Optimization of Electrochemical Machining Process Based on Artificial Neural Network Technique

Noor Abd Al-Hassan
Metallurgy and Production Engineering Department, University of Technology/Baghdad
Dr. Shukry H.Aghdeab
Metallurgy and Production Engineering Department, University of Technology/Baghdad
Dr. Abbas F.Ibrahim
Metallurgy and Production Engineering Department, University of Technology/Baghdad

Received on:1/6/2016 & Accepted on:24/11/2016

ABSTRACT
Electrochemical machining (ECM) is one of nonconventional machining process used to operation the most harsh materials that difficult to operate in conventional machining. This search has been used to study impact of different parameters on material removal rate (MRR) and to improve the MRR. The workpiece material in this search is stainless steel 316L, tool material from copper and NaCl (10, 25, 50) g/l was used as electrolyte. Through the experiments noted that the MRR increasing at increased current from (50 to 200) the increasing in MRR reach to 57.60%, also MRR increasing at increasing electrolyte concentration from (10 to 50) g/l increasing in MRR (reach) to 75.17 % and MRR decreasing at increased gap size from (0.5 to 1.5) mm the decreasing in MRR reach to 39.2 %. To predict the values of MRR and to get optimization, artificial neural network was used to get minimum mean squared error (MSE) and minimum average percentage error. In network, separated some values to training set and the remaining for testing set and it was noted that the predicated and experimental values are very close to each other.
Keywords: Material removal rate (MRR), electrochemical machining (ECM), artificial neural network (ANN), means squared error (MSE).

INTRODUCTION
Electrochemical machining (ECM) operation is one of the nonconventional machining operations. This operation depends on the precept of electrolysis for material removal. The material removal is decided by the well-known Michael Faraday's laws of electrolysis (1791-1867), where the metal is fundamentally extracted in the form of slush and residue by electrochemical and chemical response that occurs in an electrolytic cell [1]. Gusseff inserted the first patent on electrochemical machining in 1929s and the first considerable expansion happened in the 1950s [2]. The operation was used for machining of high–strength and heat resistant alloys. In ECM there is no touching between tool and workpiece. The electrolyte is normally a solution of mineral salt such as sodium nitrate ($NaNO_3$) or sodium chloride (NaCl) [3]. Removal of metal by anodic dissolution in an electrolytic medium is controlled by ECM in which the tool is the cathode and workpiece is anode, both must be electrically conductive [4]. The ECM process is based on the same principles used in electroplating, except the tool is the cathode and workpiece is the anode [5]. The harsh or cruel materials those are impossible to machine by traditional machining but, can be machined by ECM [6].

Principle of ECM

https://doi.org/10.30684/etj.34.15A.16
2412-0758/University of Technology-Iraq, Baghdad, Iraq

The principle of working is removal of the material from workpiece by electrochemical process it based on the tool is negative charge (cathode) and workpiece is positive charge (anode). The material was removed by the controlled dissolution of the anode according to the well-known Faraday's law of electrolysis. Anode and cathode are submersible in the electrolyte, the dissolution of the anode as result of current flow through the system; the purpose of ECM is to remove the metal from the workpiece [7].

Literature review:

D.Chakradhar and A.Venu Gopal (2011)[8] studied the influence of the parameters: electrolyte concentration, feed rate and applied voltage. NaCl was chosen as electrolyte and performance characteristic were MRR, Ra and overcut. Analysis of variance is performed to get contribution of each parameter on the performance characteristics. The values of feed rate were 0.1, 0.21 and 0.32 mm/min, electrolyte concentration 10, 15 and 20 % and voltage 10, 15 and 20 V. Applied ANOVA to analysis, the conclusions of this study were that the optimum process parameters were electrolyte concentration 15 %, feed rate 0.32 mm/min and applied voltage 20 V, as a result MRR can be maximized and the overcut and Ra can be minimized by this method.

