

# Analysis of Transient Heat conduction in Different Geometries

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## ABSTRACT

In this thesis, an enhancement of thermal properties of dielectric has been performed by adding copper nanoparticle into it. For this purpose the nano-particles were manufactured and whole process is demonstrated experimentally. It was found that up-to some extend conductivity of the base fluid increasing with the concentration of nanoparticle addition. Moreover, the practical application of the present concept has been experimentally analyzed by conducting the experiments on Electrical discharge machining (EDM). This work primarily focuses on enhancement of thermal conductivity of dielectric fluid used in Electric Discharge Machining. Experiments were conducted on electric discharge machine to investigate the influence of copper nano particles on the material removal rate, surface roughness and enhancement of thermal conductivity of the dielectric fluid used in Electric Discharge Machining. Here, PMEDM, a new EDM technique is used where a powder is added in the dielectric fluid. PMEDM has shown good results as compared with conventional EDM. It has been observed that material removal rate increases with the increases in discharge current. The results were obtained 18 to 36 % increment in the metal removal rate due to enhancement of thermal conductivity.

## INTRODUCTION

### Introduction

The thermal conductivities of the fluids like ethylene glycol, water, etc. are quite less than solid phases. One can say that mostly solids have better heat transfer properties than traditional heat transfer fluids. This leads to the development of heat transfer fluids with high thermal conductivity. Another method is the use of additives, which enhance the heat transfer performance of base fluids. The deferred metallic or non-metallic particles increase the transport properties and heat transfer properties of the base fluid. The most operative way to

improve the thermal conductivity of base fluids is to add some small solid particles into the fluids.

It was studied that solid particles of micron size were added in the base liquid to improve heat transfer coefficient. But these small sized particles tend to settle down rapidly, clog flow through channels, corrode pipelines and that reduces process efficiency and pressure drops takes place in the pipe.

It was found that, fluid with micron-sized particles were not efficient enough to outweigh the disadvantages connected with their uses and the result which comes out by the use of nanoparticles in heat transfer liquids (Nano fluids) are very much in demand from the last decade. Nano fluids are heat transfer liquids with dispersed nanoparticles. Nano fluids are effectual of increasing the heat transport properties, thermal conductivities of the base fluid and increase the efficiency and may require applications in the field of enhanced heat transfer.

It is projected that these could be used in airplanes, micro reactors, micro machines in MEMS etc. Nano-fluids can be used in future for efficient heat transfer for the new possibilities to enhance heat transfer performance compared with pure liquids.

### **Production of Nanoparticles**

It was found that several studies used a double-step method, in the first step nanoparticles or nanotubes are formed as a dry powder and in the second step they are spread into the base fluid. On the other hand, in the single-step method mixture of nanoparticles is directly fed into the heat transfer fluid. Both the double-step and single-step methods are explained below:

#### **Double Step Process**

The preparation of nanofluids commences by direct mixing of the base fluid with the nanomaterial's. In the first step, nanomaterial's are formed as powders, and then mixed to the base fluid in the second step. Nanoparticles can be produced from many processes, so these process can be classified into five general methods. These five methods are: (i) transition metal salt reduction (ii) thermal decomposition and photochemical methods (iii) ligand reduction and displacement from organometallics (iv) metal vapor synthesis, and (v) electrochemical synthesis. Bonnemann designed a method for the manufacture of very small (less than 2 nm) and stable nanoparticles by the chemical reduction ways, which may be appropriate for submission in nanofluid synthesis.

The Double-step process is normally used for the mixture of carbon nanotube based nanofluids. Basically there are two types of carbon nanotubes. Single-wall carbon nanotubes (SWCNTs) and Multi-walled carbon nanotubes (MWCNTs), these carbon are cylindrical allotropes. SWCNTs contain a single cylinder of graphene, while MWCNTs comprises multiple graphene cylinders nesting with each other.

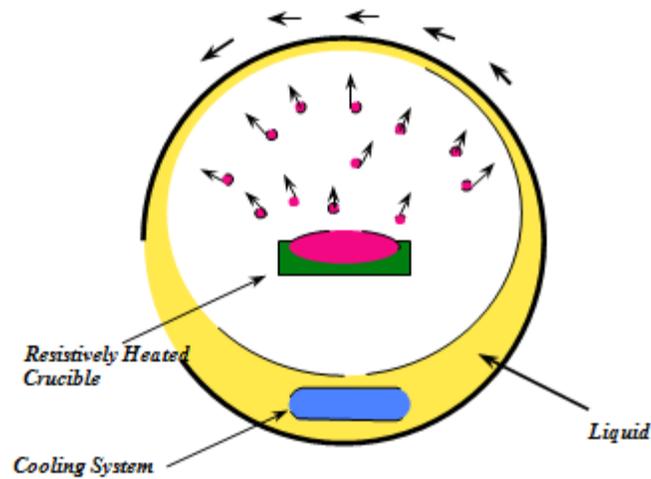
Some authors also advised that the two-step process is best only for nanofluids having oxide nanoparticles spread in de-ionized water where it contains heavier metallic nanoparticles. So that nanopowders can be found in huge quantities, there is also some advantage of using two-step synthesis methods which uses such powders.

### Single step process

There are few methods which make nanofluids through a single step process. In this method thermal decay of an organometallic forebear in the existence of a stabilizer, chemical drop and polyol mixture is done.

In this polyol method, a metal indication is melted in a liquid polyol (usually ethylene glycol), after that the experimental situations are settled to achieve the reduction of the metallic indication by the polyol, monitored by atomic metal nucleation and metal particle development. The direct-evaporation technique was established by Choi et al [6]. It contains a cylinder in which the fluid is rotated. In the middle part of the cylinder, source material is vaporized. The vapour condenses when it comes in contact with the cooled liquid (Figure 1.1). There are some disadvantages of this technique, it uses low vapour pressure liquids so that only limited quantities can be produced.

Many of the single-step chemical mixture process can be used to produce nanofluids. like as, Brust and co-workers recognized a technique for manufacturing a metallic nanoparticles in several solvents by the decrease of metal salts to produce colloidal interruptions for a huge range of applications, containing readings of thermal transport. Good control of size and very fine size supplies can be obtained by using this methods [8]. In practical, a pure copper rod is dipped in a dielectric liquid in a vacuum chamber. An appropriate electric supply is used to make an arc between 6000 - 12000 °C at this temperature, metal rod melts and vaporizes. At the same time, the deionized water is also evaporated by this arc. after that we get Nanofluids containing CuO particles of size  $49.1 \pm 38.9$  nm [10].



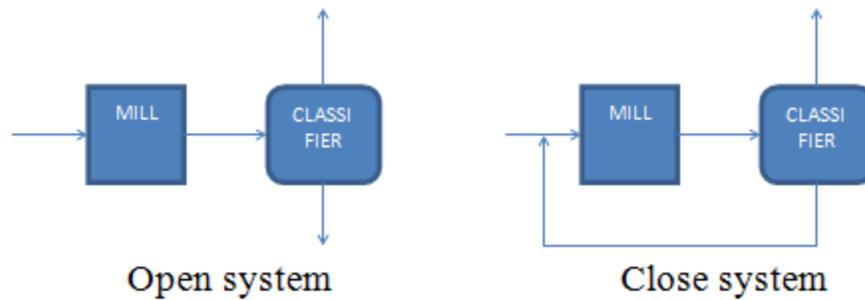
**Figure 1.1 single-step Nano fluid production system (Choi et.al. [6])**

### Crushing in Ball Mills:

Crushing in ball mills is an important technical method to decrease the size of particles which may have unlike nature and a wide variety of chemical, mechanical and physical properties. Few examples are the various ores, limestones, minerals, etc. The various applications of this ball mills are universal in mineral processing and mining industry, chemical industry, pharmaceuticals and cosmetics, ceramics, metallurgy, cement production, etc. Instead of particle size reduction, ball mills are also able to use for mixing, blending, mechanical alloying, dispersing and amorphisation of materials. In construction, a ball milling device is used which consists of a cylindrical vessel and at both the ends it allows rotation of the vessel with respect to center axis. Girth gear is used to drive this mill and a prime mover moves the pinion shaft. This prime movers is mostly synchronous motors fitted with an air clutch or gear transmission. After filling the starting material (ore, rock, etc.) and the grinding media (balls), the milling process starts during rotation result causes transfer of kinetic energy into grinding products due to moving grinding media.

