that the MRR is improved, when I is 4 A, T_{on} is 150 µs, V 65 V, the duty cycle is 65% and powder concentration is 10g/l.
Ishfaq et. al. (2020) [46]	Ti-6Al-4V	Graphene	Copper, brass, aluminum	It is showed MRR is higher when the graphene-based dielectric is used (7.60 mm^3/min), which is 64.5% more than plain dielectric.
Malhotra et.al. (2020) [50]	Aluminum 7075	SiC powder	Copper	It is found MRR is 45% better and the TWR is 15% lower than the gas EDM process.

✓ *Water*

Water is a very common dielectric fluid. Approximately 70% of the earth's surface is filled by water, therefore, it is readily accessible and low-cost. Two parts of hydrogen and one part of oxygen (H_2O) are combined and the generated form is come out. The water is tasteless and odorless at room temperature and is almost colorless. The main properties of water are described below-

- It has an attraction to polar molecules.
- Specific heat is high.
- Heat vaporization is high.
- The density is low.

The water density is 4°C (1gm/cm^3), and the specific gravity is 1. In general, two types of water are used for the EDM process. The first one is natural water, and the second one is water with deionization. However, normal tap water is mixed with many chemicals, therefore needed to kill bacteria and other microorganisms. But deionized water is a form of liquid that eliminates all its ions, and it is free of charge. It's not a substance made from hydrocarbons. For that reason, water does not produce any kind of environmental pollution [48]. Previous experiments in EDM with different work materials are shown in Table 3 using water as a dielectric fluid and powder-mixed water (acts as a dielectric fluid) shown in Table 4. Often different types of powder (such as aluminum powder, sic powder, silicon powder, and graphite powder) and emulsions are used with plain dielectric fluid to get a better result.

Table 3 Use of Deionized Water as a Dielectric Fluid on WEDM

Author and Year	**Material**	**Electrode**	**Finding**
Jeswani (1981) [51]	High carbon steel	Copper	In this study, it is observed that a higher MRR (75%) and a lower wear ratio and the surface finish are better.
Erden and Temel (1982) [52]	Steel	Copper, brass	It is discovered that the machining with T_{on} (400 - 1500 µs) improved the performance of MRR and TWR.
Jilani and Pandey (1984) [53]	Low carbon steel	Copper, brass	In this study, it is observed that the performance of EDM by using distilled water, tap water, and a mixture of 25% tap and 75% distilled water respectively. But tap water shows zero electrode wear.
Chen et. al. (1999) [38]	Ti–6A1–4V	Copper	In this literature, it is observed that the MRR is max (2 mm^3/min) and crack density is high & the depth of the white layer is thin. Some oxide is formed on the surfaces of the workpiece.
Bai and Koo (2006) [39]	Haynes 230	Al –Mo composite (85% AL,15% MO)	In this study, it is shown that the positive polarity contains a mixture of NiAl, $AlCr_2$, Al_5Cr, and Al_2O_3 phases.
Kao et. al. (2007) [54]	AISI 6061	Brass	It is found that wet EDM has better flushing capability than dry EDM.
Dhakar et. al. (2016) [55]	HSS T2 grade	Copper	It is found that the inter-electrode gap, generates more heat energy and not created any RLT.
Uhlmann et. al. (2016) [56]	Si_3N_4-TiN ceramic	Cemented carbide	It is shown that erosion time is high, lower electrode relative wire, and low RLT
Niamat et. al. (2017) [27]	AL 6061, T6 alloy	Copper	It is found that MRR is maximum (112.963 mm^3/min) when I is 12 A, T_{on} is 30 µs and TWR is minimum when (0.52 mm^3/min) I is 6 A, T_{on} is 30 µs respectively.
Pellegrini and Ravasio (2020) [45]	AISI 319L, Ti-6Al-4V	Tungsten carbide (WC), brass,	It is observed water gives the lowest environmental impact.

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Table 4 Use of Water Mixed With Powder/Emulsion on EDM

Author & Year	Material	Mixing agent	Electrode	Finding
Masuzawa and Tanaka (1983) [57]	SK4 die steel	Solution of polyethylene glycol 200, 600	Copper	It is discovered that the MRR is improved, and produces a good surface finish, and minimum RLT.
Syed and Kuppan (2013) [58]	W300 die steel	Aluminum powder	Copper	Here it is observed that the RLT is decreased with the powder concentration at every current level and when using negative polarity.
Liu et. al.(2013) [59]	Mold steel 8407	Oil emulsion	Copper	In this study, MRR and SR were significantly (with 95% confidence) influenced by I. Both MRR and TWR decrease when increasing the temperature.
Zhang et al (2014) [8]	Mould steel 8407	Oil emulsion	Steel needle	In this study, it is shown that MRR is increased.
Li et. al. (2018) [44]	Inconel 738	Oil emulsion	Hollow brass	In this literature, it is found that the value of RLT is 5.2 μm.

➢ *Hydrocarbon Oil*

Hydrocarbon oil is a commodity found in petroleum. It contained hydrogen and carbon, has a high flashing point. Previously hydrocarbon oil is used as dielectric fluid which is shown in Table 5.

Table 5 Use of Hydrocarbon Oil as a Dielectric Fluid on EDM

Author & Year	Material	Electrode	Finding
Rahang and Patowari (2015) [60]	Aluminum	P/M green compacts (Copper and tungsten powders mesh)	In this study, it is shown that low I and low T_{on} caused small damage to the masking edge with low thermal energy within a short duration. Then the quality of SR is not good.