Baqer A. Ahmed (2011)[9] investigated an AL alloy workpiece and a brass tool to study impact of The current were 40, 50, 60, 80, 100 and 120 A, electrolyte concentration were 100, 200, 300, 400 and 500 g/l and electrolyte flow rate 6, 8, 10, 12 and 14 l/min on MRR and Ra by the Genetic neural network method to analyze the results, the electrolyte type was NaCl.. He found that increasing current from 40-120 A, the MRR is increased to reach 66.66% and give better surface roughness that reaches to 1.115 μm. With increased electrolyte concentration from 100-500 g/l the MRR increased to reach 8.99% and led to increased surface roughness by 34.34% at 500 g/l of electrolyte concentration, maximum efficiency 99.72 % compared with 100 g/l, better value of Ra 1.126 μm at 100g/l. When increased electrolyte flow rate from 6-14 l/min led to increase MRR by 17.74% and at increased electrolyte flow rate from 6-14 l/min to get better Ra that reached 63.07%. He found also that current density was the most important parameter impact in the ECM process on the MRR and Ra.

Hiba H. Alwan (2011)[10] used a workpiece of steel ck35 and brass tool, to study impact of parameters were inter electrode gap 1, 2 and 3 mm, current 60, 70, 80 and 90 A on the MRR and Ra. She used two different tool roughness 2.65 μm and 3.34 μm. She then applied a statistical package for social science software for forecasting the results and used NaCl electrolyte. The results showed that an increased current 60, 70, 80 and 90 A, then MRR increased and gave efficiency 93.9% and decreased surface roughness to 31% at tool roughness 2.65 μm, inter electrolyte gap 1mm. This tool gave less surface roughness by 23% as compared with tool roughness 3.34 μm, deceased was 39% at current from 60 - 90 A at gap size 1 mm and no impact on MRR was noted. The inter electrode used was from 1-3 mm when applied 1mm gave high MRR as compared to 3 mm but the Ra increased when applied 3 mm and surface roughness became better with decreased gap to 1 mm surface roughness was less that 46%, at increased gap, the MRR decreased to 16%.

Hoda Hosny Abuzied (2012)[11] used the ANN technique to get the values of MRR and Ra. The parameters voltage, feed rate and electrolyte flow rate were used. Application voltage was from 15-35 V, electrolyte flow rate 6 and 9 l/min and feed rate from 1.5-6 mm/min. Three different algorithms were used in experiments: Levenberg-Marquardt (L-M) algorithm. The ANN technique active because it reduced effort and time needed for expectation of MRR and Ra. When using L-M algorithm in network it will give the least error between the predicted and experimental data with a small network size.

Electrolysis

Electrolysis is a chemical process in which electric current passed between electrodes dipped into a liquid solution and that solution describe to electrolyte. The wires are electrodes, cathode has negative polarity and anode has positive polarity. Electrolytes current carried by atoms or groups of atoms, which lost or gained electrons and thus atoms acquiring either positive or negative charge while the current of metallic conductors of electricity carried by electrons. That atoms are called ions and the ions that move through the electrolyte toward the cathode has positive charge and are called cations and the ions move toward the anode have negative charge and are called anions. There are many chemical reactions occur at the cathode, anode and in the electrolyte, where the electrolysis process that occur at the cathode liberates hydroxyl and free hydrogen. Insoluble metal hydroxides are produced by the reaction of hydroxyl ion with the metal ions of anode and the material is those removed from the anode. This process continues and the tool reproduces its shape in the workpiece (anode). The reaction at the cathode is the result of electrolytic dissociation [11]:

$H_2O \longrightarrow H^+ + OH^-$ …..(1)

$NaCl \longrightarrow Na^+ + Cl^-$ …..(2)

Positively charged cations: H^+ and Na^+ towards cathode and negatively charged anions: (OH^-) and (Cl^-) go towards anode.