The design and structure of a ball mill depends on the size, the equipment used to load the starting material, and the discharging output product. The size of mill is defined by the ratio of “length to diameter” and this ratio varies from 0.5 to 3.5. The starting material can be loaded either by means of a single or double helical scoop feeder.

In order to require the preferred particle size, the milling under industrial conditions is usually completed in grinding circuits with classifiers which discrete the material according to particle sizes. The possible cases of open- and closed-circuit systems are shown below in Fig. 1.2.



### Open and Closed circuit system

In the open circuit system output material is simply divided in fractions with different particle sizes and the classifier do not affect the grinding process. In the close circuit system only fine product obtained at the output because the classifier returns rough material back to the mill feed. The main objective of mills and classifier is to increase the grinding efficiency of the overall procedure.

The main purpose of the grinding process is to get preferred particle size supply in the final product without metal or other possible infection, increasing the amount of grinding particles and decrease the production cost of the overall system. To complete these objectives several mathematical and control methods are formulated and applied in practical.

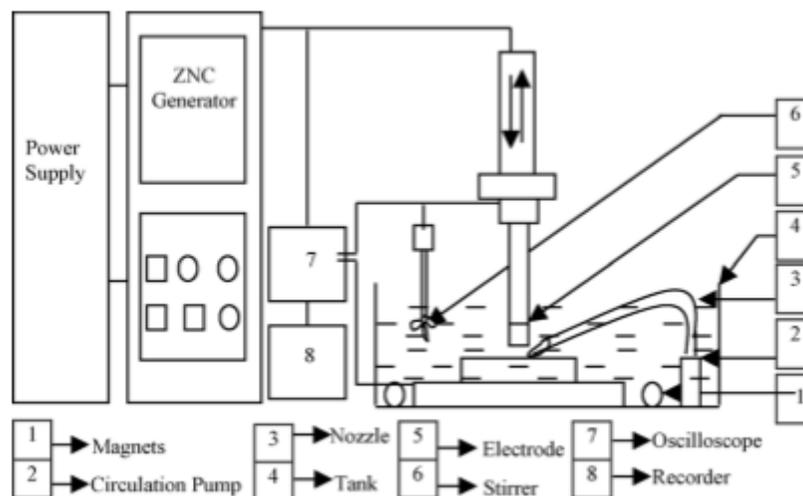
### EDM Process

Electrical discharge machining (EDM) is a nonconventional metal removal process. This process is generally used in modern metal working industry for manufacturing composite cavities in moulds and dies, which are not informal to manufactured by conventional machining process and it can also machined on hardened tool steels. Though, it has low machining efficiency (depending on thermal conductivity of dielectric) and reduced surface finish of the restricted applications. To overcome these problems, one new technique was discovered which can improve the efficiency and surface finish in EDM process in the presence of copper nanoparticles added in the dielectric fluid. So this new technique for material removal process is termed as powder mixed EDM (PMEDM). Here very fine abrasive powder of copper is added into the dielectric fluid of EDM. As we mix the

nano particles, performance of EDM changes. This powder is electrically conductive which reduces the insulating strength of the dielectric fluid and increases the spark gap between the tool and work piece. Hence we observe that process becomes more stable by enhancing thermal conductivity, so it increases material removal rate (MRR) and surface finish.

### Powder mixed EDM Procedure

An experimental setup established for PMEDM is shown in fig1.3,



### Experimental setup for PMEDM

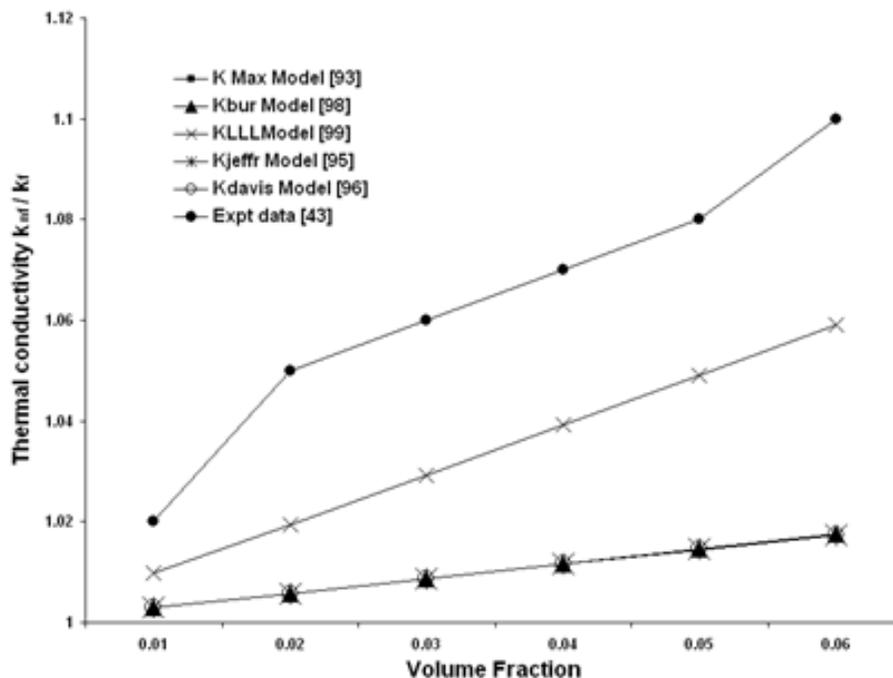
A small dielectric circulating device is added to the designed system. A stirring system is added to avoid the particle settling. These systems are added in such a way that, it can work at commercial level. A pump of micro size is attached for better circulation of the powder mixed dielectric fluid. The stirrer and pump both are attached in the same tank. In this process, copper nanoparticles are added into the dielectric fluid of EDM.

## Thermal Conductivity of dielectric fluid

Heat transfer fluids (HTFs) have many industrial and civil applications, like air-conditioning, transport, energy supply, and electronic cooling, etc. Earlier HTFs, like water, oils, glycols and fluorocarbons have naturally poor heat transfer performance because of low thermal conductivities. Research and progress activities were done to improve the heat transport properties of liquids. Solid metal materials, like as silver, copper and iron, and non-metal materials, like as alumina, CuO, SiC and carbon nanotubes, have much more thermal conductivities than earlier HTFs, solid particles of micron size, in fact millimeter sized were mixed into the base fluids or slurries. However, large solid particles creates some problems, like as abrasion of the surface, obstruction of micro channels, corroding the pipeline and increase the pressure drop, which greatly bounds the practical applications.