➢ *Jatropha Oil*

Jatropha seeds are very rich in oil (40%) which includes 4.2% ash content with minerals, like Ca, Mg, K, and Na. The oil has high levels of unsaturated fatty acids particularly oleic (44.7%) and linoleic (32.8%) [61]. Jatropha oil can be used in diesel generators and engines straight after removal. Previous studies of jatropha oil in the EDM process are shown in Table 6.

Table 6 Use of Jatropha Oil as a Dielectric Fluid On EDM

Author and Year	Material	Electrode	Finding
Valaki et. al. (2016) [42]	P20+ plastic mold steel	Copper	In this literature, it is found that when I is 18 A, T_{on} is 200 μs, T_{off} is 20 μs, and V is 50 V then shows max MRR 53.33 (mm^3/min). When SR is minimum 3.66 (μm) and MH (354 HV) is max then I is 9 A, T_{on} is 11 μs, T_{off} is 20 μs, and V is 50 V respectively.
Das et. al. (2019) [62]	Ti-6Al-4V	Copper	In this article, it is shown that MRR is improved by 15% compared to other dielectric fluids.

➢ *EDM Oil*

EDM oil is highly refined oil with outstanding oxidation resistance, it helps to reduce the incidence of oxidation of products. The oil has no color and odors and has a high flash point that helps to minimize the risk of fire during the machining process. EDM oil is a low viscose fluid, providing good flow through the spark gap between the tool and specimen. In general, EDM oil is available in the market in three grades (grades 2-4) which are used according to the EDM criteria. Nowadays oil is becoming very famous [63][64] because of its advantages and availability. Earlier using EDM oil with different material is shown in Table 7 and EDM Oil mixed with powder/surfactant are shown in Table 8.

Table 7 Use of EDM Oil as a Dielectric Fluid on EDM

Author and Year	Material	Electrode	Finding
Yu et. al. (2004) [7]	Cemented Carbide	Copper tungsten pipe	It is shown that the required machining time is less.
Pradhan and Biswas (2011) [65]	AISI D2	Copper	It is shown that pulse current was the most principal factor for finding MRR.

Pradhan and Biswas (2012) [66]	AISI D2	Copper	In this literature, it is shown that the RLT is straightly proportional to the I. But SCD is inversely proportional to the I.
Bhattacharya et. al.(2013) [41]	H11, HCHCr, AISI 1045	Graphite, W-Cu, Brass	It is found that for H11, SR is 3.93 µm, MH is 1026 HVN, for HCHCr, SR is 3.69 µm, MH is 961 HVN, for AISI 1045, SR is 2.2 µm, MH is 1006 HVN.
Sahu et. al. (2013) [65]	AISI D2	Brass	In this study, shows when I and T_{on} are increased then RLT also increases. When T_{on} decreases, higher numbers of holes and micro-cracks are detected in the workpiece.
Dewangan and Biswas (2013) [67]	AISI P20	Copper	In this study, MRR is affected by Tup and Tw. IEG (inner electrode gap) does not affect MRR.
Dhakar et. al. (2016) [55]	HSS T2 grade	Copper	In this study, observed that the surface of a material is rough, and MRR is high (3.58 mm^3/min).
Upadhyay et. al.(2016) [68]	Inconel 601	Copper	It is discovered that SCD and RLT both are straightly related to the input parameters, like I, T_{on}, V, and duty factor.
Rahul et. al. (2016) [69]	Inconel (601, 625, 718, and 825)	Graphite	It is discovered that Inconel specimens can also be measured (RLT) as an important machining performance feature for finding optimal values of input parameters.
Mohanty and Mohanty (2017) [70]	D2 steel	Direct metal laser sintered (DMLS) part	In this study, it is discovered that a Taguchi method is effective for calculating the optimum parameter.
Mishra et. al.(2018) [71]	Inconel 625	Copper	It is observed that when T_{on} increase then increased SR, SCD, and RLT.
Beravala and Pandey (2019) [72]	AISI 304	Copper	It is shown the RLT is lesser and SR is higher compared to other dielectrics

Table 8 Use of EDM Oil Mixed with Surfactant and Powder on EDM

Author and Year	**Work Material**	**Mixing agent**	**Electrode**	**Finding**
Kolli and Kumar (2015) [73]	Ti-6Al-4V	Surfactant, Graphite powder	Copper	In this study, it is observed MRR is maximum (5.9367 mm^3/min) when this dielectric is used.

➢ *Vegetable Oil*

Vegetable oils were extracted from seeds, like rapeseed, soybean, corn, sunflower, and peanut. These kinds of oils are also becoming very popular with EDM because of their advantages and availability [74]. Table 9 displays previous research on vegetable oil.

Table 9 Use of Vegetable Oil as a Dielectric Fluid on EDM

Author and Year	**Material**	**Electrode**	**Finding**
Valaki and Rathod (2015) [75]	M238 HH grade cold worked plastic mold steel	Copper	In this study, it is shown that waste vegetable oil is used as an alternative to hydrocarbon-based oil (like kerosene). MRR, TWR all values can be improved.
Ming et. al. (2022) [47]	SKD 11	W, Cu, Cu-W, graphite	It is observed SR is better than kerosene oil and vegetable oil is more sustainable.

