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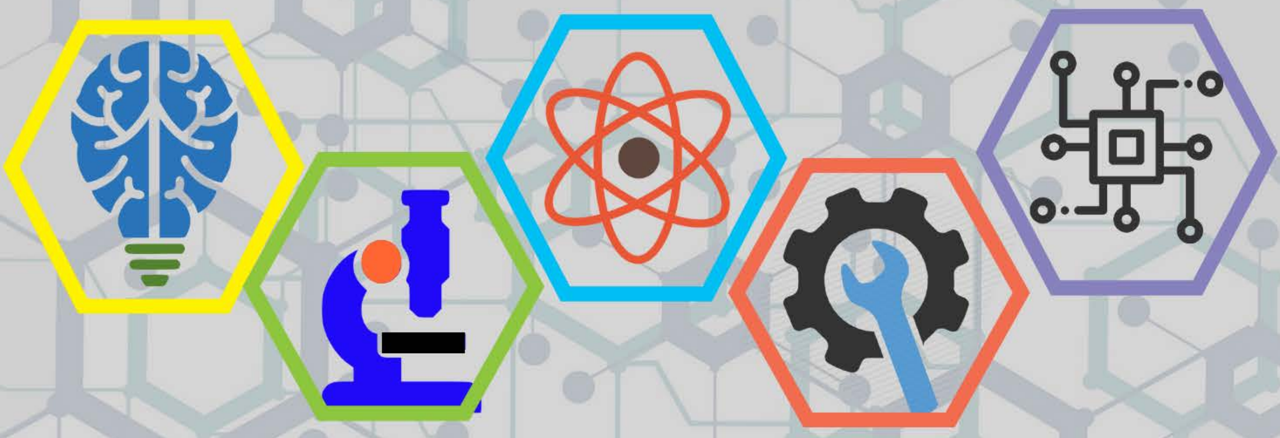

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NOISE EVALUATION IN TERMS OF OCCUPATIONAL HEALTH AND SAFETY ON THE RING SPINNING MACHINE

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ABSTRACT: People are in noisy environments in different environments of life Noise significantly affects human health and quality of life in many countries where industrialization is intense. The effects of noise on people are very diverse; It is accepted by all countries that it negatively affects human health in physiological and psychological aspects. It is important that noise causes employees to complain about their work, negatively affects their work performance and, accordingly, causes loss of workforce. Within the scope of this study, which aims to examine the noise exposure of people working in noisy environments, noise level measurements were made in the ring spinning machine section of the Suleyman Demirel University (SDU) Textile Engineering combed spinning mill. The noise values emitted by the ring spinning machine to the environment were measured. The noise level was measured at the combing yarn factory and the effects on the student were examined.

Keywords: Noise, Yarn, Ring Machine, Dosimetry, Exposure

1. INTRODUCTION

Noise can cause significant inconvenience to students using the machines in ambient conditions where more than one machine is operated together. In such environments, high noise levels adversely affect the health and productivity of employees. SDU Textile Engineering, in order to examine the negative effects of the noise generated by the ring spinning machines used in the combed cotton spinning mill on student health, it is necessary to determine the noise level emitted by these machines to the environment. Noise level measurement was made in the combed yarn mill and its effects on the students were examined [1].

Sound is an objective concept that can be measured and whose existence does not change depending on the person. Noise is a subjective concept. Noise can be defined as “unpleasant, disturbing sound”. As can be understood from the definition, the evaluation of a sound as noise may vary depending on the individuals, and it is clear that many types of noise will be accepted as noise by everyone.

A person whose hearing is damaged has a decrease in hearing ability, which is called hearing loss. Hearing loss can be temporary or permanent. The hearing loss is permanent or temporary and the degree of hearing loss; It depends on the level of the noise, the frequency of the noise, and the time the worker is exposed to the noise [2].
The duration of exposure to noise covers the time that the person is under the influence of the noise continuously and the years that the person is under the influence of the noise intermittently. Being under the influence of a certain level of sound for a while causes hearing loss. The noise limit values used in industrialized countries are the longest period of exposure to a certain level of noise in a day or a week.

Conditions such as the frequency of the noise, the duration of its presence in the environment, whether the noise originates from a point, planar or linear source, the age, physical and mental state of the person exposed to the noise, the distribution of the noise according to the time in the environment are the factors that are important for the receiver to perceive the noise as an inconvenience. The negative effects of noise on people are generally physiological and psychological [2] .

Among the physiological effects, the most common is hearing loss. It is possible to collect the hearing effects of noise in the ear in three groups as acoustic trauma, temporary and permanent hearing loss. Noise-induced hearing loss is one of the factors that is very common in industrialized societies and negatively affects the quality of life. Other physiological effects include increased blood pressure, increased heart rate, muscle reflexes, and sleep disturbances. Prolonged exposure to noise; It may cause disruption in the regulation of blood pressure through the increase of circulatory stress hormones such as adrenaline, noradrenaline and cortisol. The psychological effects of noise are more common than the physiological effects and appear in the form of distress, tension, anger, anger, concentration disorder, resting and perception difficulties.

Various protective measures are taken in order to eliminate the effects of noise on human health. The first of the measures is to identify the sources that cause noise and to reduce their effects on human health. In addition, different legal arrangements are made in many countries in order to prevent noise and reduce its effects.

2. NOISE

Noise; It is an important environmental pollutant consisting of undesirable sounds with a random spectrum that negatively affect people's hearing health and sense, disrupt the physiological and psychological balance, reduce work performance, change the quality of the environment by reducing or destroying the pleasantness and calmness of the environment [3].

2.1. Technical Abbreviations

dB : decibels
dBA : A Weighted Decibels
Leq : Equivalent Noise Level
Lmax : Maximum Noise level
Lmin : Minimum Noise Level
m : Meter
mm : Millimeter
m^2 : Square meter

kg : Kilogram
% : Percent
μ Pa : Micro Pascal

2.2. Effects of Noise on Human Health

Noise is a problem that affects everyone. It has been determined by many researchers that there are permanent hearing threshold changes in people who are in high noise environments for a long time. Although it is not easy to detect a significant damage to the hearing at lower levels or short-term exposures, the negative effects of noise on human health, behavior and happiness can be determined.

2.3. Physical Effects of Noise

It is the negative effects of noise on hearing. It can be examined in two parts as temporary and permanent. The most common temporary effects are temporary hearing threshold shift and temporary loss of hearing sensitivity known as hearing fatigue. Hearing loss becomes permanent in cases where the exposure is too much and the hearing system is affected by noise again in regaining its old features.

2.4. Physiological Effects of Noise

These are changes that occur in the human body. Major physiological effects; muscle tensions, stress, increase in blood pressure, changes in heart rate and blood circulation, pupil dilation, respiratory acceleration, circulatory disorders and sudden reflexes.

2.5. Psychological Effects of Noise

In the press of the psychological effects of noise; nervous disorder, fear, discomfort, uneasiness, fatigue and mental effects slow down. The sudden increase in noise level can cause fear in people.

2.6. Effects of Noise on Performance

These are the effects of noise, such as reducing work efficiency and not understanding the sounds heard. The inhibition of functions such as speech perception and understanding is largely related to the level of background noise. Studies on the effects of noise on work efficiency and productivity have shown that the environment where complex work is done requires a quiet environment, while the environment where simple work is done requires a bit of noise. In summary, if the background noise determined for a certain job or function in the environment is excessive, work efficiency decreases [4,5].

3. GENERAL PRINCIPLES

Principles of Personal Exposure Noise Measurement

a-During the noise measurements, care is taken not to make any noise that would affect the measurements of the device.
b-The measuring device should be positioned in such a way that it does not interfere with the work of the selected personnel while being mounted on it.

c-It should be noted that the measurement is made for eight hours during the working hours of the personnel [4].

4. METHOD AND DEVICE USED

Exposure noise measurements made at the facility are measured with a dosimetric noise measurement device, and the exposure to noise in the workplace within the scope of the Regulation on the Protection of Employees from Noise-Related Risks.

Determination of noise estimation of hearing loss caused by this noise was made according to TS 2607 ISO 1999 method. Measurements were made with CA110 A DoseBadge dosimetric noise meters with serial number CIRRUS 69033 / CA8185 / CA7384 / CA7084 / CA8200 / CA8183 / CA8189 / CA6941 / CA7392 / CA6967 / CA7083 / CA6957. The technical specifications of the devices are given below[5].

CIRRUS Brand 110 A DoseBadge Personal Noise Dosimeter
Compact, durable design weighs only 51 grams,
Critical sound levels 80dB, 85dB, 90 dB.
93 one-minute data records during the 8-hour measurement period,
It can make measurements of 8, 12, 16 and 18 hour time periods,
Thanks to infrared communication, it reduces the intervention of the personnel to the device,
Rechargeable battery,
There are ATEX, IECEx and FM certifications for hazardous environments.

In the experimental studies, noise measurements were made on the ring spinning machines used in the SDU. Personal exposure noise measurement was made according to TS 2607 ISO 1999 method. The exposure noise levels normalized to the 8-hour working day of the exposure measurement made according to the TS 2607 ISO 1999 method are given in Table.1

Figure 1. Ring spinning machine

Table 1. Measurement result

N	ENVIRONMENTAL CONDITIONS			Measurement Result Leq, dBA
	Pressure (kPa)	Temperature (°C)	Humidity (%)	
1	101,03	22,3	50,3	80,3
2	101,03	22,5	47,8	85,99
3	101,03	22,1	48,9	83,32
4	101,03	22,3	49,3	91,36
5	101,03	22,4	49,7	84,92
6	101,03	22,4	49,7	92,64
7	101,03	22,5	49,8	90,25
8	101,03	22,4	49,8	87,29
9	101,03	22,5	49,9	88,5
10	101,03	22,4	50,0	83,56
11	101,03	21,3	50,3	82,36
12	101,03	22,3	50,2	85,58
13	101,03	23,0	50,1	82,61
14	101,03	22,0	50,2	88,69
15	101,03	23,0	50,2	90,95
16	101,03	23,0	50,1	90,12
17	101,03	23,2	50,3	83,87
18	101,03	22,8	50,1	80,75
19	101,03	22,7	50,3	80,47
20	101,03	22,8	50,3	83,97

In the study, when the measurement values obtained in the operating conditions where the knitting and raising machines are used for noise measurements are examined, the personal exposure contribution of the task emitted by the raising machines and the personal exposure values are higher than the knitting machines. The difference in the noise level in the measured work areas is due to the functional structure of the raising machines compared to the knitting machine. When evaluated together with the measurement uncertainty, the measurement uncertainty calculated in accordance with the TS EN ISO 9612 standard is ±3 dB for the Raising section. [6-8].

6. CONCLUSIONS

It is a reality accepted by everyone that noise should be reduced, which disrupts the silence of the environment in which people live, negatively affects human health, and has a great impact on the emergence of results that cannot only be corrected. It is necessary to raise awareness of societies, especially young generations, about noise pollution and its dangers, the effects of which are gradually increasing on the health of the society. As with all pollution problems, the solution to the problem is through education and management.

Physiological effects of noise on humans gain importance depending on the duration of exposure to noise. Among them, the most important ones are permanent hearing loss due to noise, respiratory disorders, high blood pressure, cardiovascular diseases, and slowing of nervous reactions. It has been revealed by observations and studies that noise has important psychological effects besides its negative physiological effects on humans. The most prominent among them is the decrease in performance and reluctance due to noise observed in those working in noisy environments, which can be directly related to the level of noise. Among the negative effects of noise on human health and behavior, the health problem that most affects employees is; It is permanent hearing loss due to noise, as it is seen quite frequently among workers and can be directly associated with noise. Even if the hearing loss in question is not in the form of a complete loss of hearing, it can significantly affect the quality of life of the person. In the advanced stages of hearing loss due to noise, the intelligibility of speech is significantly affected, and accordingly, interpersonal communication and occupational safety in the working environment may be adversely affected.

Working at a high noise level in a combed spinning mill negatively affects health. In this study, the noise level values emitted by the ring spinning machine to the environment were determined. The highest exposure action value emitted by ring spinning machines is between 80.3 and 92.64 dB for 8 hours.

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Research Article

IDENTIFICATION OF THE EFFECTS AND INTERACTIONS OF FACTORS ON THE E.D.M. PROCESS IN ORDER TO MODEL IT USING TAGUCHI METHODE

Authors: Taoufik Kamoun, Walid Meslameni

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IDENTIFICATION OF THE EFFECTS AND INTERACTIONS OF FACTORS ON THE E.D.M. PROCESS IN ORDER TO MODEL IT USING TAGUCHI METHODE

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ABSTRACT: This article presents the identification of the influence of the effects and interactions of the machining parameters (EDM) of the machine (EROTECH basic 450) in order to model the material removal rate (MRR), the tool wear rate (TWR) and the roughness of the part (Ra). We look at all the machining parameters and collect the effects by the design of experiments method. The modeling carried out is thus carried out by the response surfaces method (RSM). We use the statistical method (ANOVA) analysis of variance to approve the robustness of the models and to verify that they are statistically significant. The Taguchi method was implemented to formulate mathematical models to predict EDM machining parameters. The prediction of responses by empirical models is compared with experimental validation tests and the results are satisfactory.