So many other ideas were given by researchers around the volume fraction and particles geometry. Hamilton-Crosser (HC) model which depends on the Maxwell's model, about both the fa

**Fig 1.5 shows the relation between thermal conductivity and volume fraction for different models.**



**Figure 1.5 Comparison of the Conventional Models with the Experimental Data**

## 1.9 Organization of Thesis

This thesis is organized in the following six chapters. Few chapters are based on progresses from the former chapters, but overall can be read as independently self-contained entities.

**Chapter 1** of the thesis define about the introduction of the work about enhanced thermal conductivity of dielectric fluid. The chapter also presents the background and motivation to carry this work along with the scope and objectives of the work. The methodology of the present work is also discussed in this chapter, working principle of EDM process, brief mechanisms of material removal and its importance have been explored.

**Chapter 2** presents the review of research on enhanced thermal conductivity of the fluids by adding nano-particle into them. A parametric study of the process from the theoretical modeling point of view is also presented in this chapter.

**Chapter 3** deals with various process parameters and characteristics of the dielectric fluid. Experiments were conducted by adding various concentration of particle. This chapter also presents some theoretical analyses by using the developed models (equations) to find out the thermal conductivity of dielectric.

**Chapter 4** deals with the design and description of an experimental set up for EDM including nanoparticles mixed with dielectric. In this chapter I have discussed about observation table and calculation to find theoretical as well as experimental values.

**Chapter 5** presents the results and discussion about the work obtained after the experimentation. Some graphs are presented to study the enhancement of thermal conductivity, process parameters involved in the EDM machine are also been explored. This chapter also presents the mathematical relations between pulse ON time, pulse OFF time, Duty cycle and peak current etc.

**Chapter 6** presents the concluding remarks drawn from the present work. The probable areas of future research work in this field are discussed.

## CHAPTER 2

### LITERATURE REVIEW

In this chapter some literature review are discussed to know about the effect of various parameters of EDM to enhance material removal rate and decrease tool wear reduction are : pulsating current ,concentration of nanoparticles, duty cycle etc. with the help of these literature review the objective has been achieved by performing various experimentation.

#### 2.1 Objective of the work:

There are many advantages of the addition of nano-particle in fluids, it was interesting to understand the process properties. Till date, many researchers did work on this area on thermal properties like, enhancement on thermal conductivity, viscosity, thermal diffusivity, etc. have been discussed. But their industrial application is still in liberal stage. By this work, it was trying to use enhancement of thermal conductivity by the addition of cu- nanoparticle at different concentration. Mostly, experiments were performed on commonly known electric discharge machine to examines the result on dielectric property of EDM process.

Lastly, we get the optimized parameters in powder mixed electrical discharge machining (PMEDM). These are :Pulse on time, peak current, duty cycle, and different concentration of the copper nanoparticles which are added into the dielectric of EDM were chosen as variables to find the different parameters in the enhancement of thermal conductivity, like :

- 1) Material removal rate and
- 2) Tool wear reduction.

We have prepared a advanced experimental setup in laboratory to get the results which maximize material removal rate and minimize surface roughness.

## 2.2 Some Literature review about EDM

**Spedding and Wang (1997)** have tried to optimize the process parametric combinations by using Artificial neural network (ANN) process and describe the surface in wire electrical discharge machining (WEDM) on AISI 420 through time series methods.

**Zhang et al. (1997)** inspected the effects on MRR, surface roughness and diameter of discharge points in electro-discharge machining (EDM) on ceramics. From the experimental results, it is found that the material removal rate, surface roughness and the diameter of discharge point all are increase with increasing in pulse-on time and discharge current.

**Tsai and Wang (2001a)** have recognized a semi-empirical model of surface finish on work for various materials (three different grades of steel) in EDM and the parameters of the model viz. peak current, pulse duration, electric polarity and properties of materials have been fitted based on the experimental data using Taguchi method and it is found that developed model is dependent on work and tool materials.

**Tsai and Wang (2001b)** have established and compared models to estimate surface finish in EDM process on the work piece of iron and aluminum based on neural networks and a neuro-fuzzy network. They have calculated different models with different training algorithms.

**Lee and Li (2001)** have calculated the effect of MRR, relative wear ratio and surface quality on work piece of tungsten carbide on EDM. Different Cutting parameters are electrode material, electrode polarity, open-circuit voltage, peak current, pulse duration, pulse interval and flushing. It is also detected that higher MRR, better surface finish and lower relative wear ratio is obtained by negative tool polarity and as surface roughness increases it also increases peak current and pulse duration.

**Ramaswamy and Blunt (2002)** have observed that the factors in modifying the surface touches using Taguchi method in EDM on M300 tool steel. He said that the direct current is the most dominant factor in modifying the surface texture, especially the root mean square of peaks ( $S_q$ ), the material volume ( $S_m$ ). The relations between current and distance between electrodes is very important as compared to the individual effect of the last variable.

**Lin and Lin (2002)** have studied that to optimize the EDM process (work-piece polarity, pulse on time, open discharge voltage, discharge current, dielectric fluid, and duty factor) with different performance characteristics viz. MRR, surface roughness and electrode wear ratio using grey relational analysis.

**Lin and Lin (2005)** have tried to improve the EDM process using grey-fuzzy logic. The parameters used in machining are pulse on time, duty factor and discharge current, MRR, tool wear ratio and surface roughness. An orthogonal array, grey relational generating, grey relational coefficient, grey-fuzzy reasoning grade and analysis of modification are applied to study the performance characteristics of the machining process. They found that these approaches can improve the process replies such as the tool wear ratio, MRR and surface roughness in the EDM process.

**Amorima and Weingaertner (2005)** have detected an experimental investigation on EDM of the AISI P20 tool steel under finish machining. The MRR, volumetric relative wear and work piece surface texture  $R_a$  are inspected against the electrical variable of EDM using electrode tool of copper. From the study, it is seen that increase of average surface roughness results in increase in discharge current and discharge duration.

**Mandal et al. (2007)** have tried to optimize the EDM process with the help of soft computing techniques. Artificial neural network (ANN) model is developed using current, pulse on time and pulse off time as input neurons and output networks are MRR and tool wear. The output Testing results prove that the model is suitable for forecasting the reply parameters.

**Assarzadeh and Ghoreishi (2008)** have accessible an integrated neural network- based method for the calculation and selection of different process parameters in die sinking EDM with a flat electrode. The current, period of pulses, and source voltage are selected as network inputs and the material removal rate (MRR) and surface roughness ( $R_a$ ) are calculated as output parameters of the model. The output results show that the neural model can forecast process performance with reasonable accuracy, with varying machining conditions.

**Sahoo et al. (2009)** have examined the effect of machining parameters, viz., pulse on time and pulse off, time pulse current, on the quality of surface produced in EDM of mild steel, brass and tungsten carbide materials uses response surface procedure. Five roughness parameters, viz., centre line average roughness,

root mean square roughness, skewness, kurtosis and mean line peak spacing have been measured. It is observed that the pulse current has the maximum effect on the roughness parameters as compared to pulse on time. However, pulse off time has no major effect on roughness parameters.

**Shah et al. (2010)** calculated the effects of some different machining constraints in addition to changing the material thickness on the machining responses such as material removal rate and surface roughness of tungsten carbide samples machined by wire electrical discharge machining (WEDM). For thinner work pieces, the spark energy decreased with reduce MRR and fine surface finish.

E.D.M is basically a non-conventional material removal process which is broadly used to produce dies, punches and moulds, finishing parts for aerospace and automotive industry, and surgical components. This process can be effectively used to machine electrically conductive parts irrespective of their hardness, shape and toughness.