➢ *Glycerine*

Glycerine's trade name is glycerol, which is not pure. It has 95% glycerol, which is a basic compound of polyol. This has no color and no sense of smell, is sweet-tasting and non-toxic, it is a viscous liquid. The chemical formula is $C_3H_8O_3$ with 92.09382 g/mol molar mass and 1.26 g/cm^3 density. The name given to IUPAC is propane-1,2,3-triol and the temperature to melt is 17.8°C. Table 10 displays previous studies of glycerine in the EDM process.

Table 10 Use of Glycerin as a Dielectric Fluid on EDM

Author and Year	**Material**	**Electrode**	**Finding**
Dhakar et. al. (2016) [55]	HSS T2 grade	copper	In the literature, it is shown that the value of MRR (8.99 mm^3/min) in near-dry EDM, three-times higher than others (water and EDM oil).
Yadav et. al. (2019) [76]	Molybdenum based HSS	Hollow copper	It is observed I was the significant parameter for MRR and SR. The highest MRR is 24.45 mm^3/min.

Nowadays, dielectric gas also plays a critical role in various EDM processes [77][78]. However, gaseous mediums are usually less dangerous than dielectric liquids, as they do not interfere with the human body and do not produce dangerous vapors [79]. The commonly used dielectric gases in the EDM process are listed briefly below.

- *Oxygen*

Oxygen is a common component of air. Two oxygen molecules are chemically bound to form an oxygen atom at normal temperature and pressure. It has no taste, no color, and no odor. On the periodic table, it is a member of the chalcogen group. Its atomic no is 8, atomic mass is 15.999 u, bond energy is 498 kJ/mol, the boiling point is 183°C, and melting point is 218.8°C. Table 11 shows previous studies on oxygen, in the EDM process.

Table 11 Use of Oxygen as a Dielectric Gas in EDM Drilling

Author and Year	Material	Electrode	Finding
Tao et al (2008) [77]	NA	Copper, Graphite	It is found that when MRR is increased then exothermal oxidation occurs.
Liqing and Yingjie (2013) [80]	Quenched 45-carbon steel	Copper tube	It was found that the oxygen-air mixture when used then improved MRR (1.4 mm^3/min).
Beravala and Pandey (2018) [81]	AISI 304	Copper	It is observed the MRR was increased with an increase of I, duty cycle, air pressure, and magnetic flux density while decreasing with an increase in T_{on}.
Pellegrini and Ravasio (2020) [45]	AISI 319L and Ti-6Al-4V	Tungsten carbide (WC), brass,	It is discovered that oxygen offers betters output for other dielectric gases.

- *Nitrogen*

The Nitrogen's symbol is 'N,' the number of atoms is 7 and the weight of the atom is 14.01u. It has no color and odor, condensed to -195.8°C. The element is made out of N_2 molecules, so the bond energy of 226 kilocalories/mole, is only surpassed by the carbon monoxide (256 kilocalories/mole). Table 12 displays earlier studies of the EDM process with nitrogen gas
.

Table 12 Use Of Nitrogen as a Dielectric Gas on Micro EDM and EDM.

Author and Year	Material	Electrode	Finding
Zou et al (2018) [78]	Brass H62	Tungsten	In this study, it is shown that the discharge distance NPJ (Nitrogen plasma jet) is greater than NJ (Nitrogen jet) but smaller than DIW (Deionized water).
Liqing and Yingjie (2013) [80]	Quenched 45-carbon steel	Copper tube	It is found that for dry medium MRR value is 0.10 mm^3/min.

- *Helium*

The Helium's symbol is 'He', and the atomic number is 2. Its position is first in the periodic table among the noble gas group. Helium has no color, no odor, and no taste, and transforms to liquid at -268.9°C(-452°F). Helium's boiling point is -268.9°C(-452°F), atomic number is 2, atomic mass is 4.0026 u, and melting point is 272.2°C. However, Helium's boiling point is the lowest of all elements. Former experiments with Helium in the EDM process are shown in Table 13.

Table 13 Use Of Helium as a Dielectric Gas on EDM

Author and Year	Material	Electrode	Finding
Govindan et al (2011) [82]	SS304	Copper	It is found that a higher heat capacity of gaseous dielectric, reduces sparking action. The rotation speed of the tool is the main portion to increase in MRR (0.0192 mm^3/min).

- *Argon*

Argon is the third noble gas in the periodic table. It has the same solubility as oxygen, and it is 2.5 times more water-soluble than nitrogen. This gas is available in liquid and gaseous form and it is colorless and odourless. It's atomic no 18, atomic weight 39.948 u, bond energy 4.73 ± 0.04 kJ/mol, boiling point -185.8°C, and melting point -189.4°C. Previous research with argon is described in Table 14.

Table 14 Use Of Argon as a Dielectric Gas on EDM

Author and Year	Material	Electrode	Finding
Singh et. al. (2016) [83]	The high chromium, High carbon die-steel	Copper single-hole tubular, perforated electrode	It is discovered in the process of AAEDM (Air Assisted EDM), the values of SR (3.78 µm) and % of TWR (1.45 mm^3/min) are lesser than AGAEDM (Argon-Gas-Assisted EDM) process. The MRR (22.03 mm^3/min) is

			more than AGAEDM and conventional Rotary EDM processes.
Liqing and Yingjie (2013) [80]	Quenched 45-carbon steel	Copper tube	In this literature, it is found that for dry medium MRR value is 0.10 mm^3/min.
Malhotra et.al. (2020) [50]	Aluminum 7075	Copper	It is found MRR is 75% higher compared to liquid dielectric and TWR is lower by 25 %
Beravala and Pandey (2019) [72]	AISI 304	Copper	It showed surface crack was reduced by 72% and RLT reduced by 43%.