Keywords: Experimental design, EDM, Screening, Modelling, MRR, TWR, Surface Roughness

1. INTRODUCTION

One of the non-traditional machining processes is electrical discharge machining (EDM) which is a widely used process in the manufacture of parts with complex shapes and parts in the material is very hard. The material removal occurs by a series of successive electric discharges, separated from each other in time, in the main and secondary machining parameters have a major influence on the workpiece and the tool during machining [1].

Numerous studies have been carried out on the process of machining by spark erosion regardless of by experimental methods [1-2-3-4-5-6-7-8-9-10-11-12-13-14] or by numerical simulations using programs such as ABACUS [15] or MATLAB [16] for different types of material.

Different types of EDM machining have been carried out to remove material from a part, mainly EDM (Sinking EDM) [1-5-6-8-9-10-11-12-17] in which an electrode in the shape to be machined is inserted into the work piece to etch hard materials, particularly wire EDM [3-4-7-13-14-18-19-20] where a moving conductor wire cuts a part along a ruled surface, especially Strip EDM [17] which uses a strip electrode to machine parts of hard materials.

In general, existing studies aimed at optimizing material removal rate (MRR), tool wear rate (TWR) and roughness (Ra) of the part of the EDM machining process by studying the influence of a number of parameters [4], the principals parameters such as the pulse time (Ton), the rest time (Toff) and the discharge current (I) and other secondary such as the distance between electrode and work piece the (GAP), duty cycle (DC), voltage (V) and parameter (TUP) presented in Table 1, several researchers have tried to get a basic understanding on this process by developing experimental models.

Table 1. Research on EDM parameters

Parameters		Studies conducted
Principal	Pulse time (Ton)	[1]-[2]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]-[13]-[14]-[16]
	Rest time (Toff)	[1]-[2]-[5]-[6]-[7]-[8]-[11]-[12]-[13]-[14]
	Discharge current (I)	[1]-[3]-[4]-[5]-[6]-[7]-[8]-[9]-[10]-[11]-[12]-[14]-[16]
Secondary	Distance between electrode and work piece (GAP)	[6]
	Duty cycle (DC)	[2]-[10]-[12]]-[16]
	Voltage (V)	[2]-[3]-[4]-[8]-[10]-[12]-[13]
	Parameter (TUP)	[9]

Recently, there has been a sharp increase in the application of the experimental method based mainly on practical trials. Several experimental modeling techniques with varying degrees of complexity have been widely applied, such as the methodology of design of experiments with the full factorial design method [1], Taguchi [6-8-9-10-12-13-14-18-19-20], the response surfaces method (RSM) [11] and the artificial neural network method [7-12] are studied. The majority of empirical methods based primarily on practical tests are verified primarily by numerical statistical analyzes ANOVA [1-8-9-11-12-13] or by analyzes of the signal S / N ratio [6-8-9-14-18-19-20].

Indeed, many questions arise, especially with regard to the influence of a number of factors on the EDM machining process. Thus, all the experimental work carried out does not demonstrate the choice of the machining parameters retained, on the other hand they were made with the literature only, that is to say the previous research work, they consist in studying the effect of main parameters of the EDM process thus, they neglect the analysis of the impact of the effect of the secondary parameters and the effect of the various possible interactions.

In order to have a good industrial mastery of the die-sinking EDM machining process, we studied on the one hand the effects of the machining parameters, on the other hand identifying the interactions between these parameters, and finally modeling by a method statistically using the design of experiments to empirically formulate the material removal rate (MRR), tool wear rate (TWR) and roughness (Ra) of the part.

2. MATERIALS AND EXPERIMENTS

The experiments of this study were carried out on a die-sinking EDM machine. Experimental work begins with the identification of materials, machining response parameters and machining process parameters. Copper was chosen for the electrode and C45 unalloyed steel as the part material.

The selected EDM driving parameters were identified from a screening study of all but the most influential EDM process machining parameters.

The machining depth has been set to 1 mm and the machining time is recorded.

The output responses were identified by the material removal rate MRR, the tool wear rate TWR, and the workpiece surface roughness Ra.

The method for estimating the technical criteria of the responses is defined as follows:

- The material removal rate MRR is the rate of material ejected at the point of impact of the landfill. It is estimated from the mass of the part measured before and after machining. It is then calculated as follows:

$$\mathrm{MRR} = \frac{(\text{Initial weight piece} - \text{Final weight piece})}{\text{Processing time}} * 60 \tag{1}$$

- The tool wear rate TWR is the ratio between the difference in the mass of the tool electrode before and after machining and the difference in the mass of the part before and after machining. is then calculated as follows:

$$\text{TWR} = \frac{(\text{Initial weight electrode} - \text{Final weight electrode})}{(\text{Initial weight piece} - \text{Final weight piece})} * 100 \tag{2}$$

- Roughness Ra is the surface finish of the part measured after machining in µm.

2.1. Study strategy

The experiments were carried out on the basis of the design of experiments approach (DOE), a two-level fractional experiment design (2^{8-5}+ 4 = 12 experiments), a Taguchi L16 design according to the line graph 3 two-level, and a plan with response surface methodology (RSM) and a Taguchi L27 plan according to the three-level line graph 2 were carried out in order to discover the significant factors, the possible interactions as well as the development of the mathematical models of the different answers.

2. 2. Test conditions

The tests were carried out on the machine (EROTECH basic 450) the material of the electrode used in this study is an electrolytic copper (ETP) electrode of rectangular shape, with the dimensions which are equal to 80 × 25 × 30 mm. The physical characteristics of this material are presented in Table 2.

Table 2. The properties of the electrode

Characteristics	Copper
Density (g/cm^3)	8.89
Melting temperature (°C)	1083
Hardness (HB)	70
Electrical resistivity (10^{-8} Ωm)	1.72

The tests were carried out with parts made of C45 steel, a steel frequently used in the manufacture of press and forging tools with a dimension which is equal to 78 × 60 × 28 mm where two tests can be carried out on each side of the part. Table 3 and Table 4 respectively provide the mechanical properties and chemical composition of C45 steel.

Table 3. Mechanical properties of C45 steel

Rm (N/mm^2)	Re (N/mm^2)	A (%)	Hardness (HB)	Density (g/cm^3)
560 / 620	275 / 340	14 / 16	170	7.85

C 45 steel is an unalloyed steel with a carbon content of 0.5 to 0.52%, the chemical elements present in the steel can be classified into three categories, impurities (sulfur and phosphorus), the added element (manganese) and accompanying elements (silicon) as shown in Table 4.

Table 4. Chemical composition of C45 steel

C	S	Mn	P	Si
0.50 – 0.52	≤ 0.035	0.50 – 0.80	≤ 0.035	0.40 maxi

The dielectric liquid used in the tests is (ELECTRA 100). It has the appropriate properties for this type of machining. The machined depth was kept constant for all tests and the machining time was measured in real time using a digital stopwatch with an accuracy of ± 1ms. The masses of the parts and the electrodes were measured before and after treatment with a digital scale with an accuracy of ± 0.01g. The roughness of the parts were measured by a roughness tester of the type (SRG-2000 Phase II) with a resolution of ± 0.04µm.

3. SCREENING OF EDM MACHINING PARAMETERS

3.1. Objective of the screening study

In this work, we are interested in identifying the influences of all the effects of the machining parameters of the EROTECH basic 450 machine on the responses of the material removal rate MRR, the tool wear rate TWR and the roughness Ra .

The machining parameters for the machine are numerous, classified into two categories: principal parameters and other secondary parameters (Table 5).

The main parameters:

- The pulse time (Ton) is the length of time during which the voltage is applied;
- The rest time (Toff) is the period during which discharges are not authorized in order to cool the electrode, remove debris, and renew the dielectric;
- The discharge current (I) is the magnitude of the current flowing through the plasma.

The secondary parameters:

- The duty cycle (DC) is the ratio of the discharge time to the total cycle time:

$$\mathrm{DC} = \frac{\mathrm{Ton}}{\mathrm{Ton+Toff}} \tag{3}$$

- The (PLS) parameter is used to select the optimal evacuation signal according to the specific treatment needs;
- The electrode to work piece distance (GAP), can be identified as the distance between the electrode surface and the maximum peak of the eroded surface layer of the work piece;
- The (PRT) parameter is used to adjust the sensitivity of the protection against pollution (pollution of the GAP);
- The (TUP) TIMER UP parameter is used to adjust the stopping time, to allow the passage of the dielectric between the part and the electrode to facilitate the evacuation of burrs and the cooling of the electrode;
- The (TDW) TIMER DOWN parameter is used to set the working time which includes the duration of the approach of the electrode to the work piece and the actual duration of the discharge sequence;
- The SERVO (SRV) parameter allows adjustment of the sensitivity of the electrode feed servo system. The servo system must keep the GAP constant during machining;
- The (TWR) Timer Enable / disable parameter, that is to say activate or deactivate the protection (ENR.PROG.AUTO), an additional protection that can have a higher (Tma +) and lower (Tma-) sensitivity level) in order to allow a more efficient cleaning of the (GAP) and quickly find the stability of the working conditions;
- The (AUX) parameter provides an auxiliary protection that allows the adjustment of the sensitivity of the protection against short circuits in the GAP;
- The (V) Volte parameter which indicates the load voltage (no-load voltage);
- The (POLARITY) polarity parameter of the electrode / part pair. By definition, the polarity is positive when the potential of the electrode-tool is greater than that of the part and negative otherwise.

Table 5. The maximum and minimum values of the parameters

Parameters	Values	Min/Max
Ton	4, 5, 6, 7, 8, 9, 10, 11 and 12	Min : 4 / Max : 12
Toff	3, 4, 5, 6, 7, 8 and 9	Min : 3 / Max : 9
I	3, 4, 5, 6, 7, 8, 9, 10 and 11	Min : 3 / Max : 11
PLS	0 and 1	Min : 0 / Max : 1
GAP	8, 9, 10, 11 and 12	Min : 8 / Max : 12
TUP	300 and 400	Min : 300 / Max : 400
TDW	600, 800 and 1000	Min : 600 / Max : 1000
SRV	7	-
TWR	5	-
V	2	-
AUX	6, 7, 8, 9 and 10	Min : 6 / Max : 10
POLARITE	Electrode	Positive
	Part	Negative

The cutting parameters are selected at two levels (Maxi) and (Mini) for each parameter, as shown in Table 6.

Table 6. Parameter levels

Parameters	Level 1	Level 2
Ton (µs)	4	12
Toff (µs)	3	9
I (A)	3	11
GAP (µm)	8	12
PLS	0	1
TUP (ms)	300	400
TDW (ms)	600	800
AUX	6	10

We used the design of experiments method. The selected plan is a screening plan a fractional factorial plan:

$$\boldsymbol{N = 2^{k-p}} \quad (4)$$

- *k*: the number of factors studied;
- *2*: the number of levels per factor;
- *p*: the number of trials in the plan was divided by 2^p.

3.2. Choice of the experimental design

For the choice of the plan, we selected all the factors of the EDM process, that is to say eight input factors (at two levels). A Hadamard matrix (H_{12}) was chosen, it is an orthogonal matrix, it corresponds to a fractional factorial plane ($N = 2^{8-5}$) which is equal to eight experiments, this number of experiments is insufficient to determine the coefficients, we need at least nine experiments, but the order of a Hadamard matrix is necessarily 1, 2 or a multiple of 4 then we will have ($N = 2^{8-5} + 4 =$ 12 experiments), this gives a matrix of tests (A) of an H_{12} experimental design.

$$A = \begin{bmatrix} 1 & 1 & -1 & 1 & 1 & 1 & -1 & -1 \\ -1 & 1 & 1 & -1 & 1 & 1 & 1 & -1 \\ 1 & -1 & 1 & 1 & -1 & 1 & 1 & 1 \\ -1 & 1 & -1 & 1 & 1 & -1 & 1 & 1 \\ -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 \\ -1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -1 & -1 & -1 & 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 & -1 & -1 & 1 & -1 \\ -1 & 1 & 1 & 1 & -1 & -1 & -1 & 1 \\ 1 & -1 & 1 & 1 & 1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix}$$

Table 7. Experimental matrix for screening the parameters

N°	Factors								Reponses		
	Ton (µs)	Toff (µs)	I (A)	GAP (µm)	PLS -	TUP (ms)	TDW (ms)	AUX -	Ra (µm)	MRR (g/min)	TWR (%)
1	12	9	3	12	1	400	600	6	1.5367	0.0017	1.1905
2	4	9	11	8	1	400	800	6	3.6700	0.0614	49.631
3	12	3	11	12	0	400	800	10	4.6367	0.2415	0.0204
4	4	9	3	12	1	300	800	10	2.0300	0.0029	15.259
5	4	3	11	8	1	400	600	10	4.4267	0.0384	0.0456
6	4	3	3	12	0	400	800	6	1.7933	0.0083	10.857
7	12	3	3	8	1	300	800	10	2.6633	0.0007	6.9892

8	12	9	3	8	0	400	600	10	2.9767	0.0007	4.4025
9	12	9	11	8	0	300	800	6	3.0933	0.7847	0.0243
10	4	9	11	12	0	300	600	10	2.9367	0.0029	141.10
11	12	3	11	12	1	300	600	6	4.1667	0.1734	0.0242
12	4	3	3	8	0	300	600	6	1.8200	0.0112	8.6053

In this experimental design, we took into account the effect of eight factors in the construction of the two-level fractional factorial design in order to be able to perform the tests and subsequently measured the three responses Ra, MRR and TWR (Table 7).