The review presented in this work is on different techniques projected and inspected by researchers resulting for the improvement of material removal rate in EDM. Improvement in MRR has always been an important factor for researchers and scrutiny of the published research work highlighted the need for such a review paper reporting all the available literature and suggesting the future direction for research.

## **CHAPTER 3**

### **EXPERIMENTAL SETUP AND APPARATUS**

#### **3.1 Experimental analysis**

In this chapter the enhancement of thermal conductivity has been experimentally analyzed by conducting the experiments on EDM machine. Copper nano particles were added in the base fluid (dielectric) .PMEDM is a new EDM technique in which powder is added to the dielectric fluid. Few powders which are generally added are copper, aluminum, silicon carbide, graphite, chromium, nickel etc. PMEDM shows best results as compared to conventional EDM. It increases machining rate. It is observed that by adding of nanoparticles in the dielectric medium, it improves the break down characteristics and decreases the insulating strength which increases the spark gap between the tool and work piece. This helps in the uniform flushing of the debris which stabilizes the process and hence increases machining rate and surface finish.

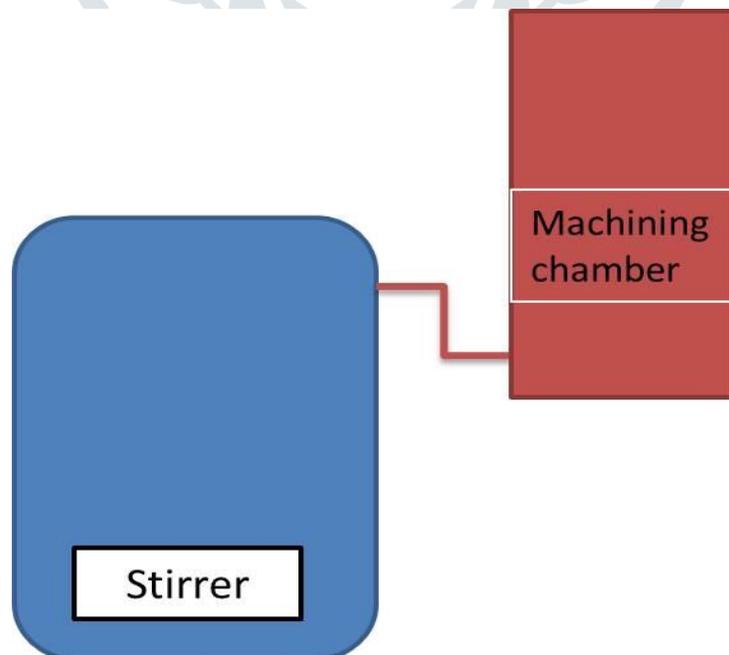
### 3.2 Experimental setup:

The fig 3.1 shows the description of adding Nano particle into the dielectric.



**Fig 3.1** Recirculation system

The next fig shows the powder mixed dielectric



**Fig 3.2** Mixing chamber

The real image of same is as follows



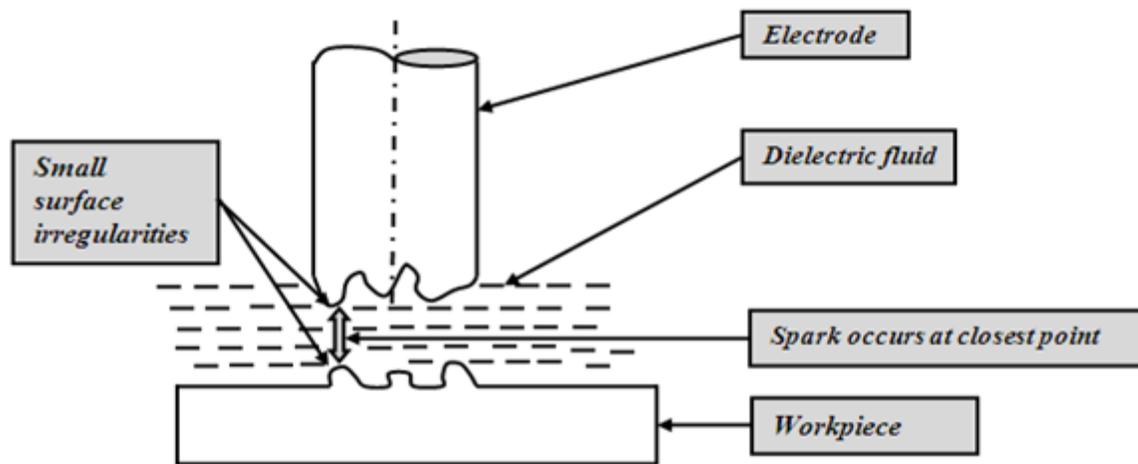
**Fig 3.3 complete setup**

### 3.3 EDM Working Principle

The working principle of EDM is based on the thermoelectric energy. This energy is produced between electrode and work piece and work piece is submerged in dielectric fluid where electric current passes. The specific small gap between work piece and electrode is called spark gap. This spark gap is filled with insulating gap, The hydrocarbon oil or de-ionized (de-mineralized) water are used as dielectric [29]. Schumacher defined the technique of material erosion employed in EDM . It is because ignition of electrical discharges in a dirty, liquid filled gap, when applying EDM, is generally known as ion action identical as found by physical research of discharges in air or in vacuum as well as with investigations on the innovation strength of insulating hydrocarbon liquids.

The working principle of EDM as shown in Fig.3.4 . This technique was developed in the late 1940s . The electrode comes closer to the work piece to decrease the spark gap to increase the applied voltage to ionize the dielectric fluid .Electrode and work piece get separated during short discharge at dielectric gap. At very small cross sectional area the dielectric fluid discharge energy into a channel. It cools the two electrodes, and flushes away the material machining from the gap. The discharge energy and the time of spark start [30]get

effected due to electric resistance of dielectric. Low resistance results in early discharge. A servo system is that which compares the gap voltage with a reference value and servo system also ensure that the electrode keeps correct spark gap and moves at proper rate, and also protect the electrode if short-circuiting occurs. The feed speed increase when average gap voltage is higher than servo reference voltage. On the other hand the feed speed decreases when the average gap voltage is lower than the reference voltage, which is the used when smaller gap widths causes smaller ignition delay.



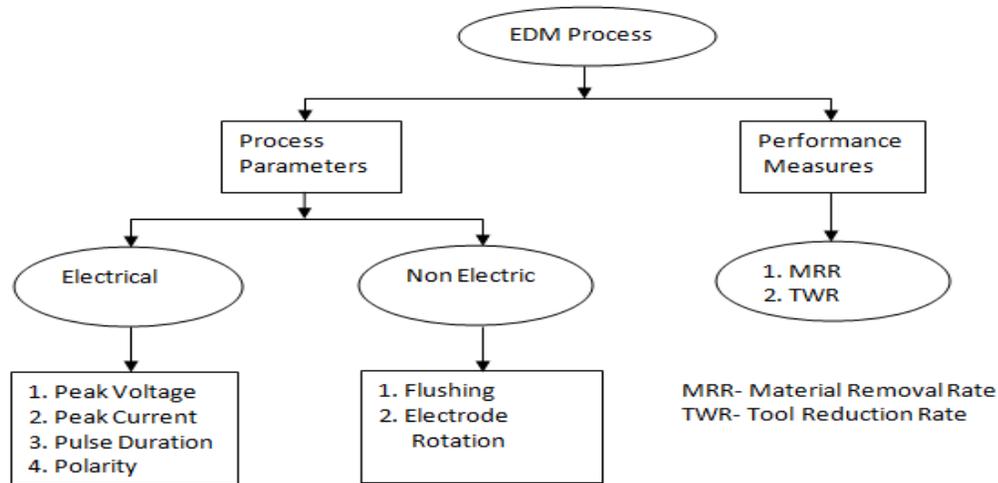
**Fig 3.4 Working principle of EDM**

In this process there is no direct contact between the work piece and electrode, thus eliminating mechanical stresses, chatter and vibration problems during machining. Different activities are accepted by researchers depend on the interest of the researchers and the availability of the technology. Rajurkar [31] has stated some future trends actions in EDM: machining hard materials, uses powder additives for mirror surface finish, automation and ultrasonic-assisted EDM and control.