At the anode:

$Fe \longrightarrow Fe^{+2} + 2e^-$ ….. (3)

At the cathode, hydrogen gas will be generated:

$2H^+ + 2e^- \longrightarrow H_2\uparrow$ …..(4)

The result of these reactions is that the ferrous ion combine with hydroxide ion to form ferrous hydroxide ($Fe(OH)_2$). The ferrous hydroxide that formed is a green-black precipitate:

$Fe^{+2} + 2OH^- \longrightarrow Fe(OH)_2$ ….. (5)

$Fe^{+2} + 2Cl^- \longrightarrow Fe(Cl)_2$ ….. (6)

$Fe(Cl)_2 + 2OH^- \longrightarrow Fe(OH)_2 + 2Cl^-$ …. (7)

Ferric hydroxide ($Fe(OH)_3$) formed from react of ferrous hydroxide ($Fe(OH)_2$) with oxygen (O_2) and change the color from green-black of ferrous hydroxide to red-brown of ferric hydroxide.

$2H_2O \rightarrow O_2\uparrow + 4H^+ + 4e^-$ …..(8)

$2Fe(OH)_2 + H_2 + O_2 \rightarrow 2Fe(OH)_3\downarrow$ ….. (9)

$Fe(OH)_3 + 3HCl \rightarrow FeCl_3 + 3H_2O$ …..(10)

$FeCl_3 + 3NaOH \rightarrow Fe(OH)_3\downarrow + 3NaCl$ …..(11)

Estimation of Material Removal Rate Experimental

The material removal rate experimental can be calculated through the equation [11]:

MRRexp=———————————————————— (g/sec or g/min).

Artificial Neural Network:

Artificial neural network model emulates a biological neural network. Neural computing is actually very limited set of concepts from biological neural system. An ANN is extremely interconnected network of senior number of processing element called neurons in an architecture inspired by the brain. The primary prominence of an ANN is the ability of network to learn from environment and to ameliorate its performance. Neural network adopt different learning mechanisms of which supervised learning and unsupervised learning methods. The network consists of an input layer used to present data, output layer to produce ANN's response, and one or more hidden layers in between [12].

Experimental Work:

Electrochemical machining (ECM) is a chemical and electrical reaction between workpiece and tool in presence of solution (electrolyte), used different parameters and that lead to remove the material from the workpiece.

ECM Cell:

Drilling Machining

Drilling machining provides a good base for the tool of ECM operation like it's rigid and easy to control the tool manually and to control the gap size between workpiece and tool. Specifications - Mark Super - Drill Press / Milling Machine, German.

Reaction Chamber

Reaction chamber is important in the ECM operation because the electrical and chemical reaction (between workpiece, tool and electrolyte) occur in this chamber also content the fixture that fixed the workpiece inside the chamber. It is made from plastic and as an insulating material. The dimensions of reaction chamber are length 300 mm, width 200 mm and height 170 mm.

Workpiece Fixture

The fixture is used to keep the workpiece rigid to prevent it from vibration that influence on operation if the workpiece move in their place.

Power Supply

Consider the power supply paramount device in the operation of ECM because is supply the process in electric, to forcing the electrolyte from the workepiece to the tool it need a power supply. The power supply used in this operation is the D.C welding machine power supply with current (5 A/10 V- 400 A/36V) type CEBORA.

Electrolyte

The electrolyte was used in this empirical mixing from tap water and NaCl contents refined salt (sodium chloride), grounding preventer material (potassiumferro siyanid E536) and potassium iodide (25-40 mg /kg), electrolyte concentration (10, 25 and 50) g/l, make in Saudi and have purity 98%.

Electrolyte Pump

The pump put inside the reaction chamber, it will pump the electrolyte in to the gap between workpiece and tool to remove the sludge to easy the operation**.** As shown in the table (1) some properties of pump.

Table (1). Properties of electrolyte pump.