It is clear from the above study, various types of dielectric fluids and gases are used to improve the responses for the EDM process. The effect of the dielectric medium on various responses is illustrated in detail below (Table 15), Also the findings are also graphically represented in Fig. 5a-c.

Table 15 Used Deionized Water in WEDM

Material	**KERF (mm)**	**MRR (mm^3/min)**	**SR (µm)**
AISI 304	----	----	2.14 [84]
AISI 6061	0.26 [85]	11.35 [86]	1.77 [84]
Al	0.28 [87]	----	3.60 [85]
Copper	----	2.28 [88]	----
Inconel 718	0.60 [20]	1.85 [21]	----
Ni Ti Alloy	0.47 [89]	----	2.47 [89]
Ti Grade5 Alloy	0.43 [30]	----	2.20 [30]
Ti Grade6 Alloy	0.30 [90]	2.51 [90]	1.99 [90]

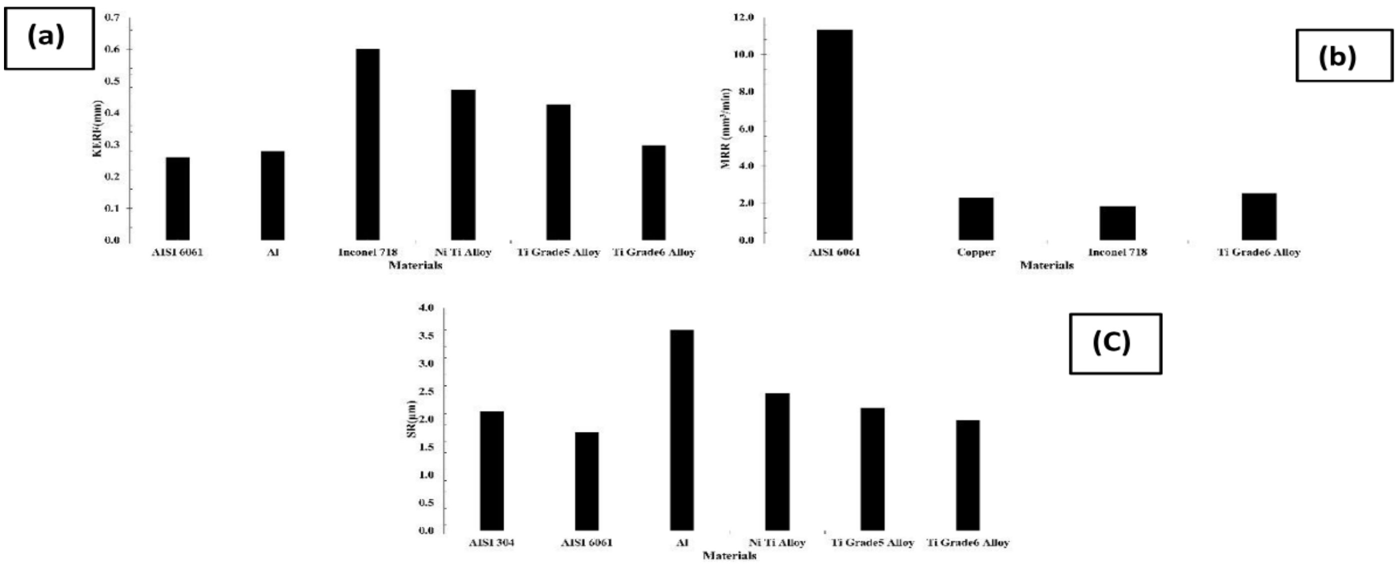

Fig 5 Materials plot for WEDM process vs (a) KERF, (b) MRR, (c) SR

Previous research on the Die sinking EDM method with different dielectric fluids and materials to determine the values of responses (TWR, RLT, SR, and MRR) as shown in Table 16-20 and graphically illustrated in Fig. 6-10.

Table 16 Used Several Dielectric Fluids For Finding TWR (mm^3/min) on EDM Process

Dielectric Fluids	**Materials**							
	WC	**Mould Steel 8407**	**HCHCr die Steel**	**AISI 304**	**TI-6AL-4V Grade5**	**AISI P20**	**D2 Steel**	**Inconel 718**
Kerosene	0.68[43]							
Water	0.58[43]							
EDM Oil	0.33[43]					0.01[91]	4.61[70]	
Water Based		0.30[59]						
Kerosene Based			0.01[6]	0.01[92]				
EDM Oil Based					0.35[73]			
Parafin Oil								2.65[93]