### 3.4 Process Parameters and Presentation Procedures

The process parameters and performance measures are shown in Fig 3.5. These process parameters can be divided into two categories i.e. electrical and non-electrical parameters. Some of the major electrical parameters are discharge voltage, peak current, pulse duration and pulse interval, electrode gap, polarity and pulse wave form[32], it is quite difficult to explain all the parameters on performance measures.

Few of the main non-electrical parameters are work piece rotation ,flushing of dielectric, and electrode rotation. To optimize performance measures these non electrical parameters play a important role .Researches[33] on flushing pressure found that it also affects the surface roughness, tool wear rate, acts as coolant and also flushing away the debris from the machining gap [34]. Rotary motion of work piece expands the temperature distribution of the work piece and circulation of the dielectric fluid in the spark gap , yielding better MRR and SR [35].



**Figure 3.5 : Process parameters and performance measures of EDM Process**

### 3.5 powder mixed EDM Process parameters

Some different process parameters that can affect the quality of component processes by PMEDM,

#### 3.5.1 Process of material removal

Material removal takes place when electro sparking method is used in which electric erosion occurs due to breakdown of electrode material done by electric discharge. The material removal takes place when the ionization of dielectric by fallen up on molecules on ions and electrons. Between two electrodes discharge is produced through a gaseous or liquid medium. In the dielectric, the electrons collapse with neutral molecules as moving in the inter-electrode space, electrons cracks and ionization occurs when it happens there is a continuous motion of electrons about the channel to the electrode, causes the passing current impulse or discharge.

### 3.5.2 Polarity

The Polarity is generally used when the tool is connected to negative and work piece to positive. Sometimes it can be inverted depending upon the use. Positive polarity work piece in EDM has higher surface roughness than negative polarity.

### 3.5.3 Pulse on time

The time period at which machining process takes place is called pulse on time. MRR depends upon the amount of energy supplied during pulse on-time.

### 3.5.4 Pulse off time

The time period between the successive sparks is termed as the Pulse off-time.

### 3.5.5 Peak current

The total amount of power required in discharge machining, measured in units of amperage, in each on-time pulse, the current increases until it reaches to the preset level, which is known as the peak current.

### 3.5.6 Discharge current

The measured value of power supplied to the discharge gap. The higher pulse energy and formation of deeper discharge craters is due to the higher current which leads these factors and this increases the MRR and the surface roughness ( $R_a$ ) value. Same effect on MRR and  $R_a$  is produced as the gap voltage ( $V_g$ ) is increased.

### 3.5.7 Pulse wave form

A controlled pulse generator is used for the higher surface finish, short spark duration and higher peak current values, so that it generate proper pulse wave form in EDM. The pulses of high energy and low frequency are used in rough machining.

### 3.5.8 Type of dielectric medium

Generally hydrocarbon oil is used as dielectric and kerosene oil, paraffin oil, lubricating oil can be used. The deionised water gives high MRR and TWR ,Jain et. al. [37]. However, the deionised water may gives higher levels of MRR in some special circumstances such as when a brass electrode at negative polarity is used ; pulse durations smaller than 500  $\mu$ s are employed and machining of Ti-6Al-4V with a copper electrode .

### 3.5.9 Electrode gap

The servo feed mechanism is used for the proper gap width. Mostly electro-mechanical (DC or stepper motors) and electro-hydraulic systems are used, and it is designed to respond to average gap voltage ,Kumar et. al. [38]. Larger gap widths cause longer ignition delays, resulting in a higher average gap voltage.

### 3.5.10 Electrode material

The electrode shape is basically same as desired product. Different electrode materials used as metallic material (copper, brass, tungsten, aluminum), non-metallic material (graphite), combined metallic and non-metallic (copper-graphite), and metallic coating as insulators (copper on molded plastic, copper on ceramic) etc. Materials have high melting-point; good electrical conductivity, low wear rate and easily machinability are usually chosen as tool materials for EDM.

## 3.6 Nanoparticle clusters

Xuan et al. [9] studied that Brownian motion and clustering of nanoparticles causes thermal conductivity.

An equation was planned to expect the thermal conductivity of nanofluids:

$$\frac{k_{nf}}{k_f} = \frac{k_p + 2k_f - 2\varphi(k_f - k_p)}{k_p + 2k_f + \varphi(k_f - k_p)} + \frac{\rho_p \varphi c_{p,p}}{2k_f} \sqrt{\frac{k_B T}{3\pi r_{cl} \mu_f}}$$

Here  $r_{cl}$  is the apparent radius of the nanoparticle clusters, which experimentally determined.

$$\frac{k_{nf}}{k_f} = \frac{k_{cl} + (n-1)k_f - (n-1)\varphi_{cl}(k_f - k_{cl})}{k_{cl} + (n-1)k_f + \varphi_{cl}(k_f - k_{cl})}$$

Where  $k_{cl}$  and  $\varphi_{cl}$  are the thermal conductivity and volume fraction of the clusters, respectively. n was

taken as 3 for the spheres and 5 for the cylinders in this work.

$$\Phi_{cl} = \varphi \left( \frac{r_{cl}}{r_p} \right)^{D-3}$$

Where  $r_{cl}$  and  $r_p$  having radii of the clusters and nanoparticles, respectively. D is called fractal index. To determine value of  $k_{cl}$ , the following equation was expressed: [38]:

$$\frac{k_{cl}}{k_f} = \frac{1}{4} \left\{ (3\Phi_{in} - 1) \frac{k_p}{k_f} + (3(1 - \Phi_{in}) - 1) + \left[ \left( (3\Phi_{in} - 1) \frac{k_p}{k_f} + (3(1 - \Phi_{in}) - 1) \right)^2 + 8 \frac{k_p}{k_f} \right]^{1/2} \right\}$$

Where  $\Phi_{in}$  is the solid volume fraction of clusters and it is defined as

$$\Phi_{in} = \varphi \left( \frac{r_{cl}}{r_p} \right)^{D-3}$$

For the estimation of  $k_{cl}$  the following nanotubes expression is as

$$\frac{k_{cl}}{k_f} = \frac{3 + \Phi_{in} [2\beta_x(1-l_x) + \beta_z(1-l_z)]}{3 - \Phi_{in} [2\beta_x l_x + \beta_z l_z]}$$

$$\text{Where } \beta_x = \frac{(K_x - K_f)}{[K_f + L_x(K_t - K_f)]}$$

$$\text{Where } \beta_z = \frac{(K_z - K_f)}{[K_f + L_z(K_t - K_f)]}$$

$K_x$  And  $K_z$  are the thermal conductivity of nanotubes about transverse and longitudinal directions, respectively.  $k_t$  is the isotropic thermal conductivity of the nanotube  $k_x$ ,  $k_z$  and  $k_t$  can be considered as equal to  $k_p$  as an approximation.  $L_x$  and  $L_z$  are defined as:

$$L_x = \frac{p^2}{2(p^2 - 1)} - \frac{p^2}{2(p^2 - 1)^{3/2}} \cosh^{-1}(p)$$

$$\text{Where } L_z = (1 - 2L_x)$$

### 3.7 Machining conditions

➤ Fixed parameters

- Open circuit voltage ( $V_g = 50 \text{ V}$ )
- Depth of hole = 2mm
- Flushing pressure=0.1bar