Property	Value	Property	Value
Name	dolphen	**Power**	20 W
Voltage	220 V	**Q.max.**	1000 l/h
Frequency	50 Hz	**Max.liquid temperature**	45°C

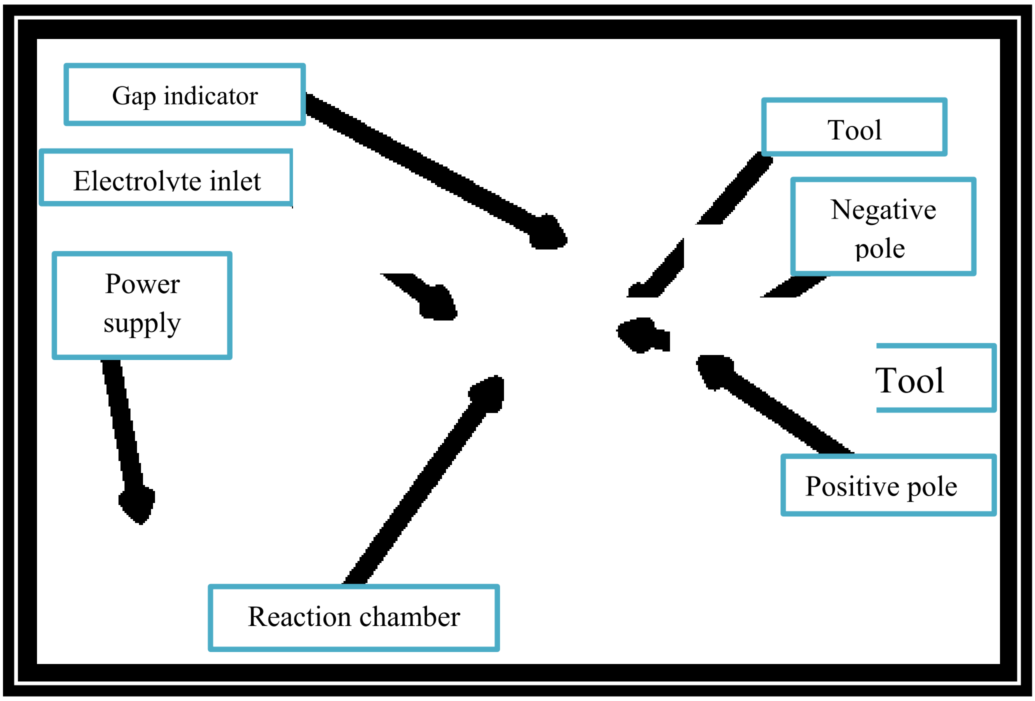
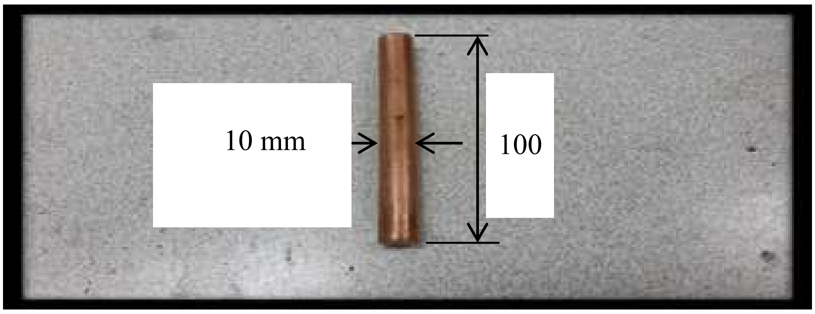


Figure (1).ECM machine

Tool and Workpiece Description

Tool Description

The tool is a cathode that made from copper purity 98 %, the diameter of tool is (Ø10) mm, as shown in the figure (2) used to study influence of (current, electrolyte concentration and gap). The purpose for utilize copper tool material are the readily to machining, high corrosion resistance and having high electrical conductivity.



Figure(2). Tool use in experimental.

Workpiece Description

The workpiece (anode) is metal plate, (stainless steel AISI 316L), as shown in the table (2) Chemical composition of workpiece. The dimensions of workpiece are (50x50x0.8) mm, as shown in the figure (3) is square shape**.** It used to study impact current (50, 100 and 200) A, electrolyte concentration (10, 25 and 50) g/l used NaCl and gap (0.5, 1 and 1.5) mm in this work. Figure (4) can see the workpiece after operation.