3.3. Results and discussion

3.3.1. Effect on roughness Ra

The mean effect of a factor is defined as the change in response observed when the factor changes modality. The graph of the mean effects of the factors, in Figure 1, where the mean values of Ra calculated in Table 8 have been plotted for the two levels of the factors.

Table 8. The average effects on Ra.

	Ton	Toff	I	GAP	PLS	TUP	TDW	AUX
Level 1	2.779	3.251	2.136	3.108	2.876	2.785	2.977	2.680
Level 2	3.178	2.707	3.821	2.850	3.082	3.173	2.981	3.278
Delta	0.399	0.544	1.685	0.258	0.206	0.388	0.004	0.598
Rang	4	3	1	6	7	5	8	2

For each factor, a line connects the means of the test results corresponding to each of the modalities in Table 7.

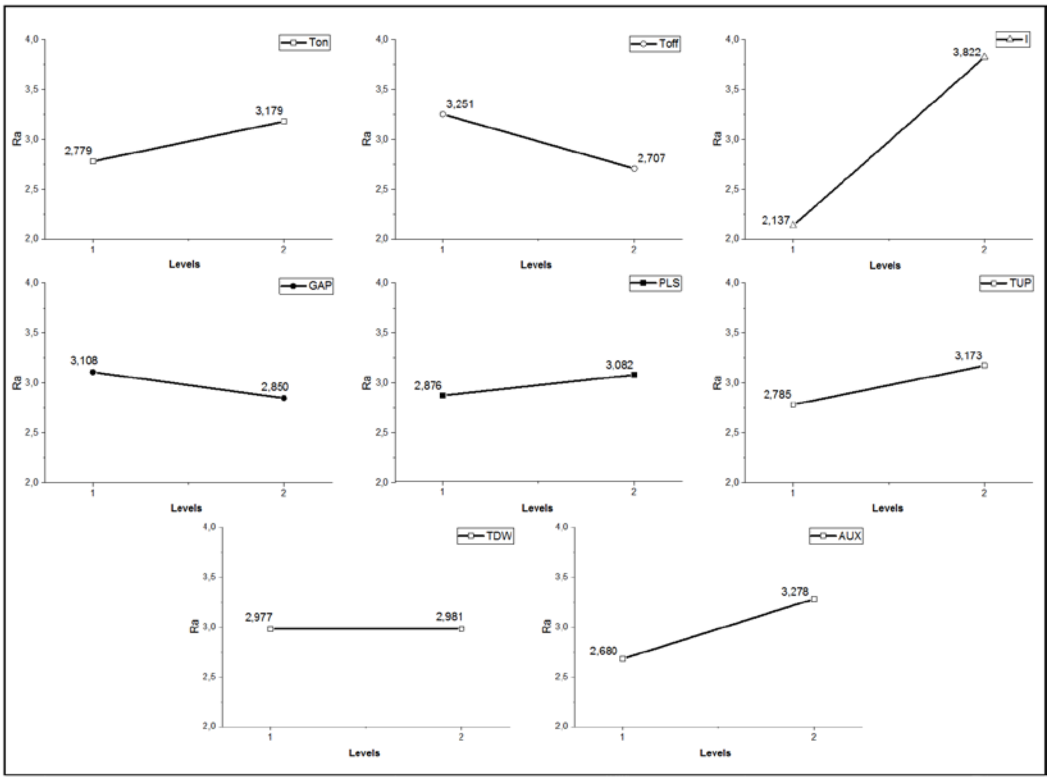

Figure 1. Representation of the average effects on Ra.

Table 8 of the average effects of the factors on the roughness Ra, shows that it is too influenced by the discharge current I, it reaches a maximum value for a discharge current I = 11 A, this phenomenon is easily understood since the EDM machining is based on sparking, when the value of the discharge current is increased from 3 to 11 A the size of the removed grain increases which justifies the increasing variation of the roughness with respect to the current (Figure 1). On the other hand, the influence of the TDW parameter is less significant with a variation in roughness between the two levels, which is equal to 0.004 µm, this variation is represented by a line almost parallel to the x-axis.

3.3.2. Effect on the flow of material removed rate MRR

Figure 2 shows the evolution of the average values of the MRR material removed flow rate calculated from Table 9 for the two levels 1 and 2 of the various factors.

Table 9. Average effects on MRR.

	Ton	Toff	I	GAP	PLS	TUP	TDW	AUX
Level 1	0.0208	0.0789	0.0042	0.1495	0.1748	0.1626	0.0380	0.1734
Level 2	0.2004	0.1423	0.2170	0.0717	0.0464	0.0586	0.1832	0.0478
Delta	0.1796	0.0634	0.2128	0.0777	0.1284	0.1039	0.1452	0.1256
Rang	2	8	1	7	4	6	3	5

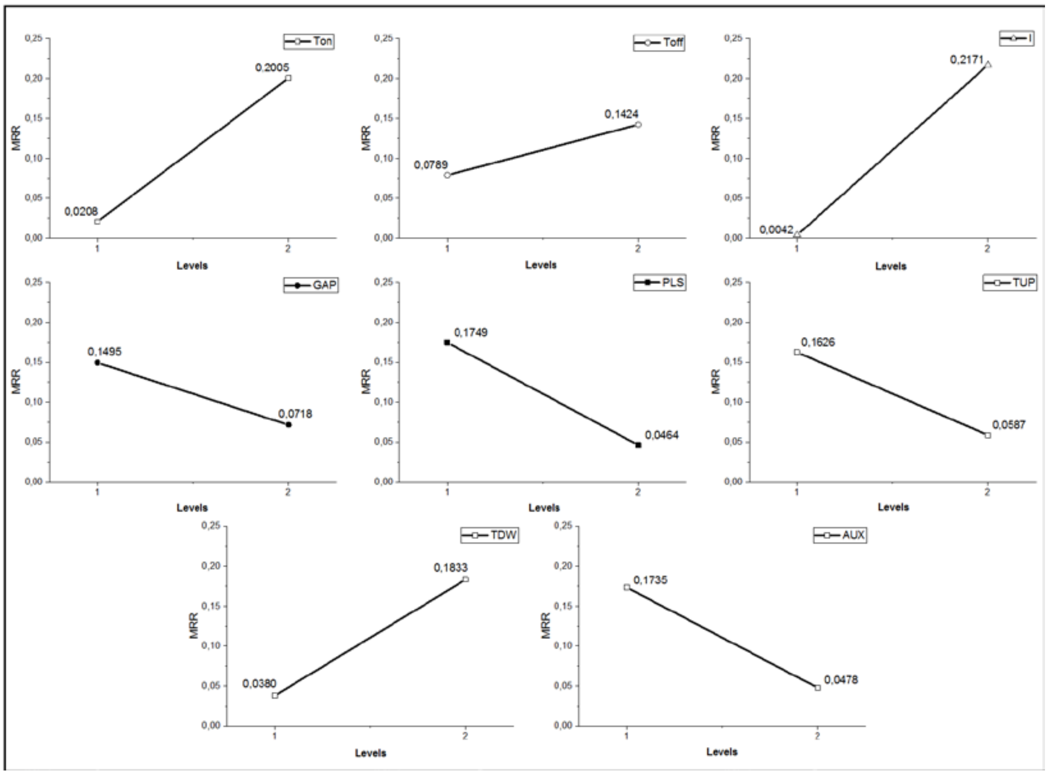

Figure 2: Representation of the mean effects on MRR.

The graphical representation of the average effects of the parameters on MRR in Figure 2, shows that the flow rate of material removed MRR is greatly influenced by the discharge current I, it reaches the value MRR = 0.212819 g / min for a discharge current I = 11A, while the influence of rest time Toff is less significant. It is also noted that the flow rate of material removed also admits a strong variation between the two levels of the pulse time Ton which is equal to 0.179612 g / min (Table 9).

3.3.3. Effect on the tool wear rate TWR

The plot of the mean factor effects, in Figure 3, represents the mean values of the TWR tool wear rate calculated from Table 10 for the two levels of the factors.

Table 10. The average effects on TWR.

	Ton	Toff	I	GAP	PLS	TUP	TDW	AUX
Level 1	37.583	4.423	7.883	11.616	27.501	28.667	25.894	11.722
Level 2	2.108	35.268	31.807	28.075	12.189	11.024	13.796	27.969
Delta	35.474	30.844	23.924	16.459	15.311	17.642	12.098	16.247
Rang	1	2	3	5	7	4	8	6

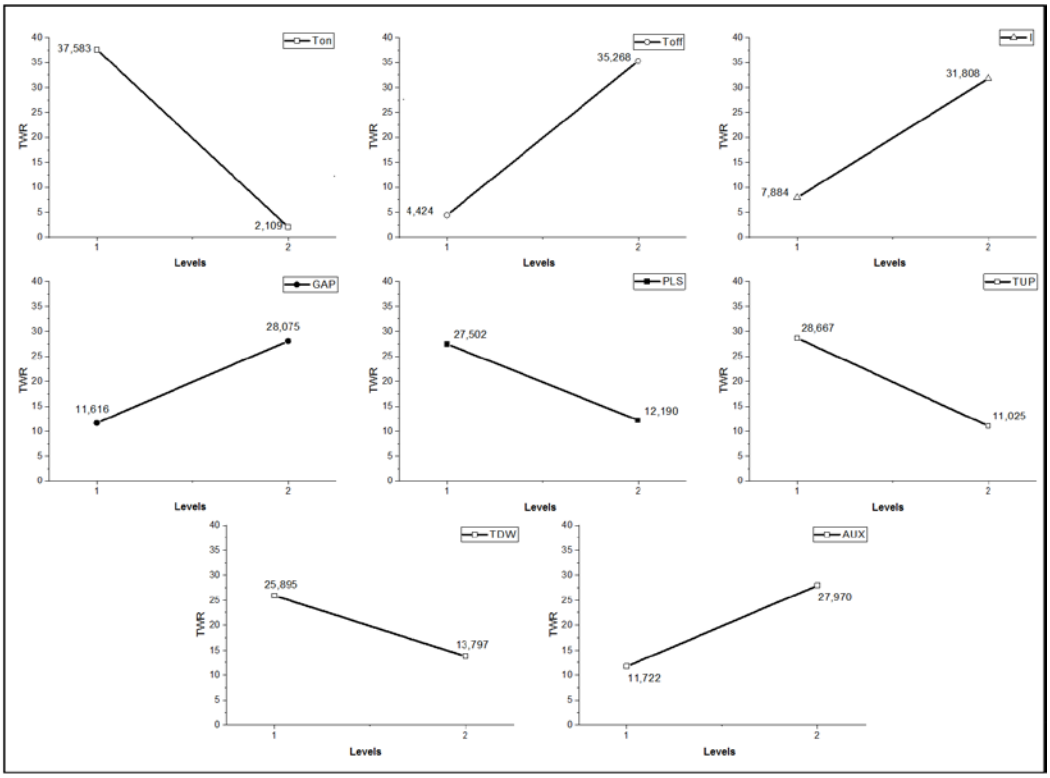

Figure 3. Representation of the mean effects on TWR.

The graphical representation of the average effects of the different factors on the TWR in Figure 3, shows that the TWR tool wear rate is greatly influenced by the pulse time Ton and the rest time Toff, we also notice that the discharge current I has a large effect on the variation of electrode wear rate. On the other hand, the influence of TDW time is less significant.

The diagram in Figure 4 is obtained directly from the results of the statistical analysis of the tests. The estimates of the coefficients of the first degree polynomial reflect the average effects of the factors.