➤ Variable parameters

- Discharge current
- Pulse on time
- Duty factor
- Powder concentration

➤ Tool electrode

- Material – copper
- Diameter – 10mm

➤ Work piece

- Material- EN8
- Thickness of work piece- 4 mm



**Table 3.1 Chemical composition of EN-8**

Element	Content (%)
Iron	97.86% to 99%
Carbon	0.35%
Silicon	0.05%
Manganese	0.60%
Sulphur	0.06% (max)
Phosphorus	0.06 % (max)

➤ Copper nanoparticles powder

No of free electrons and mean free path values are also given in below table5.4

**Table 3.2 Free electrons and path value of copper nanoparticles**

	$K_b/Wm^{-1}k^{-1}$	$\mu f/ev$	Ne 1028/m-3	$\lambda e,b/nm$
Copper	398	07	8.45	35.97

## CHAPTER 4

### EXPERIMENTAL WORK

As per design expert software, the combination of input parameters namely, concentration, current and duty cycle were taken for experimentation and their ranges are presented in Table 4.2

As Eastman et al.[3] reported that thermal conductivity of the base fluid were enhanced up-to 40% by adding the nanoparticle into it. Same concept has been considered in this work to improve the thermal conductivity of the dielectric used in the EDM process. Copper nanoparticles were considered for experimentation and their details were explained in chapter 1.

It was found through experimentation that MRR of the process was also improved by adding these particles in dielectric. The calculation of the MRR is presented below:

#### 4.1 Observation Table

**Enhancement of thermal conductivity with the addition of nanoparticles of different concentration.**

(A) Nanoparticles (gram/lit)	(B) Thermal conductivity(w/mK)
2	0.15
4	0.16
6	0.18
8	0.20
10	0.21
12	0.22
14	0.23
16	0.24
18	0.25
20	0.26

Thermal conductivity is measured with the help of thermal conductivity analyzer; Table 4.1 shows the enhancement of thermal conductivity. Thus it can be seen that with the addition of nanoparticles, thermal conductivity increases simultaneously. The graphical representation of thermal conductivity enhancement is given in the next chapter.

**Table. 4.2 Values for MRR (thermal conductivity enhancement) and TWR for various parameters of PMEDM**

Factor 1 A: current(amp)	Factor 2 B: conc (g/lit)	Factor 3 C: duty cycle	Response 1 MRR <sup>1</sup> ( mm <sup>3</sup> /sec)	Response 2 MRR after 40% Enhanced T.C ( mm <sup>3</sup> /sec)	Response 3 TWR (mm <sup>3</sup> /sec)
25.00	8.00	80	0.548	0.768	0.028
17.50	5.00	60	0.405	0.567	0.019
10.00	8.00	80	0.232	0.325	0.00101
30.11	5.00	60	0.860	1.205	0.1871
17.50	5.00	60	0.410	0.575	0.0195
10.00	8.00	40	0.196	0.275	0.00615
10.00	2.00	40	0.167	0.235	0.0099
17.50	5.00	60	0.408	0.572	0.0194
25.00	2.00	40	0.575	0.805	0.771
4.89	5.00	60	0.021	0.03	0.0005
17.50	5.00	60	0.387	0.543	0.0187
25.00	2.00	80	0.518	0.726	0.0444
17.50	5.00	60	0.399	0.559	0.0197
10.00	2.00	80	0.226	0.317	0.0015
17.50	5.00	60	0.523	0.733	0.0432
17.50	10.05	60	0.465	0.651	0.0062
25.00	8.00	40	0.465	0.651	0.224
17.50	5.00	26.36	0.355	0.498	0.0195

**Table 4.2 Value of MRR and TWR**

Since the relation between thermal conductivity and MRR is linear therefore the assumed MRR is calculated below:

Theoretical MRR is compared with the experiments and same has been evaluated in the coming portion.

#### 4.2 THEORETICAL CALCULATION TO FIND ENHANCED MRR

$$1) \text{ MRR}^1 = 0.548 \text{ mm}^3/\text{sec}$$

After adding 08 g/l copper nanoparticles at 25 amp current we get enhanced value of  $\text{MRR}^1$ ,

$$\text{MRR} = 40\% \text{ enhanced MRR}^1$$

$$\text{MRR} = 0.548 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$\text{MRR} = 0.768 \text{ mm}^3/\text{sec}$$

$$2) \text{ MRR}^1 = 0.405 \text{ mm}^3/\text{sec}$$

After adding 05 g/l copper nanoparticles at 17.50 amp current we get enhanced value of  $\text{MRR}^1$ ,

$$\text{MRR} = 40\% \text{ enhanced MRR}^1$$

$$\text{MRR} = 0.405 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$\text{MRR} = 0.567 \text{ mm}^3/\text{sec}$$

$$3) \text{ MRR}^1 = 0.232 \text{ mm}^3/\text{sec}$$

After adding 08 g/l copper nanoparticles at 10.0 amp current we get enhanced value of  $\text{MRR}^1$ ,

$$\text{MRR} = 40\% \text{ enhanced MRR}^1$$

$$\text{MRR} = 0.232 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$\text{MRR} = 0.325 \text{ mm}^3/\text{sec}$$

$$4) \text{ MRR}^1 = 0.860 \text{ mm}^3/\text{sec}$$

After adding 05 g/l copper nanoparticles at 30.11 amp current we get enhanced value of  $\text{MRR}^1$ ,

$$\text{MRR} = 40\% \text{ enhanced MRR}^1$$

$$\text{MRR} = 0.860 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$\text{MRR} = 1.205 \text{ mm}^3/\text{sec}$$

$$5) \text{ MRR}^1 = 0.410 \text{ mm}^3/\text{sec}$$

After adding 05 g/l copper nanoparticles at 17.50amp current we get enhanced value of  $MRR^1$ ,

$$MRR = 40\% \text{ enhanced } MRR^1$$

$$MRR = 0.410 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$MRR = 0.575 \text{ mm}^3/\text{sec}$$

$$6) MRR^1 = 0.196 \text{ mm}^3/\text{sec}$$

After adding 08 g/l copper nanoparticles at 10.0 amp current we get enhanced value of  $MRR^1$ ,

$$MRR = 40\% \text{ enhanced } MRR^1$$

$$MRR = 0.196 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$MRR = 0.275 \text{ mm}^3/\text{sec}$$

$$7) MRR^1 = 0.167 \text{ mm}^3/\text{sec}$$

After adding 02 g/l copper nanoparticles at 10.0 amp current we get enhanced value of  $MRR^1$ ,

$$MRR = 40\% \text{ enhanced } MRR^1$$

$$MRR = 0.167 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$MRR = 0.235 \text{ mm}^3/\text{sec}$$

$$8) MRR^1 = 0.408 \text{ mm}^3/\text{sec}$$

After adding 05 g/l copper nanoparticles at 17.50 amp current we get enhanced value of  $MRR^1$ ,

$$MRR = 40\% \text{ enhanced } MRR^1$$

$$MRR = 0.408 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$MRR = 0.572 \text{ mm}^3/\text{sec}$$

$$9) MRR^1 = 0.575 \text{ mm}^3/\text{sec}$$

After adding 02 g/l copper nanoparticles at 25.0 amp current we get enhanced value of  $MRR^1$ ,

$$MRR = 40\% \text{ enhanced } MRR^1$$

$$MRR = 0.575 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$MRR = 0.805 \text{ mm}^3/\text{sec}$$

$$10) MRR^1 = 0.021 \text{ mm}^3/\text{sec}$$

After adding 05 g/l copper nanoparticles at 4.89amp current we get enhanced value of  $MRR^1$ ,

$$MRR = 40\% \text{ enhanced } MRR^1$$

$MRR = 0.021 * 40\%$  , we get enhanced value after 40%

$MRR = 0.03 \text{ mm}^3/\text{sec}$

**11)  $MRR^1 = 0.387 \text{ mm}^3/\text{sec}$**

After adding 05 g/l copper nanoparticles at 17.50 amp current we get enhanced value of  $MRR^1$ ,