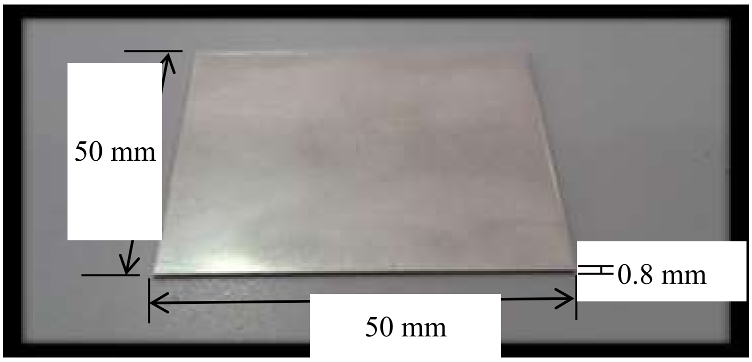
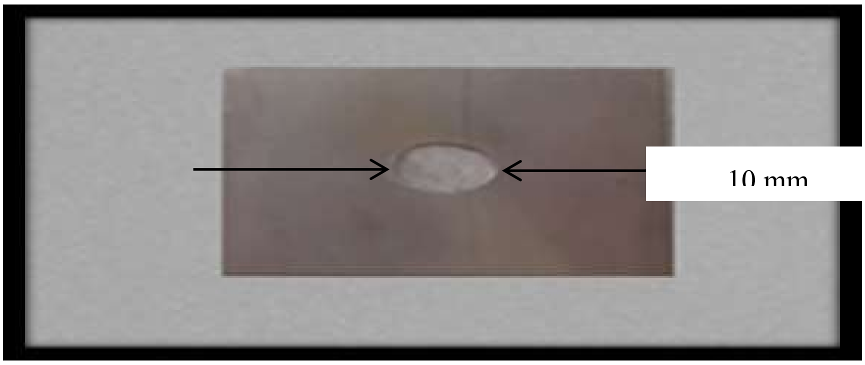


Figure (3) Workpiece before operation

Table (2) Chemical composition of the workpiece AISI 316L

Element	Wt (%)	Element	Wt (%)
C	0.034	**Ni**	9.64
Si	0.339	**Co**	0.174
Mn	1.62	**Cu**	0.412
P	0.033	**V**	0.069
Cr	18.72	**Al**	<0.001
Mo	2.09	**Fe**	remain



Figure(4). Workpiece after operation.

Results and Discussion

From the results, can be seen that the MRRexp increasing at increasing current from (50 to 200) A, the ratio of increasing MRRexp was 57.60% as shown in the figure (5). According to the " the amount of mass disssolved is stright commensurate to the amount of electricity which has flowed" according to Faraday's low, as shown the Table (3).

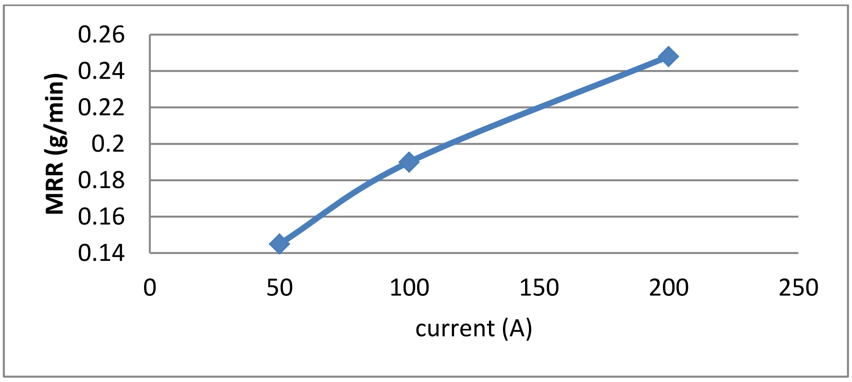


Figure (5) Influence of current in MRRexp.