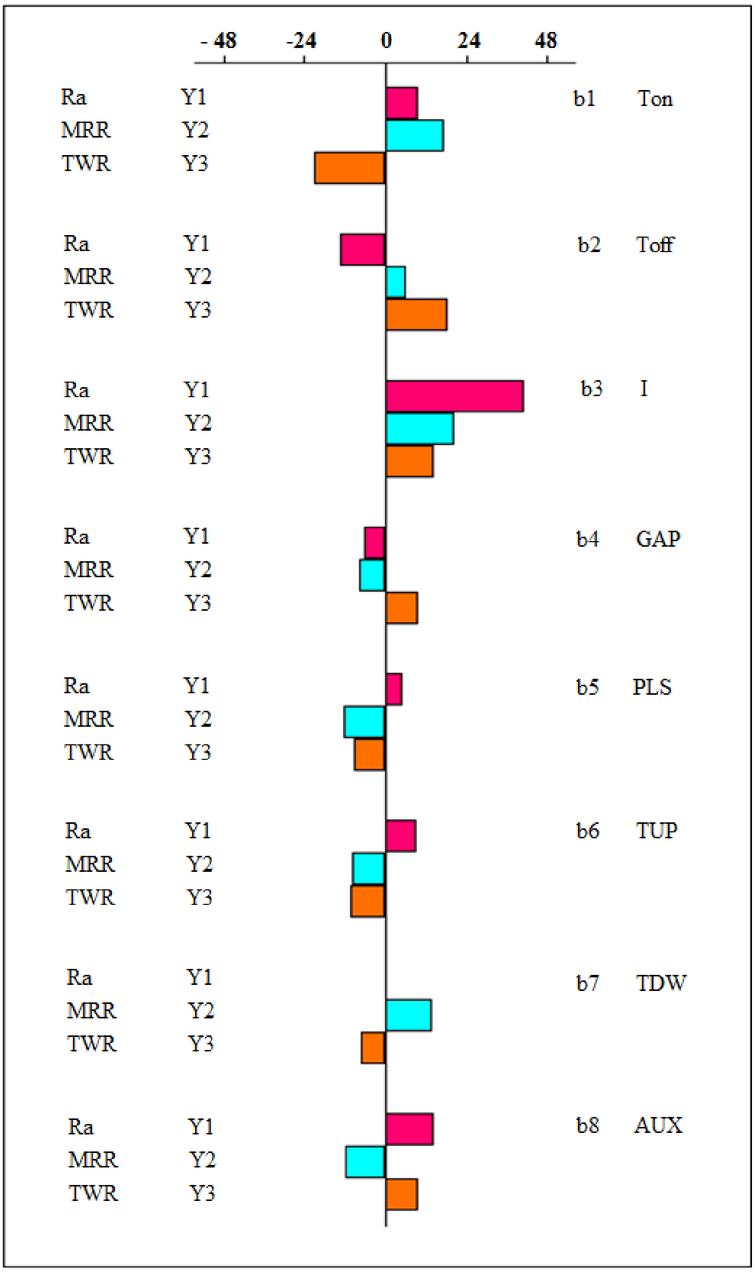

Figure 4. Effects of screening on parameters

The results of the screening tests show us that:

- The intensity of the current I is the most dominant parameter on the variation of Ra and MRR, on the other hand its effect on the TWR is less important;
- The AUX parameter has a significant effect on the response Ra, its value is very close to the value of the Toff effect;
- A weak influence for the PLS and zero for TWD on the roughness Ra, while they have an average effect on the MRR and very weak on the TWR;
- We can conclude that the parameters Ton, Toff, I and AUX turn out to have important effects.

According to the screening tests carried out, it was not possible to see the benefit of the choice of the GAP parameter among the elements of the study, but referring to the work of Kolse et al. [6] he demonstrates that the distance from the GAP varies according to the average

contamination of the GAP and also according to the parameters of the process. So that's why we added the GAP parameter to our study.
Among the 8 potentially influencing factors identified, we therefore identified 5 factors having a significant influence on the three responses.
We notice that the parameters Ton, Toff, I and AUX seem to have important effects, with regard to the others, we can say that they are weak and on any TWD.

4. SCREENING OF INTERACTION FOR THE FACTORS SELECTED

4.1. Objective

In a complex system, the parameters are often coupled, knowledge of the effects of each parameter is not sufficient to be able to estimate the responses. Information is therefore needed on the influence of the variation in each of the factors on the effect of the other factors, this notion called interaction.
The aim of this part is to study the interactions of order 2 between the electro erosion parameters selected in the study of the parameter screening in order to eliminate the negligible interactions. The five machining parameters are chosen at two levels as shown in Table 11.

Table 11: Matrix of interaction screening levels.

	I	Ton	Toff	GAP	AUX
Level 1	3	4	3	8	6
Level 2	11	12	9	12	10

4.2. Choice of the experimental design

The orthogonal L16 table is chosen according to the Taguchi design with five input factors that were selected in this study. According to the line graphs in this table, it can expect up to 10 interactions. We then chose a fractional factorial design L16 which corresponds to a number of trials of 16 experiments which is represented by the trial matrix (B).

$$B=\begin{bmatrix}
-1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1\\
-1 & -1 & -1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1\\
-1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1\\
-1 & -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1\\
-1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1\\
-1 & 1 & 1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1\\
-1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1\\
-1 & 1 & 1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & -1\\
1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1\\
1 & -1 & 1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & 1\\
1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1\\
1 & -1 & 1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & -1\\
1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & 1 & 1\\
1 & 1 & -1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & -1\\
1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1\\
1 & 1 & -1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1
\end{bmatrix}$$

Taguchi associated three line graphs with table L16 (Figure 5), which allow the choice of the model of coupling of interpretations between the factors to be studied.

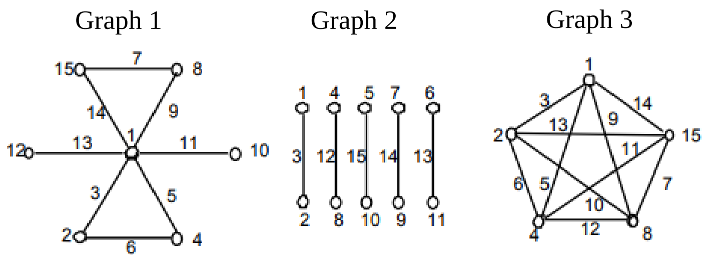

Figure 5. Taguchi L16 line graphs.

With 5 factors and 10 interactions, Taguchi's graph 3 meets the need for the study, to test all interactions between machine parameters. Table 12 illustrates the distribution of factors according to line graph 3 and Table 13 illustrates the experimental plan for the tests to be carried out.

Table 12. Matrix interaction screening experiment.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N°	I	TON	I-TON	TOFF	I-TOFF	TON-TOFF	GAP-AUX	GAP	I-GAP	TON-GAP	TOFF-AUX	TOFF-GAP	TON-AUX	I-AUX	AUX
1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	1	1	1	1
3	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1
4	-1	-1	-1	1	1	1	1	1	1	1	1	-1	-1	-1	-1
5	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1
6	-1	1	1	-1	-1	1	1	1	1	-1	-1	1	1	-1	-1
7	-1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1
8	-1	1	1	1	1	-1	-1	1	1	-1	-1	-1	-1	1	1
9	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1
10	1	-1	1	-1	1	-1	1	1	-1	1	-1	1	-1	1	-1
11	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1
12	1	-1	1	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1
13	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1
14	1	1	-1	-1	1	1	-1	1	-1	-1	1	1	-1	-1	1
15	1	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1
16	1	1	-1	1	-1	-1	1	1	-1	-1	1	-1	1	1	-1

The experimental plan is therefore presented in Table 13.

Table 13. Experimental plan for screening interactions

	1	**2**	**4**	**8**	**15**	**Reponses**		
N°	I	T_{ON}	T_{OFF}	GAP	AUX	Ra (µm)	MRR(g/min)	TWR (%)
1	3	4	3	8	6	1.7300	0.0193	9.5833
2	3	4	3	12	10	1.7800	0.0205	6.6874
3	3	4	9	8	10	2.3166	0.0021	38.8185
4	3	4	9	12	6	2.5633	0.0034	24.4196
5	3	12	3	8	10	2.8933	0.0008	10.9649
6	3	12	3	12	6	1.5000	0.0033	2.7933
7	3	12	9	8	6	1.3133	0.0039	203.653
8	3	12	9	12	10	3.0333	0.0005	5.6604
9	11	4	3	8	10	4.7200	0.0564	0.5208
10	11	4	3	12	6	4.0433	0.1533	61.1594
11	11	4	9	8	6	3.7566	0.0418	85.2833
12	11	4	9	12	10	3.2800	0.0779	59.4096
13	11	12	3	8	6	3.7466	0.6888	0.0233
14	11	12	3	12	10	3.5800	0.4103	0.0177
15	11	12	9	8	10	3.5400	1.3151	0.0287
16	11	12	9	12	6	4.3233	0.9676	0.0327

4.4. Results and discussion

The aim of this analysis is to identify the interactions having a statistically significant influence on the observed responses Ra, MRR and TWR.

4.4.1. Interactions of machining parameters with Roughness Ra

To facilitate the analysis of the effects of the interactions, we plotted the graphs of the interactions between the 5 parameters selected, thus, we obtained the graphs of Figure 6 which are associated with the effects of the interactions for the roughness Ra.

The examination of the graphs of the interactions of the EDM machining parameters on the roughness Ra in Figure 6 first shows the existence of the possible interactions between the discharge current I and the other parameters AUX, GAP, Toff and Ton the most strong is to detect between the discharge current I and the auxiliary protection AUX, in the second step we also track the existence of two less significant interactions located between the distance between the electrode-part GAP and the rest time Toff and also between the distance the GAP workpiece electrode and the AUX auxiliary protection.

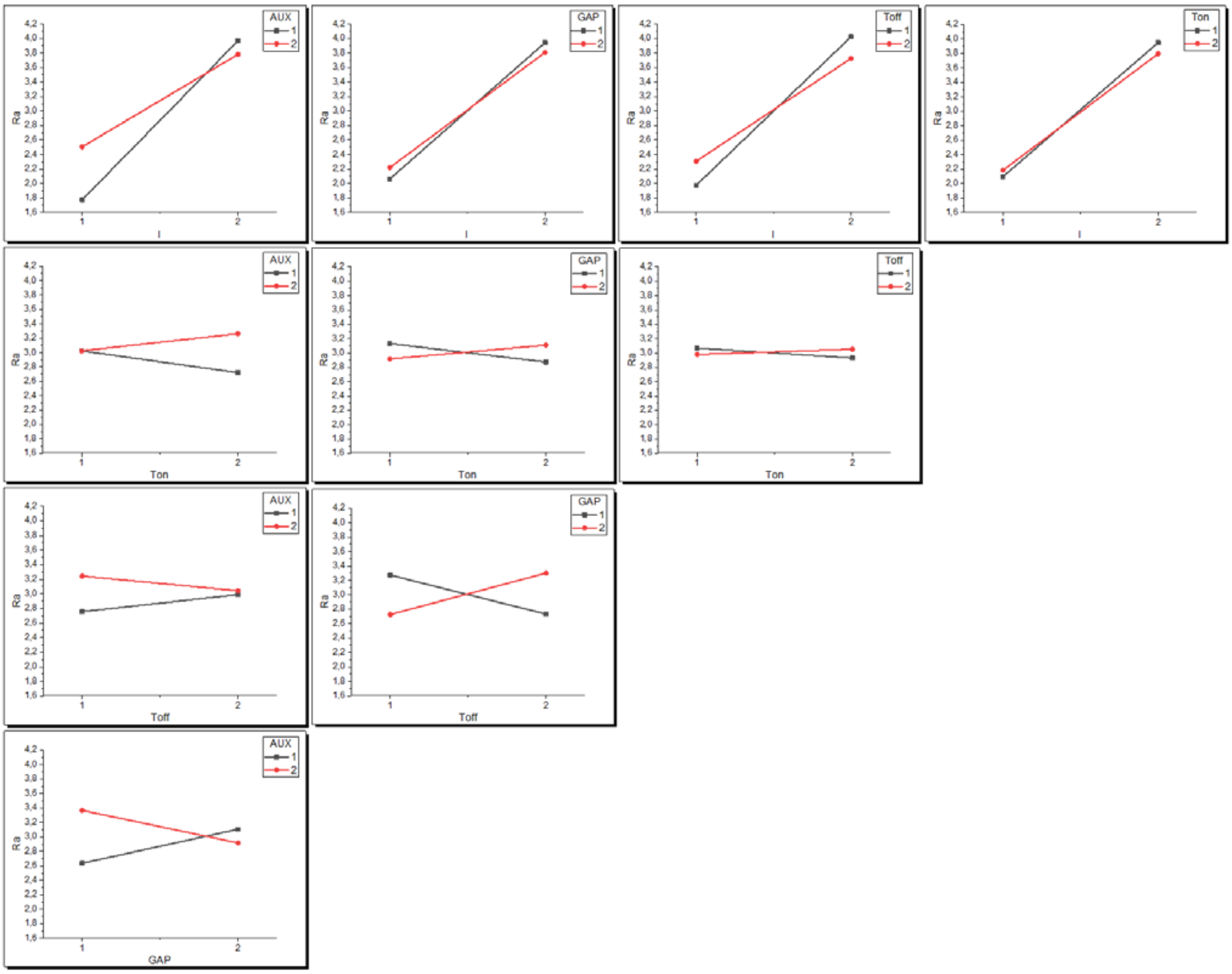

Figure 6. Graphs of interactions between EDM machining parameters for Ra

4.4.2. Interactions of the machining parameters with the MRR

A strong interaction is observed in Figure 7 between the discharge current I and the pulse time Ton on the one hand, an important interaction with the Toff on the other hand, on the other hand there is no interaction between the discharge current I and AUX auxiliary protection.

Most of the interaction graphs in Figure 7 admit intersections which means the existence of interaction, but very weak compared to that of (I-Ton) and (I-Toff) except when the two lines are parallel or therefore no interaction detected.