$MRR = 40\%$  enhanced  $MRR^1$

$MRR = 0.387 * 40\%$  , we get enhanced value after 40%

$MRR = 0.543 \text{ mm}^3/\text{sec}$

**12)  $MRR^1 = 0.518 \text{ mm}^3/\text{sec}$**

After adding 02 g/l copper nanoparticles at 25.0amp current we get enhanced value of  $MRR^1$ ,

$MRR = 40\%$  enhanced  $MRR^1$

$MRR = 0.518 * 40\%$  , we get enhanced value after 40%

$MRR = 0.726 \text{ mm}^3/\text{sec}$

**13)  $MRR^1 = 0.399 \text{ mm}^3/\text{sec}$**

After adding 05 g/l copper nanoparticles at 17.50amp current we get enhanced value of  $MRR^1$ ,

$MRR = 40\%$  enhanced  $MRR^1$

$MRR = 0.399 * 40\%$  , we get enhanced value after 40%

$MRR = 0.559 \text{ mm}^3/\text{sec}$

**14)  $MRR^1 = 0.226 \text{ mm}^3/\text{sec}$**

After adding 02 g/l copper nanoparticles at 10.0 amp current we get enhanced value of  $MRR^1$ ,

$MRR = 40\%$  enhanced  $MRR^1$

$MRR = 0.226 * 40\%$  , we get enhanced value after 40%

$MRR = 0.317 \text{ mm}^3/\text{sec}$

**15)  $MRR^1 = 0.523 \text{ mm}^3/\text{sec}$**

After adding 05 g/l copper nanoparticles at 17.50 amp current we get enhanced value of  $MRR^1$ ,

$MRR = 40\%$  enhanced  $MRR^1$

$MRR = 0.523 * 40\%$  , we get enhanced value after 40%

$MRR = 0.733 \text{ mm}^3/\text{sec}$

$$16) \text{MRR}^1 = 0.465 \text{ mm}^3/\text{sec}$$

After adding 10.05 g/l copper nanoparticles at 17.50 amp current we get enhanced value of  $\text{MRR}^1$ ,

$$\text{MRR} = 40\% \text{ enhanced } \text{MRR}^1$$

$$\text{MRR} = 0.465 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$\text{MRR} = 0.651 \text{ mm}^3/\text{sec}$$

$$17) \text{MRR}^1 = 0.465 \text{ mm}^3/\text{sec}$$

After adding 08 g/l copper nanoparticles at 25.0 amp current we get enhanced value of  $\text{MRR}^1$ ,

$$\text{MRR} = 40\% \text{ enhanced } \text{MRR}^1$$

$$\text{MRR} = 0.465 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$\text{MRR} = 0.651 \text{ mm}^3/\text{sec}$$

$$18) \text{MRR}^1 = 0.355 \text{ mm}^3/\text{sec}$$

After adding 05 g/l copper nanoparticles at 17.50amp current we get enhanced value of  $\text{MRR}^1$ ,

$$\text{MRR} = 40\% \text{ enhanced } \text{MRR}^1$$

$$\text{MRR} = 0.355 * 40\% \quad , \text{ we get enhanced value after 40\%}$$

$$\text{MRR} = 0.498 \text{ mm}^3/\text{sec}$$

### 4.3 Experimentally calculated MRR

$$\text{MRR} = \frac{W_b - W_a}{t}$$

Where,  $W_b$  : Weight of work piece before machining

$W_a$ : Weight of work piece after machining

and  $t$ : Machining time for a duty cycle

**Table 4.3 Improved % of MRR for various parameters of PMEDM**

<b>Factor 1</b> <b>A:</b> <b>current(amp)</b>	<b>Factor 2</b> <b>B: conc</b> <b>(g/lit)</b>	<b>Factor 3</b> <b>C: duty</b> <b>cycle</b>	<b>Response 1</b> <b>MRR<sup>1</sup> (</b> <b>mm<sup>3</sup>/sec)</b>	<b>Response 2</b> <b>MRR after</b> <b>adding</b> <b>nanoparticles</b> <b>or enhanced</b> <b>T.C (</b> <b>mm<sup>3</sup>/sec)</b>	<b>%Change</b> <b>in the</b> <b>MRR</b>
25.00	8.00	80	0.548	0.698	27.3%
17.50	5.00	60	0.405	0.501	23.7%
10.00	8.00	80	0.232	0.299	28.8%
30.11	5.00	60	0.860	1.099	27.7%
17.50	5.00	60	0.410	0.488	19.02%
10.00	8.00	40	0.196	0.243	23.97%
10.00	2.00	40	0.167	0.205	22.75%
17.50	5.00	60	0.408	0.498	22.05%
25.00	2.00	40	0.575	0.700	21.73%
4.89	5.00	60	0.021	0.299	13.23%
17.50	5.00	60	0.387	0.485	25.32%
25.00	2.00	80	0.518	0.677	30.69%
17.50	5.00	60	0.399	0.510	27.81%
10.00	2.00	80	0.226	0.288	27.43%
17.50	5.00	60	0.523	0.678	29.63%
17.50	10.05	60	0.465	0.595	27.95%
25.00	8.00	40	0.465	0.588	26.45%
17.50	5.00	26.36	0.355	0.415	16.90%

#### 4.4 Improved Percentage in the MRR

$$1) \text{ MRR}^1 = 0.548 \text{ mm}^3/\text{sec}$$

By adding 08 g/l copper nanoparticles and keeping current of 25 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

$$\text{Final MRR} - \text{Initial MRR} / \text{Initial MRR} * 100$$

$$0.698 - 0.548 / 0.548 * 100 = 27.3\%$$

$$\text{New MRR} = 27.3\% \text{ enhanced MRR}^1$$

$$2) \text{ MRR}^1 = 0.405 \text{ mm}^3/\text{sec}$$

By adding 05 g/l copper nanoparticles and keeping current of 17.50 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

$$\text{Final MRR} - \text{Initial MRR} / \text{Initial MRR} * 100$$

$$0.501 - 0.405 / 0.405 * 100 = 23.7\%$$

$$\text{New MRR} = 23.7\% \text{ enhanced MRR}^1$$

$$3) \text{ MRR}^1 = 0.232 \text{ mm}^3/\text{sec}$$

By adding 08 g/l copper nanoparticles and keeping current of 10amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

$$\text{Final MRR} - \text{Initial MRR} / \text{Initial MRR} * 100$$

$$0.299 - 0.232 / 0.232 * 100 = 28.8\%$$

$$\text{New MRR} = 28.8\% \text{ enhanced MRR}^1$$

$$4) \text{ MRR}^1 = 0.860 \text{ mm}^3/\text{sec}$$

By adding 05 g/l copper nanoparticles and keeping current of 30.11amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

$$\text{Final MRR} - \text{Initial MRR} / \text{Initial MRR} * 100$$

$$0.1099 - 0.860 / 0.860 * 100 = 27.7\%$$

$$\text{New MRR} = 27.7\% \text{ enhanced MRR}^1$$

$$5) \text{ MRR}^1 = 0.410 \text{ mm}^3/\text{sec}$$

By adding 05 g/l copper nanoparticles and keeping current of 17.50 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.488 - 0.410 / 0.410 * 100 = 19.02\%$$