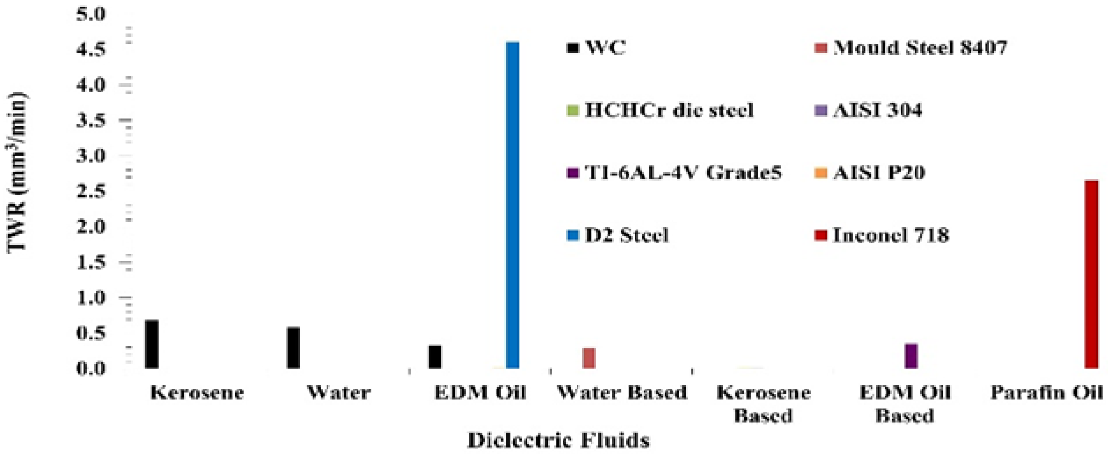

Fig 6 TWR vs Dielectric fluids plot for various materials

Table 17 Used Several Dielectric Fluids For Finding RLT (μm) on EDM Process

Dielectric Fluids	**Materials**					
	Inconel738	W300 Die Steel	TI-6AL-4V Grade5	AISI D2	Inconel 625	Inconel 601
Kerosene	4.80[94]					
EDM Oil				6.19[66]	13.75[71]	14.63[68]
Water Based	5.20[94]	17.14[58]				
EDM Oil Based			13.26[73]			

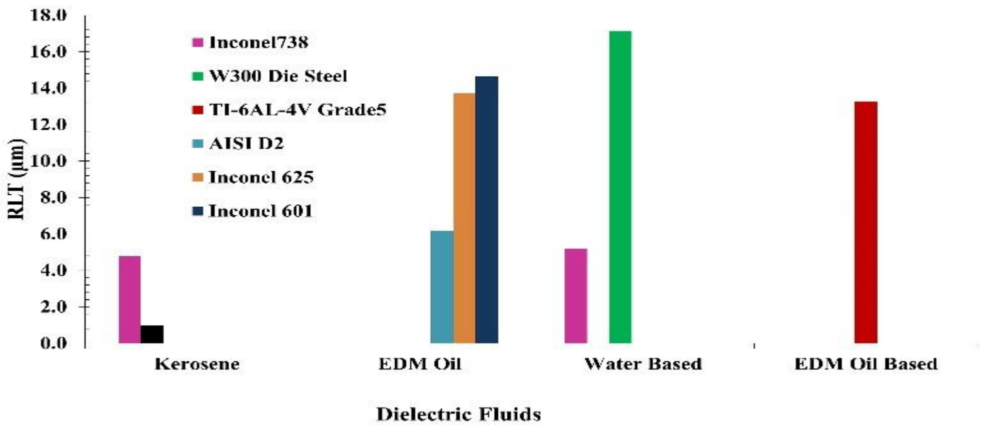

Fig 7 RLT vs Dielectric Fluids Plot Various Materials

Table 18 Used Several Dielectric Fluids for Finding SR (μm) on EDM Process

Dielectric Fluids	**Materials**													
	P 20 Mould Steel	**Supper Alloy Haynes 230**	**SKD 61 Steel**	**H11**	**HCHCr**	**AISI 1045**	**Mould Steel 8407**	**AISI 304**	**TI-6AL-4V Grade5**	**AISI D2**	**Inconel 625**	**D2 Steel**	**Inconel 718**	**Inconel 601**	**Inconel 825**
Kerosene	3.65 [42]	5.68 [39]	0.43 [95]	3.41 [41]	2.10 [41]	2.95 [41]			5.98 [62]						
Water		4.11 [39]													
Jatropha Oil	3.66 [42]								5.82 [62]						
EDM Oil				3.93 [41]	3.69 [41]	2.20 [41]			5.05 [31]	4.59 [65]	6.67 [71]	3.14 [70]	4.93 [96]	4.97 [96]	3.73 [96]
Water Based							5.03 [59]								
Kerosene Based			0.17 [95]		1.26 [6]			5.64 [92]							
EDM Oil Based									1.90 [73]						
Parafin Oil													6.80 [97]		
Neem Oil									5.31 [62]						
Canola Oil									5.12 [62]						

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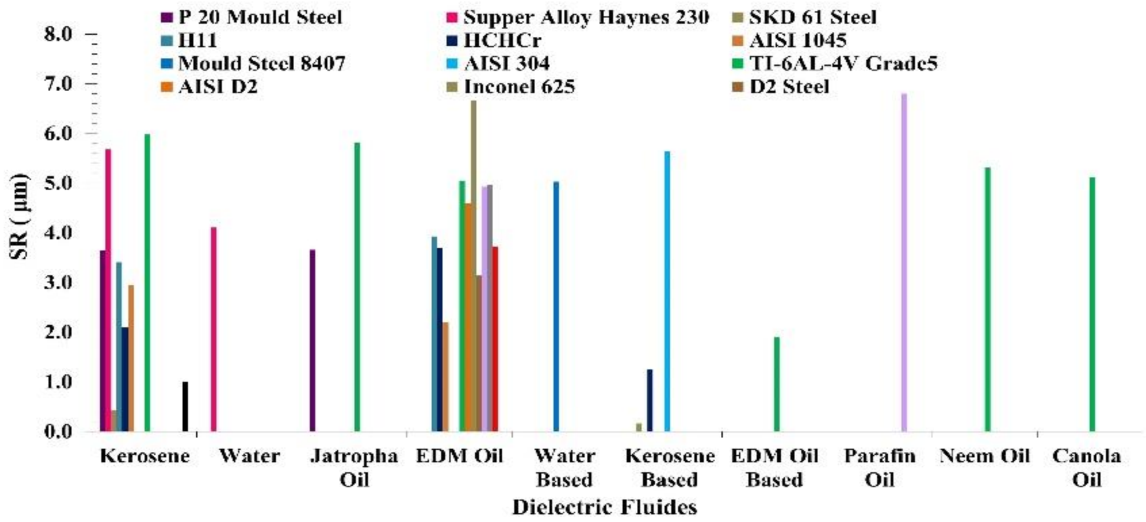