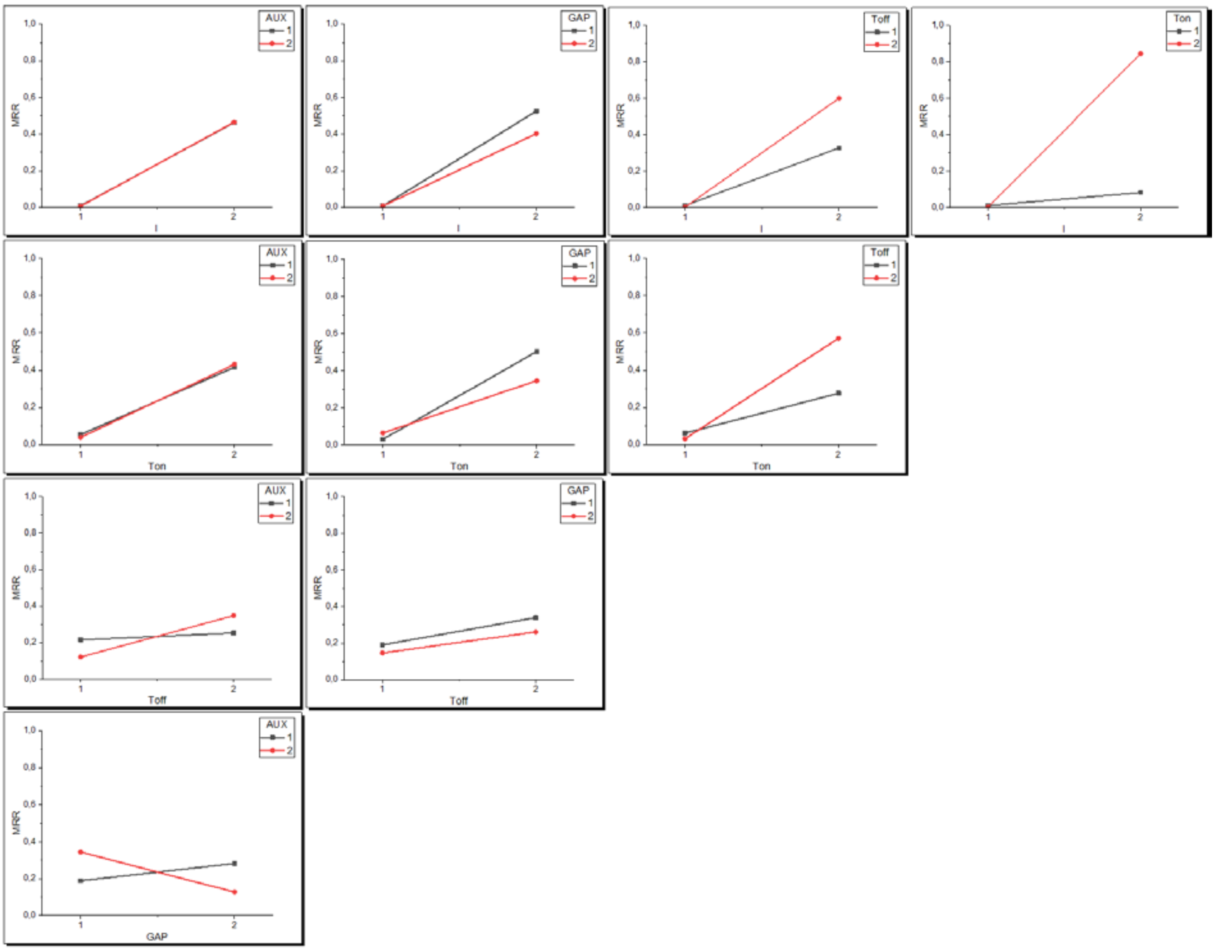

Figure 7. Graphs of interactions between EDM machining parameters for MRR.

4.4.3. Interactions of machining parameters with the TWR tool wear rate

The lines of the interaction graphs in Figure 8 are not parallel or superimposed; we can conclude that there is:

- an interaction between (I-Toff), (I-GAP) and (I-Ton).
- a weak interaction between (Ton-Toff) and (I-AUX).

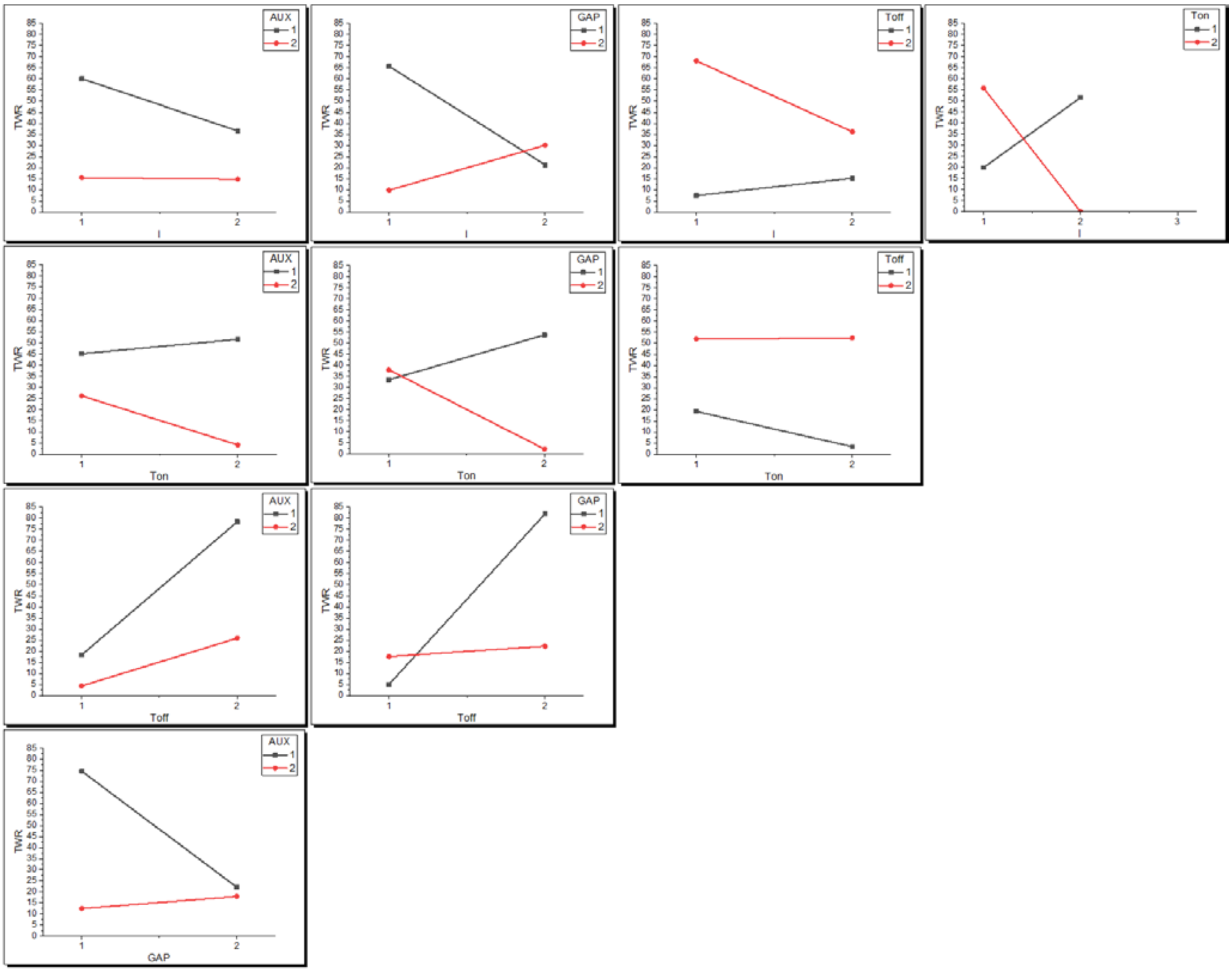

Figure 8. Graphes des interactions entre les paramètres d'usinage EDM pour TWR.

5. MODELING

The purpose of the Response Surface Method (RSM) is to explore the relationships between dependent and independent variables involved in the EDM machining process. After having identified the list of factors and influencing interactions and to study the response surfaces, it is necessary to increase the number of levels of the factors (to three levels) in order to better control their actions. The 5 machining parameters are chosen in three levels as shown in Table 14.

Table 14: Matrix of the levels of the response surfaces.

	I	Ton	Toff	GAP	AUX
Level 1	4	4	3	8	6
Level 2	7	8	6	10	8
Level 3	10	12	9	12	10

In the two presiding screening experiments, we noticed the existence of tests that exceed 30 hours of machining, so to limit the machining time, we limited the range of current intensity from 4 to 10 A instead of 3 to 11 A, it is also necessary to keep the same central value of the domain.

5.1. Choice of the experimental design

Taguchi's experimental design L27 was chosen to study the 5 parameters I, Ton, Toff, GAP and AUX and the interactions with the discharge current (I) I-Ton, I-Toff, I-GAP and I- AUX which were selected from the preceding screening, a plan L27 which corresponds to a number of tests which is equal to 27 experiments presented by the following test matrix (C):

$$C=\begin{bmatrix}
-1&-1&-1&-1&-1&-1&-1&-1&-1&-1&-1&-1&-1\\
-1&-1&-1&-1&0&0&0&0&0&0&0&0&0\\
-1&-1&-1&-1&1&1&1&1&1&1&1&1&1\\
-1&0&0&0&-1&-1&-1&0&0&0&1&1&1\\
-1&0&0&0&0&0&0&1&1&1&-1&-1&-1\\
-1&0&0&0&1&1&1&-1&-1&-1&0&0&0\\
-1&1&1&1&-1&-1&-1&1&1&1&0&0&0\\
-1&1&1&1&0&0&0&-1&-1&-1&1&1&1\\
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0&-1&0&1&1&-1&0&1&-1&0&1&-1&0\\
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0&1&-1&0&-1&0&1&1&-1&0&0&1&-1\\
0&1&-1&0&0&1&-1&-1&0&1&1&-1&0\\
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1&-1&1&0&-1&1&0&-1&1&0&-1&1&0\\
1&-1&1&0&0&-1&1&0&-1&1&0&-1&1\\
1&-1&1&0&1&0&-1&1&0&-1&1&0&-1\\
1&0&-1&1&-1&1&0&0&-1&1&1&0&-1\\
1&0&-1&1&0&-1&1&1&0&-1&-1&1&0\\
1&0&-1&1&1&0&-1&-1&1&0&0&-1&1\\
1&1&0&-1&-1&1&0&1&0&-1&0&-1&1\\
1&1&0&-1&0&-1&1&-1&1&0&1&0&-1\\
1&1&0&-1&1&0&-1&0&-1&1&-1&1&0
\end{bmatrix}$$

Taguchi associated two line graphs for table L27 as they appear in the line graph in Figure 9.

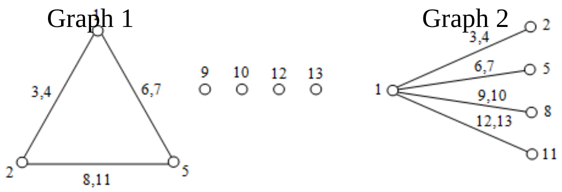

Figure 9. Taguchi L27 line graphs.

With graph 2 of the experimental design L27 only the interactions between the factors (1-2), (1-5), (1-8) and (1-11) which have a significant effect on the responses can be considered in this analysis. Table 15 illustrates the distribution of factors according to line graph 2.

Table 15. Matrix of experience of response surfaces.

	1	2	3	4	5	6	7	8	9	10	11	12	13
N° Exp	I	Ton	I-Ton	Ton-I	Toff	I-Toff	Toff-I	GAP	I-GAP	GAP-I	AUX	I-AUX	AUX-I
1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	-1	-1	-1	-1	0	0	0	0	0	0	0	0	0
3	-1	-1	-1	-1	1	1	1	1	1	1	1	1	1
4	-1	0	0	0	-1	-1	-1	0	0	0	1	1	1
5	-1	0	0	0	0	0	0	1	1	1	-1	-1	-1
6	-1	0	0	0	1	1	1	-1	-1	-1	0	0	0
7	-1	1	1	1	-1	-1	-1	1	1	1	0	0	0
8	-1	1	1	1	0	0	0	-1	-1	-1	1	1	1
9	-1	1	1	1	1	1	1	0	0	0	-1	-1	-1
10	0	-1	0	1	-1	0	1	-1	0	1	-1	0	1
11	0	-1	0	1	0	1	-1	0	1	-1	0	1	-1
12	0	-1	0	1	1	-1	0	1	-1	0	1	-1	0
13	0	0	1	-1	-1	0	1	0	1	-1	1	-1	0

14	0	0	1	-1	0	1	-1	1	-1	0	-1	0	1
15	0	0	1	-1	1	-1	0	-1	0	1	0	1	-1
16	0	1	-1	0	-1	0	1	1	-1	0	0	1	-1
17	0	1	-1	0	0	1	-1	-1	0	1	1	-1	0
18	0	1	-1	0	1	-1	0	0	1	-1	-1	0	1
19	1	-1	1	0	-1	1	0	-1	1	0	-1	1	0
20	1	-1	1	0	0	-1	1	0	-1	1	0	-1	1
21	1	-1	1	0	1	0	-1	1	0	-1	1	0	-1
22	1	0	-1	1	-1	1	0	0	-1	1	1	0	-1
23	1	0	-1	1	0	-1	1	1	0	-1	-1	1	0
24	1	0	-1	1	1	0	-1	-1	1	0	0	-1	1
25	1	1	0	-1	-1	1	0	1	0	-1	0	-1	1
26	1	1	0	-1	0	-1	1	-1	1	0	1	0	-1
27	1	1	0	-1	1	0	-1	0	-1	1	-1	1	0

5.2. Results and discussion

The experimental design is defined by Table 16, the results are obtained through tests planned according to the Taguchi L27 plan at three levels and two repetitions.

Table 16. Experimental design of response surfaces.