New MRR = 19.02% enhanced MRR<sup>1</sup>

$$6) \text{ MRR}^1 = 0.196 \text{ mm}^3/\text{sec}$$

By adding 08 g/l copper nanoparticles and keeping current of 10 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.243 - 0.196 / 0.196 * 100 = 23.97\%$$

New MRR = 23.97% enhanced MRR<sup>1</sup>

$$7) \text{ MRR}^1 = 0.167 \text{ mm}^3/\text{sec}$$

By adding 02 g/l copper nanoparticles and keeping current of 10 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.205 - 0.167 / 0.167 * 100 = 22.75\%$$

New MRR = 22.75% enhanced MRR<sup>1</sup>

$$8) \text{ MRR}^1 = 0.408 \text{ mm}^3/\text{sec}$$

By adding 05 g/l copper nanoparticles and keeping current of 17.50 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.498 - 0.408 / 0.408 * 100 = 22.05\%$$

New MRR = 22.05% enhanced MRR<sup>1</sup>

$$9) \text{ MRR}^1 = 0.575 \text{ mm}^3/\text{sec}$$

By adding 02 g/l copper nanoparticles and keeping current of 25 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.700 - 0.575 / 0.575 * 100 = 21.73\%$$

New MRR = 21.73% enhanced MRR<sup>1</sup>

$$10) \text{ MRR}^1 = 0.021 \text{ mm}^3/\text{sec}$$

By adding 05 g/l copper nanoparticles and keeping current of 4.89amp. The enhanced % value of MRR<sup>1</sup> is calculated by:

$$\text{Final MRR} - \text{Initial MRR} / \text{Initial MRR} * 100$$

$$0.299 - 0.021 / 0.021 * 100 = 13.23\%$$

New MRR = 13.23% enhanced MRR<sup>1</sup>

$$11) \text{ MRR}^1 = 0.387 \text{ mm}^3/\text{sec}$$

By adding 05 g/l copper nanoparticles and keeping current of 17.50 amp. The enhanced % value of MRR<sup>1</sup> is calculated by:

$$\text{Final MRR} - \text{Initial MRR} / \text{Initial MRR} * 100$$

$$0.485 - 0.387 / 0.387 * 100 = 25.32\%$$

New MRR = 25.32% enhanced MRR<sup>1</sup>

$$12) \text{ MRR}^1 = 0.518 \text{ mm}^3/\text{sec}$$

By adding 02 g/l copper nanoparticles and keeping current of 25 amp. The enhanced % value of MRR<sup>1</sup> is calculated by:

$$\text{Final MRR} - \text{Initial MRR} / \text{Initial MRR} * 100$$

$$0.677 - 0.518 / 0.518 * 100 = 30.69\%$$

New MRR = 30.69% enhanced MRR<sup>1</sup>

$$13) \text{ MRR}^1 = 0.399 \text{ mm}^3/\text{sec}$$

By adding 05g/l copper nanoparticles and keeping current of 17.50 amp. The enhanced % value of MRR<sup>1</sup> is calculated by:

$$\text{Final MRR} - \text{Initial MRR} / \text{Initial MRR} * 100$$

$$0.510 - 0.399 / 0.399 * 100 = 27.81\%$$

New MRR = 27.81% enhanced MRR<sup>1</sup>

$$14) \text{ MRR}^1 = 0.226 \text{ mm}^3/\text{sec}$$

By adding 02 g/l copper nanoparticles and keeping current of 10 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.288 - 0.226 / 0.226 * 100 = 27.43\%$$

New MRR = 27.43% enhanced MRR<sup>1</sup>

$$15) \text{ MRR}^1 = 0.523 \text{ mm}^3/\text{sec}$$

By adding 05 g/l copper nanoparticles and keeping current of 17.50 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.678 - 0.523 / 0.523 * 100 = 29.63\%$$

New MRR = 29.63% enhanced MRR<sup>1</sup>

$$16) \text{ MRR}^1 = 0.465 \text{ mm}^3/\text{sec}$$

By adding 10.05g/l copper nanoparticles and keeping current of 17.50 amp. The enhanced % value

of MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.595 - 0.465 / 0.465 * 100 = 27.95\%$$

New MRR = 27.95% enhanced MRR<sup>1</sup>

$$17) \text{ MRR}^1 = 0.465 \text{ mm}^3/\text{sec}$$

By adding 08g/l copper nanoparticles and keeping current of 25 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.588 - 0.465 / 0.465 * 100 = 31.39\%$$

New MRR = 31.39% enhanced MRR<sup>1</sup>

$$18) \text{ MRR}^1 = 0.355 \text{ mm}^3/\text{sec}$$

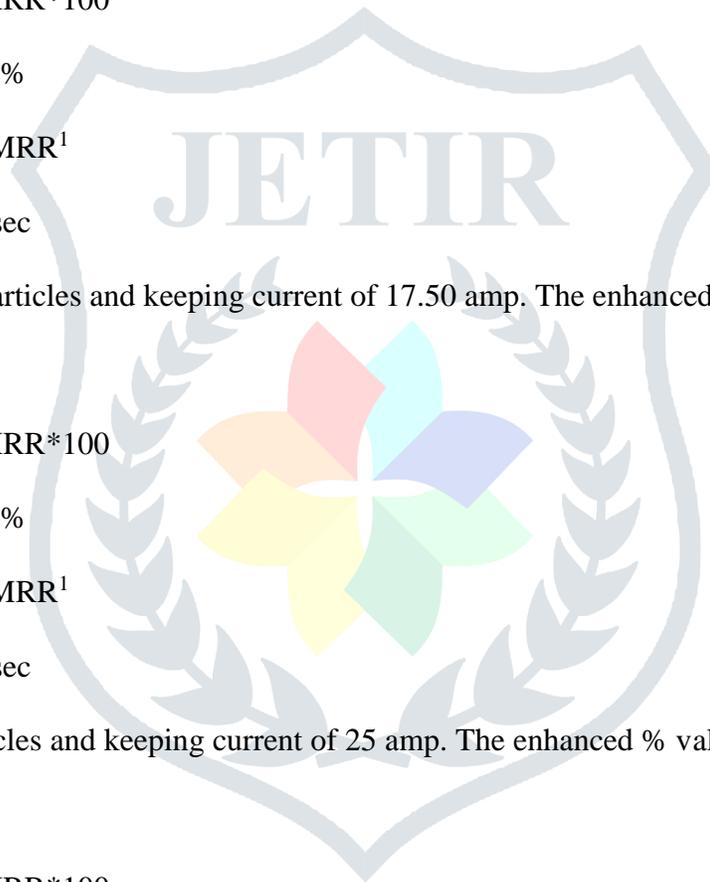
By adding 05 g/l copper nanoparticles and keeping current of 17.50 amp. The enhanced % value of

MRR<sup>1</sup> is calculated by:

Final MRR- Initial MRR/Initial MRR\*100

$$0.415 - 0.355 / 0.355 * 100 = 16.90\%$$

New MRR = 16.90% enhanced MRR<sup>1</sup>



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