Fig 8 SR vs Dielectric fluids plot various materials

Table 19 Used Several Dielectric Fluids for Finding MRR (mm^3/min) on EDM Process

Dielectric Fluids	Materials												
	Al 6061	P 20 Mould Steel	WC	Mould Steel 8407	HCHCr	AISI 304	AISI P20	AISI D2	Inconel 625	D2 Steel	Inconel 718	Inconel 601	Inconel 825	Ti Alloy Gr5
Kerosene		29.21 [42]	8.72 [43]											14.64 [62]
Water	112.96 [27]		8.75 [43]											
Jatropha Oil		53.33 [42]												18.49 [62]
EDM Oil			9.12 [43]				9.97 [91]	51.09 [65]	63.20 [71]	12.83 [70]	31.60 [69]	17.65 [69]	25.95 [69]	6.29 [31]
Water Based				115.62 [59]										
Kerosene Based					21.51 [6]	8.01 [92]								
EDM Oil Based														5.94 [73]
Parafin Oil											48.90 [97]			
Neem Oil														15.58 [62]
Canola Oil														17.13 [62]

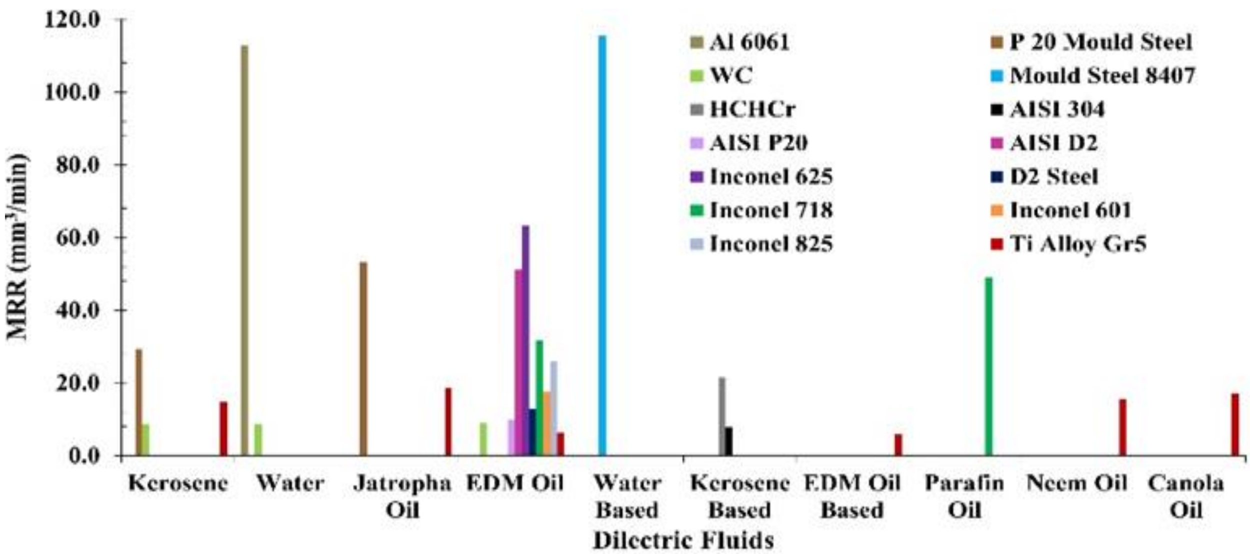

Fig 9 MRR vs Dielectric Fluids Plot Various Materials

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Table 20 Used Several Dielectric Gases For Finding MRR (mm[3]/min) on EDM Process

Dielectric Gases	Materials	
	Quenched 45-carbon steel	**SS304**
Oxygen	1.40[98]	
Helium		0.02[19]
Nitrogen	0.10[98]	
Air	0.30[98]	
Argon	0.10[98]	