N°	Factors					Response					
	1	2	5	8	11	Ra (µm)		MRR (g/min)		TWR (%)	
	I	Ton	Toff	GAP	AUX	Reading 1 and 2	Mean	Reading 1 and 2	Mean	Reading 1 and 2	Mean
1	4	4	3	8	6	2.04333 2.06333	2.05333	0.04048 0.03960	0.04004	23.6434 24.5005	24.0719
2	4	4	6	10	8	2.10666 2.60333	2.35499	0.02258 0.02233	0.02246	20.3603 21.6666	21.0135
3	4	4	9	12	10	2.61333 2.38000	2.49666	0.00346 0.00331	0,00339	51.1210 50.8920	51.0065
4	4	8	3	10	10	3.26333 3.00666	3.13500	0.01592 0.01651	0,01621	5.98146 4.63576	5.30861
5	4	8	6	12	6	4.20000 3.83333	4.01666	0.03524 0.03523	0.03523	0.33333 0.46598	0.39965
6	4	8	9	8	8	4.06333 4.17333	4.11833	0.02414 0.02490	0.02452	0.85470 1.09823	0,97646
7	4	12	3	12	8	3.81666 3.83333	3.82500	0.00537 0.00429	0.00483	0.17323 0.09165	0,13244
8	4	12	6	8	10	3.89000 3.55333	3.72166	0.00131 0.00111	0.00121	12.4413 11.5755	12.0084
9	4	12	9	10	6	1.02000 0.99333	1.00666	0.00561 0.00567	0.00564	0.06389 0.06265	0.06327
10	7	4	3	8	6	3.56333 2.78333	3.17333	0.01074 0.01083	0.01078	1.06209 0.03505	0,54857
11	7	4	6	10	8	2.79333 3.03666	2.91500	0.09918 0.09542	0,09730	40.4512 39.6341	40.0427
12	7	4	9	12	10	3.10666 2.84000	2.97333	0.01696 0.01733	0.01714	67.7729 67.9462	67.8595
13	7	8	3	10	10	2.64000 3.10333	2.87166	0.10569 0.09402	0.09986	0.02844 0.03395	0.03120
14	7	8	6	12	6	4.38333 4.17333	4.27833	0.26148 0.25075	0,25612	2.51060 4,24628	3.37844
15	7	8	9	8	8	4.11666 3.99666	4,05666	0.19227 0.19040	0.19134	6.21890 6.89163	6.55527
16	7	12	3	12	8	3.68333 3.90333	3.79333	0.02363 0.02072	0.02218	0.09407 0.05903	0.07655
17	7	12	6	8	10	3.00666 4.01000	3.50833	0.25289 0.20151	0.22720	0.11444 0.02778	0.07111
18	7	12	9	10	6	3.75666 3.83000	3.79333	0.22093 0.22210	0.22151	0.03017 0.02843	0.02930
19	10	4	3	8	6	3.57333 3.32000	3,44666	0.03546 0.03682	0.03614	1.33333 0.51282	0.92307
20	10	4	6	10	8	3.66666 2.99000	3.32833	0.25370 0.23114	0.24242	49.3384 49.0419	49.1902
21	10	4	9	12	10	3.47000 3.50666	3.48833	0.04590 0.04608	0.04599	72.21750 72.47329	72.3454
22	10	8	3	10	10	3.20000 3.91333	3.55666	0.27361 0.30502	0.28932	0.019944 0.023375	0.02166
23	10	8	6	12	6	4.38333 4.28333	4.33333	0.83666 0.79569	0.81617	9.255286 9.334182	9.29473
24	10	8	9	8	8	3.42333 3.30666	3.36500	0,63275 0,60015	0.61645	20.37444 21.56306	20.9687

25	10	12	3	12	8	4.16000	4.06000	0.25503	0.24658	0.037174	0.02800
						3.96000		0.23812		0.018835	
26	10	12	6	8	10	4.23000	3.88000	1.10986	1.09733	0.021427	0.02124
						3.53000		1.08480		0.021070	
27	10	12	9	10	6	5.18666	4.89500	0.86429	0.83830	0.020550	0.02110
						4.60333		0.81231		0.021654	

The influences of the machining parameters on the material removal rate MRR, the tool wear rate TWR and the roughness Ra were studied then the robustness of the models was verified by the statistical method: analysis of variance ANOVA [22].

5.2.1. Modeling of Ra as a function of parameters and interactions

A polynomial roughness model has been determined, which takes into account the first and second order factors along with the interactions.

$$Ra = b0 + b1 \times I + b2 \times Ton + b3 \times I{\times}Ton + b4 \times Toff + b5 \times I{\times}Toff + b6 \times GAP + b7 \times I{\times}GAP + b8 \times AUX + b9 \times I{\times}AUX + b11 \times I^2 + b22 \times Ton^2 + b44 \times Toff^2 + b66 \times GAP^2 + b88 \times AUX^2 \quad (5)$$

The statistical analysis led us to the variance examination table in Table 17, which indicates that the model used is fitted, since the sum of squares of residuals is not small compared to the sum of the regression squares.

Table 17. ANOVA analysis of variance of Ra.

Source of variation	Sum of squares (SS)	Degrees of freedom (DOF)	Medium square (MS)	Rapport (F)	Signif
Regression (R)	25.0415	18	1.3912	**4.5040**	< 0.01 ***
Residues (E)	10.8107	35	0.3089		
Total (T)	35.8522	53			

With:

$$SS_T = SS_R + SS_E \quad (6)$$

$$MS_R = SS_R / DOF_R \quad (7)$$

$$MS_E = SS_E / DOF_E \quad (8)$$

By calculation:

$$F \text{ Ratio} = MS_R / MS_E \quad (9)$$

From the Fisher table we deduce:

$F\ 0.05\ (DOF_R; DOF_E) = 1.91 < 4.5040$

$F\ 0.01\ (DOF_R; DOF_E) = 2.5 < 4.5040$

$F\ 0.001\ (DOF_R; DOF_E) = 3.38 < 4.5040$ (***)

The Fisher test therefore makes it possible to demonstrate the existence of a statistically significant difference at the 99.9% confidence level indicated in Table 17 by the appearance of three stars in front of the significance of the regression.

To note :

- (*) Significant value at a confidence level of 95%
- (**) Significant value at a confidence level of 99%
- (***) Significant value at a confidence level of 99.9%

In other words, the more significant the result of the hypothesis test, the more it is associated with a significant number of stars.

A more detailed analysis of the estimates and statistics of the coefficients by the multiple linear correlation coefficient R2 which is evaluated by:

$$R2 = SS_R / SS_T = 1 - (SS_E / SS_T) \quad (10)$$

With a value between ($0 \le R2 \le 1$) and an excellence value R2 = 0.7.

The correlation coefficient R2 has a value, which is equal to 0.698 ≈ 0.7 (Table 18) which means that the model is fitted.

Table 18. Statistics of the coefficients of Ra.

Standard deviation of the response	0.5558
R2	0.698
R2A	0.543
R2 pred	0.289
PRESS	25.492
Number of degrees of freedom	35

We estimated the various parameters of the model in Table 19, for each coefficient (bi) or (bij), we tested the hypothesis of their nullities.
The nullity hypothesis to test the significance of each coefficient is:

$$b_i = 0 \tag{11}$$

If the assumption of Eq. (11) is not true, it indicates that (Xi) can be eliminated from the model. The statistical test of this hypothesis is the Student's test which leads us to calculate the value (ti):

$$t_i = \frac{b_i}{\text{Standard Deviation of } b_i} \tag{12}$$

Interestingly, only the interaction effect between factors (I) and (AUX) seems to be significant.

Table 19. Estimation of the model parameters.

Name	bi	Standard Devi.	ti	Signif. %
b0	3.7606	0.2508	14.99	< 0.01 ***
b1	0.4236	0.0926	4.57	< 0.01 ***
b2	0.3474	0.0926	3.75	0.0638 ***
b3	-0.1154	0.0926	-1.25	22.1
b4	0.0155	0.0926	0.17	86.8
b5	-0.1368	0.0926	-1.48	14.9
b6	0.1079	0.0926	1.16	25.2
b7	-0.1171	0.0926	-1.26	21.4
b8	-0.0758	0.0926	-0.82	41.9
b9	0.3117	0.0926	3.36	0.187 **
b11	-0.0914	0.1604	-0.57	57.3
b22	-0.4861	0.1604	-3.03	0.458 **
b44	-0.2536	0.1604	-1.58	12.3
b66	0.4931	0.1604	3.07	0.409 **
b88	-0.1669	0.1604	-1.04	30.5

According to the results obtained from Table 19, we can write the response Ra in the following form:

$$Ra = 3.7606 + 0.4236 \times I + 0.3117 \times I \times AUX - 0.4861 \times Ton^2 + 0.4931 \times GAP^2 \tag{13}$$

This model has been intentionally simplified by eliminating interaction effects and order 2 parameters deemed insignificant in the previous analysis. This makes it easier to manipulate this reduced expression while maintaining a quality of fit.
Figure 10 makes it possible to judge more precisely the quality of the adjustment made experiment by experiment. The comparison between the $Y_{exp.}$ (measured responses) and $Y_{calc.}$ (model predicted responses) curves of Ra confirms that the model is fitted. We can notice that the maximum difference between the calculated and experimental values of roughness almost equal 1µm.

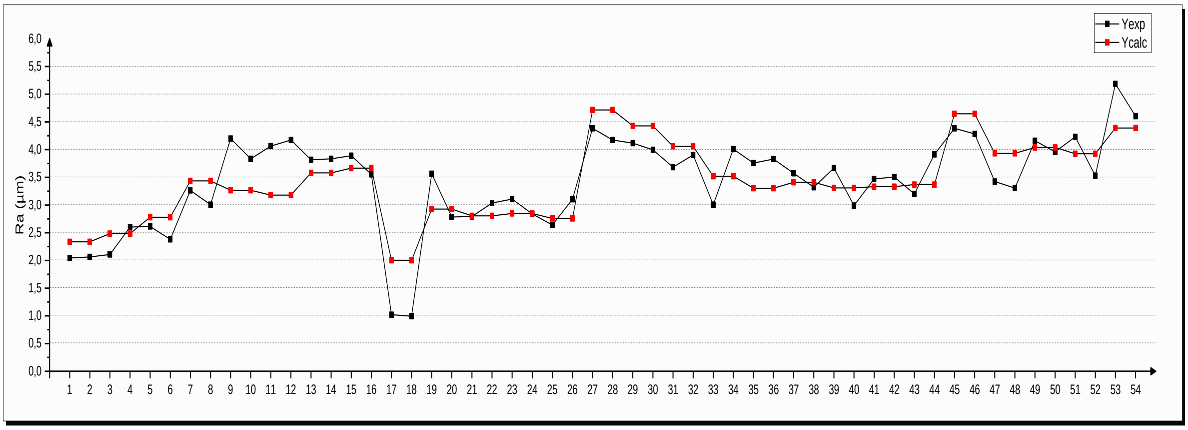

Figure 10. Comparison between the measured $Y_{exp.}$ and the predicted $Y_{calc.}$ by the model of Ra.

Response surfaces can show variations in responses based on only 2 factors at a time, with the other factors set to a fixed value. Figures 11, 12 and 13 show the response surfaces associated with the roughness model. We have chosen to present the variation of (I / Ton), (Ton / Toff) and (Toff / AUX), the other factors being fixed at the center of the experimental domain.
Figure 11 shows the simultaneous reproduction of the variation in discharge current and pulse time in two and three dimensions, it is observed that the optimum (minimum) of roughness is obtained when the values of I and Ton are equal to I = 4 A and Ton = 4 µs the value of the roughness Ra increases proportionally with the discharge current I.
Figure 12 shows the simultaneous two- and three-dimensional image of the pulse time variation Ton and the rest time Toff, where it can be seen that there is a stationary point almost at the center of the response surface with a maximum of roughness for the values of Ton = 8 µs and Toff = 6 µs.