Table (3). Results of experiments of influence current in MRR

Time (min)	Current (A)	Electrolyte concentration (g/l)	Gap size (mm)	Weight before machining (g)	Weight after machining (g)	MRRexp (g/min)
8.28	50	50	0.5	15.3525	14.1515	0.145
7.01	100	50	0.5	15.3578	14.0233	0.190
5.46	200	50	0.5	15.0416	13.7005	0.248

MRRexp increases with increasing electrolyte concentration from (10 to 50) g/l. At increasing electrolyte concentration the electrical conductivity of the electrolyte increases in which lead to increasing in machining current in gap between workpiece and tool that lead to higher MRR, as shown in the figure (6) and Table (4).

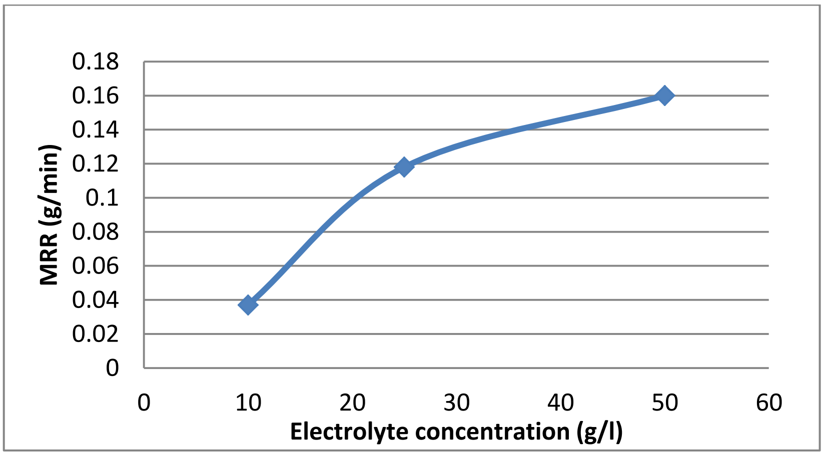


Figure (6) Impact of electrolyte concentration on MRRexp

Table (4).Results of experiments of influence electrolyte concentration in MRR

Time (min)	Current (A)	Electrolyte concentration (g/l)	Gap size (mm)	Weight before machining (g)	Weight after machining (g)	MRRexp (g/min)

8.39	50	25	0.5	15.1009	14.0466	0.126
9.01	50	25	1	15.4629	14.5841	0.097
10.37	50	25	1.5	15.6223	14.7439	0.085

The increase in gap size from (0.5 to 1.5) mm leads to decreasing MRRexp as shown in the figure (7). Increasing in gap size leads to spent more electrical energy without increasing in MRR, as shown in Table (5) which shows the influence of gap size in MRRexp.

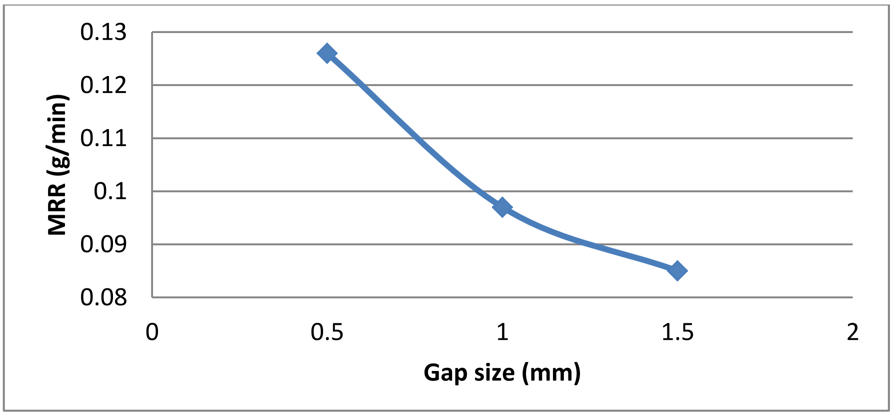


Figure (7).Influence of gap size on MRRexp

Table (5).Results of experiments of influence gap size on MRR

Time (min)	Current (A)	Electrolyte concentration (g/l)	Gap size (mm)	Weight before machining (g)	Weight after machining (g)	MRRexp (g/min)
21.18	100	10	1	15.5257	14.7385	0.037
8.05	100	25	1	15.3835	14.436	0.118
7.21	100	50	1	15.4993	14.3454	0.160

Advantage of Artificial Neural Network

There are advantages of artificial neural network like [13]:

1- Neural network teach themselves the pattern in the data freeing the analyst for more good work because the system developed by learing not by programming.