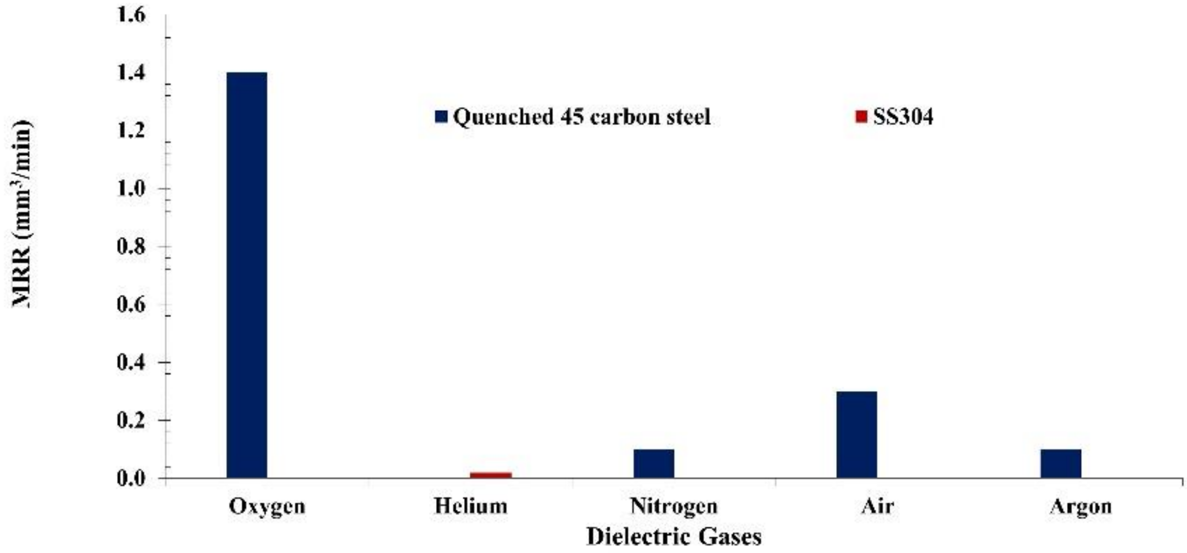

Fig 10 MRR vs Dielectric Gases Plot Various Materials

III. OVERALL OBSERVATION FROM PREVIOUS STUDIES

It is observed from a previous study, EDM's machining efficiency is closely related to the type of dielectric fluid. Table 21-26 shows the various responses of their class values like high, medium, and low against dielectric fluids for different materials. A range of values is also mentioned for those classes.

Table 21 Performance of various Dielectric Fluids on Several Materials for MRR (mm[3]/min)

MRR														
Dielectric Fluids	Materials													
	AL6061	P 20 Mould Steel	WC	Mould Steel 8407	HCHCr	AISI 304	AISI P20	AISI D2	Inconel 625	D2 Steel	Inconel 718	Inconel 601	Inconel 825	Ti Alloy GR5
Kerosene		M	L											M
Kerosene Based					M	L								
Water	H		L											
Water Based				H										
Jatropha Oil		H												M
EDM Oil							L	H	H	M	M	M	M	L
EDM Oil Based														L
Neem Oil														M
Canola Oil														M
Parafin Oil											M			
Note: The range of MRR (mm[3]/min): High (H) >50; Medium (M): 50 to 10; Low (L) <10														

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Table 22 Performance of various Dielectric Fluids on Several Materials For SR (µm)

SR															
Dielectric Fluids	Materials														
	P 20 Mould Steel	Mould Steel 8407	HCHCr	AISI 304	AISI D2	Inconel 625	D2 Steel	Inconel 718	Inconel 601	Inconel 825	Ti Alloy Gr5	Supper Alloy 230	SKD 61 Steel	H11	AISI 1045
Kerosene	M		L								H	H	L	M	L
Water												M			
Jatropha Oil	M										H				
EDM Oil			M		M	H	M	M	M	M	M			M	L
Water Based		M													
Kerosene Based			L	M									L		
Parafin Oil								H							
EDM Oil Based	L														
Canola Oil											M				
Neem Oil											M				
Note: The range of SR (µm): High (H) >6; Medium (M): 6 to 3; Low (L) <3															

Table 23 Performance of various Dielectric Fluids on Several Materials For RLT (µm)

RLT						
Dielectric Fluids	**Materials**					
	AISI D2	**Inconel 625**	**Inconel 601**	**Ti Alloy Gr5**	**Inconel 738**	**W300 Die Steel**
Kerosene					M	
EDM Oil	M	H	H			
Water Based					M	H
EDM Oil Based				H		
Note: The range of RLT (µm): High(H) >10; Medium(M): 10 to 2; Low(L) <2						

Table 24 Performance of various Dielectric Fluids on Several Materials For TWR (mm^3/min)

TWR								
Dielectric Fluids	**Materials**							
	WC	**Mould Steel 8407**	**HCHCr die steel**	**AISI 304**	**TI-6AL-4V Grade5**	**AISI P20**	**D2 Steel**	**Inconel 718**
Kerosene	M							
Water	M							
EDM Oil	M					L	H	
Water Based		M						
Kerosene Based			L	L				
EDM Oil Based					M			
Paraffin Oil								H
Note: The range of TWR (mm^3/min): High (H) >1.00; Medium (M): 1.00 to 0.30; Low (L) <0.30								

Table 25 Performance of various Dielectric Gases on Several Materials For MRR (mm^3/min).

MRR		
Dielectric gases	**Materials**	
	Quenched 45-carbon steel	**SS304**
Oxygen	H	
Helium		L
Nitrogen	L	
Air	L	
Argon	L	
Note: The range of MRR (mm^3/min): High (H) >1.50; Medium(M):1.50 to 1.00 Low (L) <1.00		

Table 26 Performance of Dielectric Fluid (deionized water) on Several Materials for KERF (mm), MRR (mm^3/min), SR (μm) on WEDM Process.