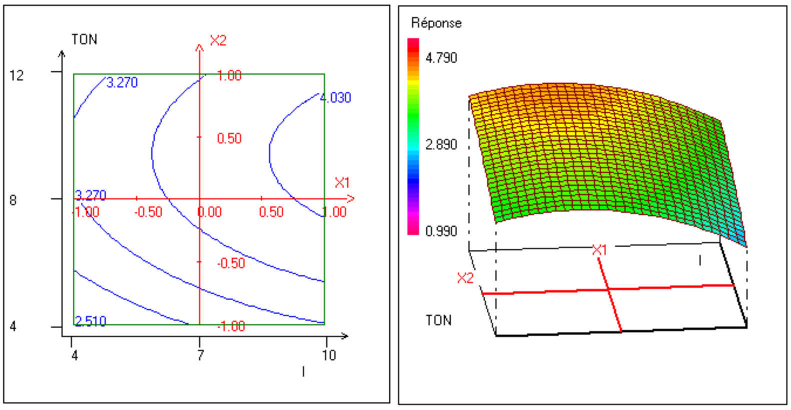

Figure 11. 2D and 3D response surface of Ra in the I, Ton plane.
Variation of the response Ra in the I, Ton plane for the fixed factors: Toff = 6µs, GAP = 10µm, AUX = 8

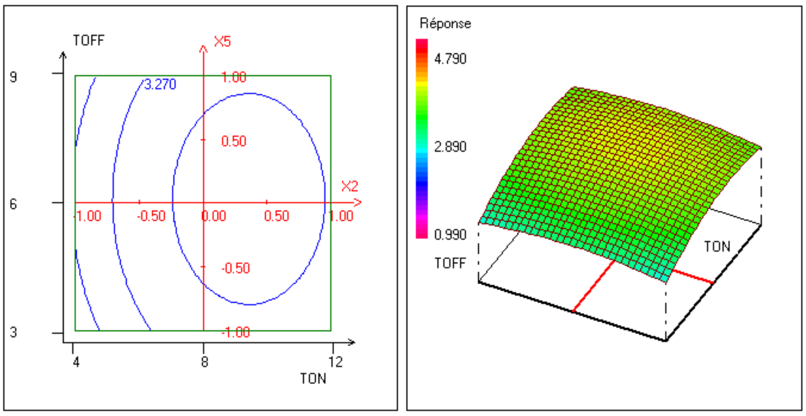

Figure 12. 2D and 3D response surface of Ra in the Ton, Toff plane
Variation of the response Ra in the Ton, Toff plane for the fixed factors: I = 7A, GAP = 10µm, AUX = 8

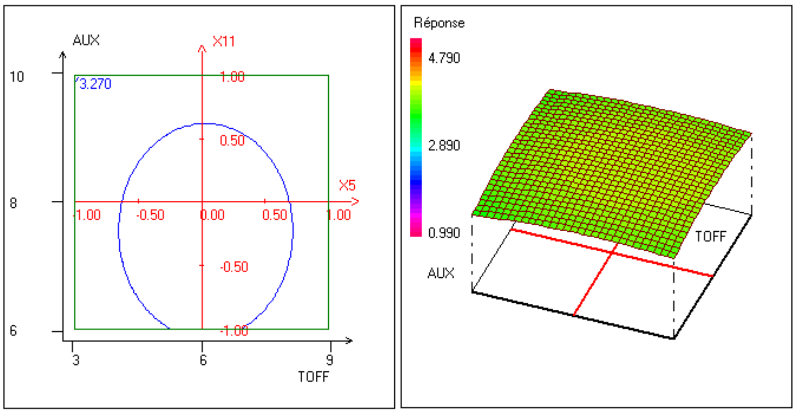

Figure 13. 2D and 3D response surface of Ra in the Toff plane, AUX
Variation of the response Ra in the Toff plane, AUX. For the fixed factors: I = 7A, Ton = 8µs, GAP = 10µm.

From the simultaneous representation of Figure 13 in two and three dimensions of the variation of the rest time Toff and the auxiliary protection AUX, it can be seen that there is a stationary point almost at the center of the response surface with maximum roughness for Toff = 6 µs and AUX = 8.

5.2.2. Modeling of MRR as a function of parameters and interactions

We have defined a polynomial model of the material removed rate that takes into account the second order parameters and the interactions selected.

$$MRR = b0 + b1 \times I + b2 \times Ton + b3 \times I{\times}Ton + b4 \times Toff + b5 \times I{\times}Toff + b6 \times GAP + b7 \times I{\times}GAP + b8 \times AUX + b9 \times I{\times}AUX + b11 \times I^2 + b22 \times Ton^2 + b44 \times Toff^2 + b66 \times GAP^2 + b88 \times AUX^2 \qquad (14)$$

The statistical analysis leads us to the analysis of variance table in Table 20. It mainly indicates that the model used is fitted, since the sum of the squares of residuals is not small compared to the sum of the regression squares.

Table 20. Analysis of variance of MRR.

Source of variation	Sum of squares (SS)	Degrees of freedom (DOF)	Medium square (MS)	Rapport (F)	Signif
Regression (R)	3.8218	18	0.2123	**10.6706**	< 0.01 ***
Residues (E)	0.6964	35	0.0199		
Total (T)	4.5182	53			

From the Fisher table, we deduce:

$F\ 0.05\ (DOF_R;\ DOF_E) = 1.91 < 10.6706$

$F\ 0.01\ (DOF_R;\ DOF_E) = 2.5 < 10.6706$

$F\ 0.001\ (DOF_R;\ DOF_E) = 3.38 < 10.6706$ (***)

The Fisher test, therefore, makes it possible to highlight the existence of a statistically significant difference at the 99.9% confidence level in Table 19 by the appearance of three stars in front of the significance of the regression. In other words, the more significant the result of the hypothesis test, the more it is associated with a significant number of stars.

Further analysis of the estimates and statistics of the coefficients in Table 21 gives us the result of the multiple linear correlation coefficient R2 which is equal to 0.846 a value greater than the excellence value of R2 which is acceptable which means that the model is well adjusted.

Table 21. Statistics of MRR coefficients.

Standard deviation of the response	0.1410593
R2	0.846
R2A	0.767
R2 pred	0.637
PRESS	1.642
Number of degrees of freedom	35

Regarding the estimation of the various parameters of the model (Table 22), for each coefficient of (bi) or (bij), we tested the hypothesis of their nullities.
Interestingly, only the interaction effect between the factors (I-Ton) and (I-Toff) seems to be significant.

Table 22. Estimation of the model parameters.

Name	bi	Standard Devi.	ti	Signif. %
b0	0.2464091	0.0636650	3.87	0.0453 ***
b1	0.2263984	0.0235099	9.63	< 0.01 ***
b2	0.1193956	0.0235099	5.08	< 0.01 ***
b3	-0.0763985	0.0235099	-3.25	0.255 **
b4	0.0665743	0.0235099	2.83	0.762 **
b5	-0.0811561	0.0235099	-3.45	0.147 **
b6	-0.0442989	0.0235099	-1.88	6.8
b7	0.0267111	0.0235099	1.14	26.4
b8	-0.0256834	0.0235099	-1.09	28.2
b9	0.0273157	0.0235099	1.16	25.3
b11	0.1164086	0.0407203	2.86	0.712 **
b22	-0.0838891	0.0407203	-2.06	4.69 *
b44	-0.1589255	0.0407203	-3.90	0.0413 ***
b66	0.0014777	0.0407203	0.04	97.1
b88	0.0623021	0.0407203	1.53	13.5

According to the results obtained from Table 22, the response MRR is then written in the following form:

$$MRR = 0.2464091 + 0.2263984 \times I + 0.1193956 \times Ton - 0.0763985 \times I{\times}Ton + 0.0665743 \times Toff - 0.0811561 \times I{\times}Toff + 0.1164086 \times I^2 - 0.0838891 \times Ton^2 - 0.1589255 \times Toff^2 \quad (15)$$

This model was simplified by eliminating the interaction effects and the second-order parameters deemed insignificant in the previous analysis. This makes it easier to manipulate this reduced expression while maintaining a quality of fit.
Figure 14 allows a more precise judgment of the quality of the adjustment made experiment by experiment. The comparison between the Y_{exp} (measured responses) and Y_{calc} (model predicted responses) curves of MRR confirms that the moderately fitted model.
It can be noted that the maximum difference between the calculated and experimental values of the material flow rate removed can be 0.2 g / min.

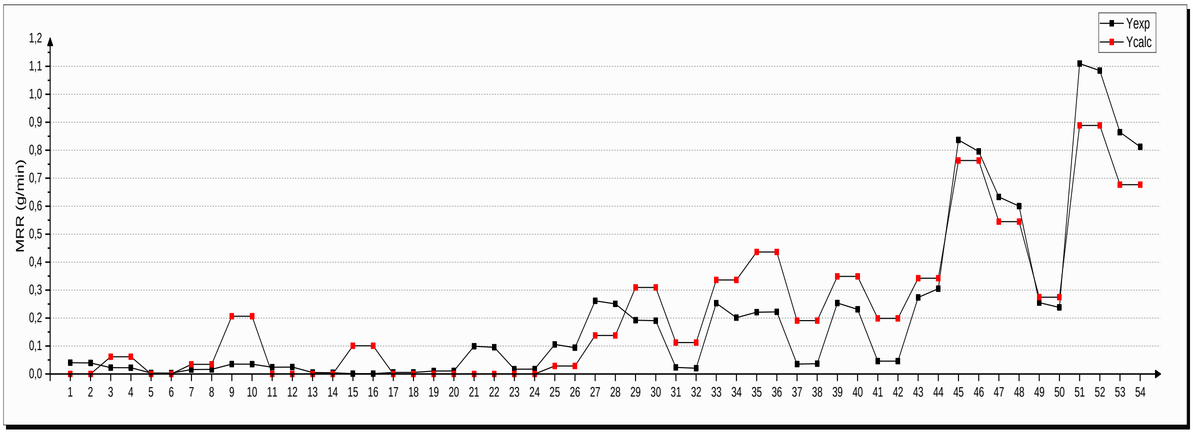

Figure 14. Comparison between the measured Y_{exp} and the predicted Y_{calc} by the MRR model.

Figures 15, 16 and 17 show the response surfaces associated with the material removed flow model. We have chosen to present the variation of (I / Ton), (I / Toff) and (GAP / AUX), the other factors being fixed at the center of the experimental domain. From the simultaneous two- and three-dimensional representation of the variation in discharge current I and pulse time Ton in Figure 15, it can be seen that the minimum of the material flow rate removed is obtained when the values I = 4 A and Ton = 4 µs and the maximum flow is obtained for the values I = 10 A and Ton = 12 µs. The value of MRR increases proportionally with the discharge current I and the pulse time Ton.

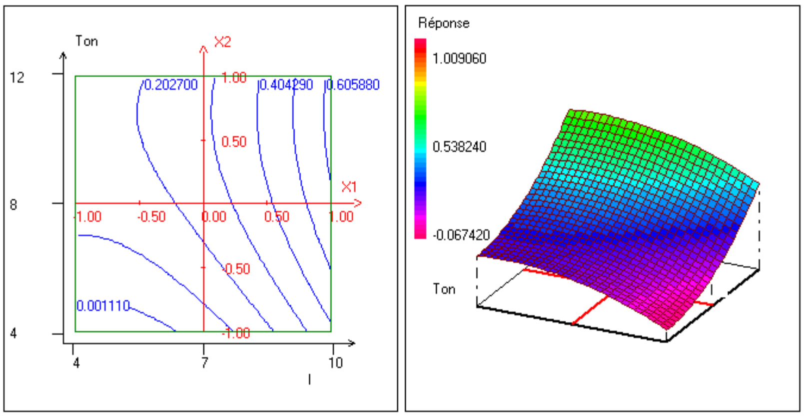

Figure 15. 2D and 3D response surface of MRR in the I, Ton plane.
Variation of MRR response in the I, Ton plane. Fixed Factors: Toff = 6µs, GAP = 10µm, AUX = 8.

From the 2D diagram and the response surface graph in Figure 16 of the variation in discharge current I and rest time Toff, we can see:

- the maximum material removal rate for the values of Toff = 6 µs and I = 10 A;
- the minimum material flow for two removes the Toff values, i.e. 3 µs or 9 µs and I = 3 A.

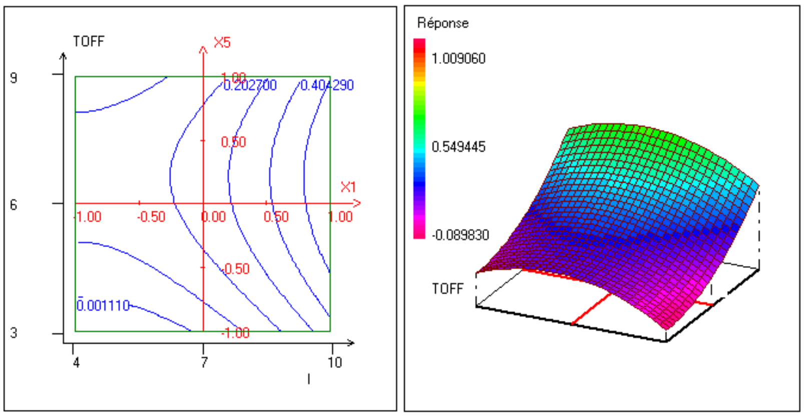

Figure 16. 2D and 3D response surface of MRR in the I, Toff plane.
Variation of MRR response in plane I, Toff. Fixed Factors: Ton = 8µs, GAP = 10µm, AUX = 8.

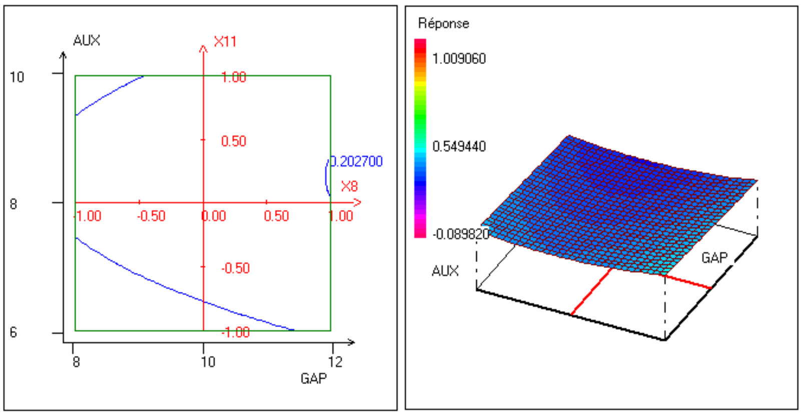

Figure 17. 2D and 3D response surface of MRR in the GAP, AUX plane.
Variation of the MRR response in the GAP, AUX plan. For the fixed factors: I = 7A, Ton = 8µs, Toff = 6µs.