2- Self-Organization: in ANN from the information that get from learning it can create its own representation.

3- Neural network learn to recognize the pattern which exist in the data set.

Application [12]

The real time applications of Artificial Neural Networks are:

1. Functional approximation, including time series prediction and modeling.
2. Call control- answer an incoming call (speaker-ON) with a swipe of the hand while driving.
3. Classification, including pattern and sequence recognition, pattern detection and sequential decision making

Predicated MRR by used artificial neural network

In ANN divided the input values to 9 for training and three for testing. At comparison the results of MRR in experimental with predicated in ANN for training find the results are very close to each other as can see in the Table (6) and figure (8). In Table (7) and figure (9) that for ANN testing finds the results also very close between MRR experimental and MRR predicted in

ANN. In figure (8) it can see the little different in values, machining condition, different parameters used in experiments led to that different.

Table (6) Comparison between MRR experimental and MRR predicated in ANN

No of exp	MRRexp (experimental) (g/min)	MRRper (predicated) (g/min)
1	0.145	0.1450
2	0.190	0.190
3	0.248	0.2537
4	0.126	0.1260
5	0.097	0.0970
6	0.085	0.0942
7	0.037	0.037
8	0.118	0.118
9	0.160	0.160

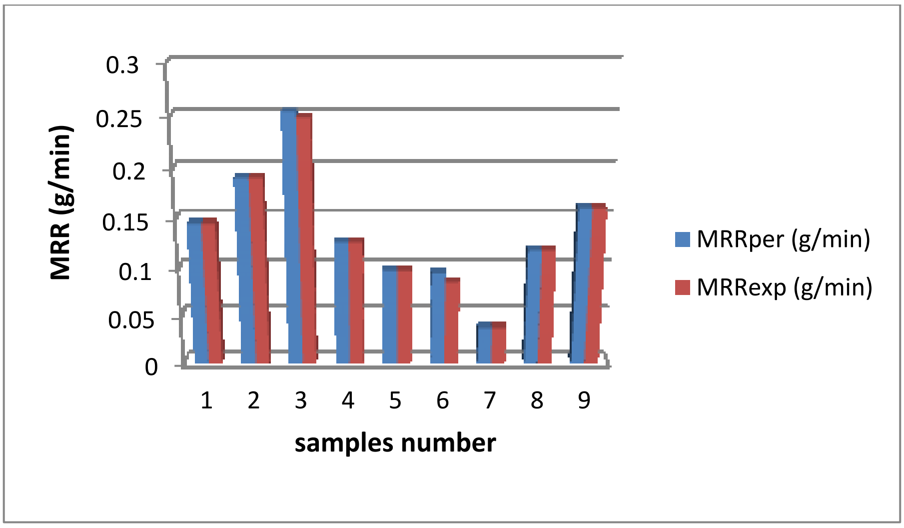


Figure (8) Comparison between MRR experimental and MRR predicated in ANN model

Table (7) Comparison between MRR experimental and MRR predicated in ANN model

No of exp	MRRexp (experimental) (g/min)	MRRper (predicated) (g/min)
1	0.046	0.046
2	0.133	0.13284
3	0.179	0.17879