Materials	**KERF (mm)**	**MRR (mm^3/min)**	**SR(μm)**
AISI 304			M
AISI 6061	L	H	L
Al	L		H
Copper		M	
Inconel 718	H	L	
Ni-Ti Alloy	M		M
Ti Grade5 Alloy	M		M
Ti Grade6 Alloy	M	M	L
Note: The range of KERF (mm): High (H) >0.5; Medium (M): 0.50 to 0.30; Low(L) <0.30			
The range of MRR (mm3/min): High (H) >5; Medium (M): 5 to 2; Low (L) <2			
The range of SR (μm): High (H) >3; Medium (M): 3 to 2; Low (L) <2			

- From the above observation it is clear to find MRR, used pure kerosene for three different materials (P20 mold steel, WC, Ti alloy grade) there MRR rate is respectively M, L, M. But for SR when the same dielectric fluid is used for P20 mold steel and H11, shows the rate is M and for another two metals i.e., Ti alloy grade5 and Supper alloy230 provides H rate. When kerosene is used for HCHCr, SHD 61 steel, AISI 1045, shows L rate. For measuring others' responses (RLT, TWR) use of similar dielectric fluid for the materials of Inconel 718, WC, Al6061 T6 is shown as M rate.
- When kerosene is mixed with aluminum powder, graphite powder, emulsion, and surfactants offer better outcomes. For HCHCr and AISI 304, MRR shows M, and L rates respectively. On the other hand, finding TWR (same materials) shows L rate. But for finding SR, shows L, and M rates respectively. Only SKD 61 showed L rate for finding SR.
- Pure water used as a dielectric fluid for AISI 6061 and WC to determine MRR, shows H and L rates respectively. But for WC, the TWR shows M rate. For AISI 6061, MRR and EWR are shows M rates. For Supper alloy230 is shown M rate to determine SR.
- Sometimes the water is mixed with an oil emulsion or aluminum powder for a better outcome. For Mould steel 8407, MRR, SR, and TWR are show H, M, M rates. Inconel 738 and W300 offers M and H rates for evaluating RLT
- When used Jatropha oil as a dielectric fluid for P20 mold steel and Ti alloy grade 5, shows H and M rates respectively. But measuring SR on the same materials shows M and H rates.
- Pure EDM oil when used as dielectric fluid for finding MRR on the materials AISI P20 steel and Ti alloy grade5, shows L rate for all, but for AISI D2 steel and Inconel 625 shows H rate. For finding the same Inconel (718, 601, 625), shows M rate. When measuring SR for HCHCr, AISID2 steel, Inconel (718, 601, 625), Ti alloy grade 5, H11, shows M rate. Only Inconel 625 shows H rate and AISI 1045 shows L rate for SR. For measuring RLT, Inconel (625 and 601) shows H rate and M rate for AISI D2. But for TWR, Inconel (625, 718, 601, 825) shows L rate.
- When surfactant or graphite powder is mixed with EDM oil for measuring MRR, RLT, and TWR for Ti alloy grade 5 shows L, H, and M rates respectively. But P20 Mould steel shows L rate for measuring SR.
- Only neem oil and canola oil show M rate for finding MRR and SR in the EDM process.
- Inconel 718 shows M, H, and H rates for determining MRR, SR, and TWR in the EDM process when paraffin oil is used as a dielectric fluid.
- Especially in dry EDM when used different gases like oxygen, nitrogen, air, and argon for determining MRR, then quenched 45 carbon steel shows H, L, L, L rates respectively for different gases. But helium gas shows L rate for SS304.
- On WEDM, deionized water is used as a dielectric fluid for finding output parameters. For measuring KERF with AISI 6061, Aluminium, Inconel 718, Ni-Ti alloy, and Ti alloy grades shows L, L, H, M, M, and M rate respectively. But for calculating the MRR of AISI 6061, Copper, Inconel 718, and Ti alloy grade shows H, M, L, and M rate respectively. For SR, of AISI 304, AISI 6061, Aluminium, Ni-Ti alloy, and Ti alloy grade shows M, L, H, M, M, and L rate respectively.

IV. CONCLUSION

It is observed from the overall study that dielectric fluid and gas played an important role in finding various responses. For measuring MRR, TWR, SR, RLT, and KERF, dielectric fluids alone may not perform best. Therefore, different types of powder (graphite, aluminum, silicon, surfactant, etc.) may be mixed with a dielectric fluid to obtain the best result. The following observations can be drawn:

- To achieve maximum MRR, pure deionized water is used for AI 6061. However, water mixed with powder offers the best result for machining Mould steel 8407. Moreover, Jatropha oil shows a higher value of MRR for P20 mold steel. Also, pure EDM oil shows a great performance for AISI D2 steel and Inconel 625 machining.

- In the case of the gaseous dielectric medium, higher MRR offers for oxygen of quenched 45-carbon steels.
- To achieve lower SR, for machining of HCHCr, SKD 61 and AISI 1045 used pure kerosene. Kerosene mixed with any mixing agent(powder/surfactant/emulsion) reveals lower values of SR. However, EDM oil is ideal for AISI 1045 machining, and when EDM oil is mixed with powder or emulsion for P20 mold steel shows better output results.
- Lower RLT can achieve using Kerosene, EDM oil, Water mixed fluid for machining D2 steel, W300 steel, and Titanium alloy.
- To achieve lower TWR, pure EDM oil showed better performance for AISI P20 alloy. Kerosene and kerosene mixed dielectric fluid shows better results for machining HCHCr die steel and AISI 304 alloys.
- Deionized water is commonly used for WEDM due to its low viscosity and availability. For machining AISI 6061 and Aluminium to achieve minimum KERF and maximum MRR deionized water shows better results. But Ti alloy and AISI 6061 offer lower SR when used same dielectric fluid.

➢ *Declarations*

➢ *Data availability and materials*

Since the manuscript already has all the information required to recreate the work, a separate archive is not necessary.

➢ *Compliance with ethical standards*

The authors state that they are clear of any financial conflicts that have the potential to affect the research presented in this study.

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➢ *Author Contribution*

Both authors contributed to the study conception and design. Data collection and analysis were performed by [Shatarupa Biswas].

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