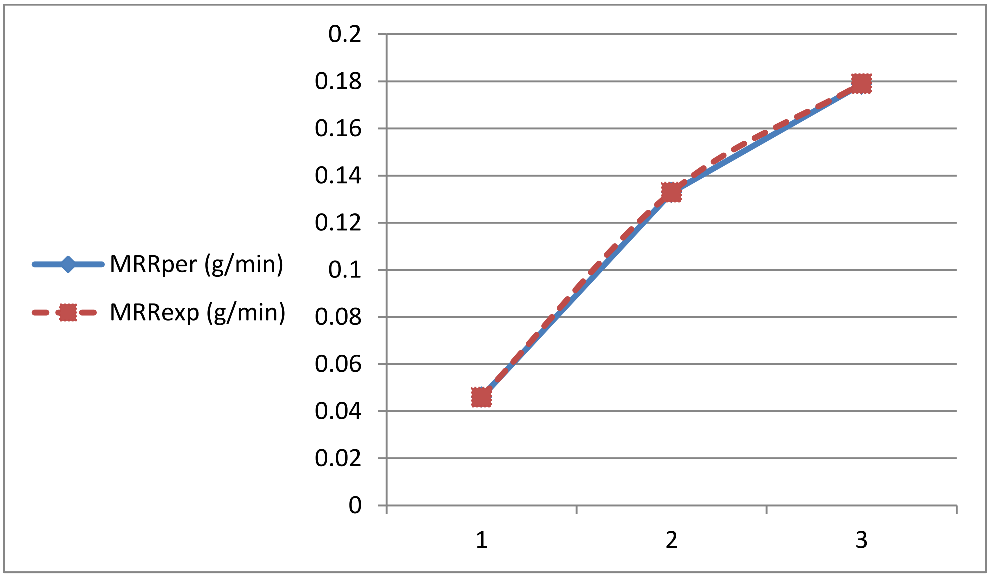


Figure (9).Comparison between MRR experimental and MRR Predicated in ANN model

CALCULATIONS

The conclusions from experimental work are:

1- Increasing in current lead to improvement in MRRexp.
2- MRRexp increasing with increased in electrolyte concentration.
3- Increased in gap size lead to decreasing in MRRexp.
4- Getting optimization in the Predicted MRR by using artificial neural network (ANN).

REFERENCE

[1] H. Al-Hofy, "Advanced Machining Process, Nontraditional and Hybrid machining", Mcgraw-Hill Company, pp. 77-99, 2005.

[2] E. P. Degrmo, JT. Black and RONALD A. KOHSER, "Material and Process in Manufacturing", Eleventh Edition, Chapter 28, International Student Version, Auburn University-Emeritus, pp.773-786, 2013.

[3] R. K. RAJPUT, "A Textbook of Manufacturing Technology (Manufacturing Processes)", First Edition, Published by LAXMS Publications (p) LTD, Chapter 28, New Delhi, pp.694-697, 2007.

[4] A. K. Meher and B. K. Nada, "ECM Process Characteristics", Department of Mechanical Engineering National Institute of Technology Rourkela, pp.8-26, 2009.

[5] Phillip F. and Ostwald. Jairo Muñoz, "Manufacturing Process and System", Ninth edition, Chapter 20, Published Simultaneously Canada, pp.482-483, 1997.

[6] D. K. Singh, "Fundamentals of Manufacturing Engineering ", Ane's Student Edition, Chapter 20, Published By Ane Book India, pp.453-458, 2008.

[7] M. K. Singh, "Unconventional Manufacturing Process", First Edition, Chapter 7, New Age International Publishers, New Delhi, pp.55-73, 2008.

[8] Seker T. and Marappan R., "Improving Material Removal Rate of Electrochemical Machining", International Journal of Machine Tools & Manufacture, vol.44 pp. 60–63, India, 2008.

[9] S. K. Shather and B. A. Ahmed, "Experimental Investigation to Improve Metal Removal rate MRR and Surface Roughness Ra in Electrochemical machining ", Engineering and Technology Journal, Vol.30, No.11, PP.1948 -1959, 2012.
[10] S. K. Sather and H. H. Alwan, "Predication of Metal Removal Rate and Surface Roughness in Electrochemical Machining", Engineering and Technology Journal, Vol.30, No.8, PP.1415-1427, 2012.
[11] H. H. Abuzied, "Prediction of Electrochemical Machining Process Parameters Using Artificial Neural Networks", International Journal on Computer Science and Engineering, Vol.4, No.1, PP.125-132, 2012.
[12] JAY E. ARONSON, "Decision Support Systems and Intelligent Systems", Sixth Edition, Chapter15, Prentice-Hall International, New Jersey, pp.603 -657, 2001.