A small variation is observed when varying the distance between the electrode-work piece (GAP) and the auxiliary protection (AUX) in Figure 17.

5.2.3. Modeling of TWR according to parameters and interactions

A third polynomial model is defined of the TWR electrode wear rate as a function of the first and second order parameters with the fixed interactions as shown in Eq. (16).

$$TWR = b0 + b1 \times I + b2 \times Ton + b3 \times I \times Ton + b4 \times Toff + b5 \times I \times Toff + b6 \times GAP + b7 \times I \times GAP + b8 \times AUX + b9 \times I \times AUX + b11 \times I^2 + b22 \times Ton^2 + b44 \times Toff^2 + b66 \times GAP^2 + b88 \times AUX^2 \quad (16)$$

The statistical analysis leads us to the study table of the variance of Table 23. It mainly indicates that the determined model is very well fitted, since the sum of the squares of residuals is very small compared to the sum of the regression squares.

Table 23. Analysis of variance of TWR.

Source of variation	Sum of squares (SS)	Degrees of freedom (DOF)	Medium square (MS)	Rapport (F)	Signif
Regression (R)	2.45591E+0004	18	1.36440E+0003	**55.0365**	< 0.01 ***
Residues (E)	8.67677E+0002	35	2.47908E+0001		
Total (T)	2.54268E+0004	53			

From the Fisher table, we deduce:

$F\ 0.05\ (DOF_R;\ DOF_E) = 1.91 < 55.0365$

$F\ 0.01\ (DOF_R;\ DOF_E) = 2.5 < 55.0365$

$F\ 0.001\ (DOF_R;\ DOF_E) = 3.38 < 55.0365$ (***)

The Fisher test makes it possible to demonstrate the existence of a statistically significant difference with a confidence level of 99.9% in Table 22 by the appearance of three stars in front of the significance of the regression, in other words, more the result of the hypothesis test is significant the more robust the model is.
A more detailed analysis of the estimates and statistics of the multiple linear correlation coefficient R2 in Table 24 clearly shows the very good quality of the fit since R2 = 0.966 which is very close to 1.

Table 24. Statistics of TWR coefficients.

Standard deviation of the response	4.9790333
R2	0.966
R2A	0.948
R2 pred	0.919
PRESS	2061.393
Number of degrees of freedom	35

Table 25 represents the estimation of the various parameters of the model, for each coefficient of (bi) or (bij), it is possible to test the hypothesis of its nullity. It is interesting to note that all of the interaction effects between the factors appear to be significant.

Table 25. Estimation of the model parameters.

Name	bi	Standard Devi.	ti	Signif. %
b0	4.4965876	2.2472143	2.00	5.3
b1	2.1018455	0.8298389	2.53	1.60 *
b2	-17.4750068	0.8298389	-21.06	< 0.01 ***
b3	2.4896034	0.8298389	3.00	0.495 **
b4	10.4824214	0.8298389	12.63	< 0.01 ***
b5	-3.6640050	0.8298389	-4.42	< 0.01 ***
b6	7.6875799	0.8298389	9.26	< 0.01 ***
b7	-2.8267610	0.8298389	-3.41	0.167 **
b8	9.4413138	0.8298389	11.38	< 0.01 ***
b9	-2.0803749	0.8298389	-2.51	1.70 *
b11	1.7005328	1.4373231	1.18	24.5
b22	13.6435274	1.4373231	9.49	< 0.01 ***
b44	-1.1040170	1.4373231	-0.77	44.8
b66	2.1790636	1.4373231	1.52	13.8
b88	-1.6979927	1.4373231	-1.18	24.5

After checking the hypothesis of their nullities (Eq. 11), the results obtained in Table 25 allow us to write the predicted TWR response as follows:

$$TWR = 4.4965876 + 2.1018455 \times I - 17.4750068 \times Ton + 2.4896034 \times I\times Ton + 10.4824214 \times Toff - 3.6640050 \times I\times Toff + 7.6875799 \times GAP - 2.8267610 \times I\times GAP + 9.4413138 \times AUX - 2.0803749 \times I\times AUX + 13.6435274 \times Ton^2 \quad (17)$$

This expression has been simplified by eliminating the effects of interactions and parameters deemed insignificant, to more easily handle the reduced model expression while maintaining goodness of fit.
Figure 18 allows a more precise judgment of the quality of the adjustment made experiment by experiment. The comparison between the Y_{exp} (measured responses) and Y_{calc} (model predicted responses) curves of (MRR) confirms that the model fits well. It can be noted that the maximum difference between the calculated and experimental values of the electrode wear rate does not exceed 10%.

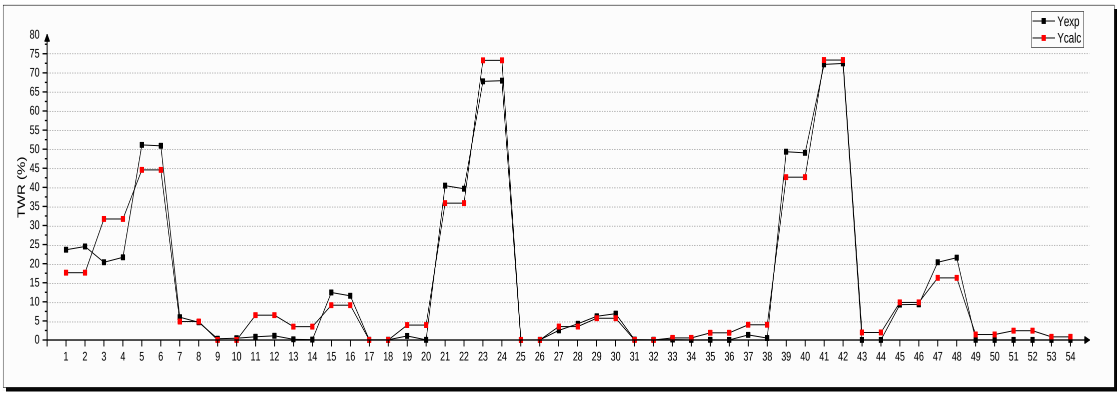

Figure 18. Comparison between the measured Y_{exp} and the predicted Y_{calc} by the TWR model.

Figures 19, 20 and 21 show the response surfaces associated with the TWR tool wear rate model. We have chosen to present the variation of (I / Ton), (I / GAP) and (Ton / Toff), the other factors being fixed at the center of the experimental domain.

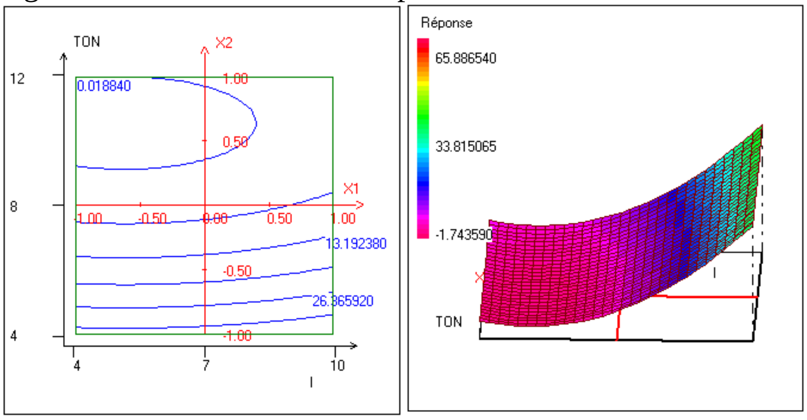

Figure 19. 2D and 3D response surface of MRR in the I, Ton plane.
Variation of the TWR response in the I, Ton plane. Fixed Factors: Toff = 6µs, GAP = 10µm, AUX = 8.

From the representation of the graphs of the variation of discharge current I and pulse time Ton in Figure 19, it can be seen that there is a stationary point approximately at the values Ton = 12 µs and I = 4 A with a minimum tool wear rate.

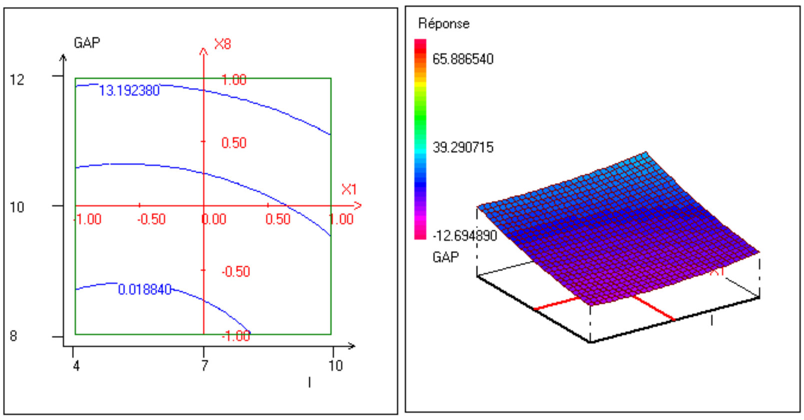

Figure 20. 2D and 3D response surface of MRR in the I, GAP plane.
Variation of TWR response in plan I, GAP. Fixed Factors: Ton = 8µs, Toff = 6µs, AUX = 8.

A small variation is observed when varying the two parameters, the discharge current I and the distance between the electrode and the GAP part in Figure 20.

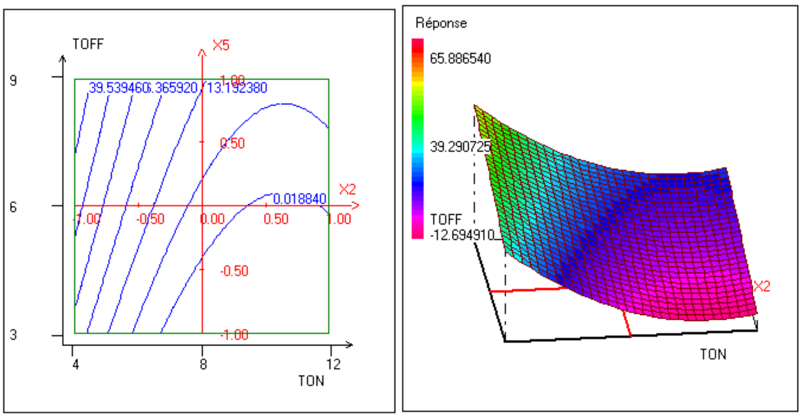

Figure 21. 2D and 3D response surface of MRR in the Ton, Toff plane.
Variation of the TWR response in the plane Ton, Toff. Fixed Factors: I = 7A, GAP = 10µm, AUX = 8.

By examining the variation in pulse time Ton and rest time Toff in Figure 21, we can easily see the optimum (minimum) of the electrode wear rate for the values Ton = 12 µs Toff = 3µs.

6. MODEL VALIDATION

To validate the models, we performed additional tests in the experimental field at points not tested by the design of experiments, with unused factor levels.
Table 26 shows on the one hand the plan of the validation tests and the results obtained and on the other hand the comparison of the results between the model of Ra and the experimental tests.

Table 26. Plan of the validation tests of the Roughness model Ra

N°	**Parameters**					**Ra (µm)**				
	I	Ton	Toff	GAP	AUX	Model	Exp.	Difference	Relative error	
1	10	5	9	12	10	3.2	3.460	0.260	0.075	7.5%
2	10	4	5	10	10	2.4	2.668	0.268	0.100	10.0%

Table 27 presents the plan of the validation tests, the results of the experimental tests obtained and the comparison between the MRR prediction model and the experimental tests carried out.

Table 27. Plan of validation tests for the model of the material flow removed MRR

N°	**Parameters**					**MRR (g/min)**				
	I	Ton	Toff	GAP	AUX	Model	Exp.	Difference	Relative error	
1	10	5	9	12	10	0.1	0.09094	0.00905	0.0995	9.95%
2	10	12	7	10	10	0.9	0.89603	0.00442	0.0442	4.42%

Table 28 presents the plan of the validation tests with the results of the comparison between the prediction model of TWR and that of the experimental tests.

Table 28. TWR tool wear rate model validation test plan

N°	**Parameters**					**TWR (%)**				
	I	Ton	Toff	GAP	AUX	Model	Exp.	Difference	Relative error	
1	10	5	9	12	10	60	55.142	04.858	0.0880	8.8 %
2	10	4	5	10	10	40	39.767	00.233	0.0058	0.58%

The results of the validation tests of the different models show us that:

- The maximum relative error calculated for the roughness Ra is acceptable since it does not exceed 10%.
- The maximum relative error estimated for the flow rate material removed MRR is equal to 9.95%, but it is acceptable.

- The maximum relative error of the TWR electrode wear rate results is 8.8% so the result is acceptable.

7. CONCLUSION

In this study, the influence of die-sinking EDM machining parameters and the influence of interactions between process parameters was investigated using the design of experiments method. The experimental results were used to develop material removal rate (MRR), tool wear rate (TWR) and roughness (Ra) models which were successfully analyzed using the statistical method. (ANOVA).

From the results, it was found that the pulse time (Ton) the idle time (Toff) the discharge current (I) and the sensitivity of the protection against short circuits in the GAP (AUX) play an important role in spark erosion operations. It has been noticed that the interactions of the various parameters Ton, Toff, GAP and AUX with the discharge current are the most significant.

In addition, it was found that the two factors the discharge current I and the pulse time Ton are the most significant factors on the roughness Ra and the MRR. In addition, it has been noticed that the Toff resting time factor is very significant on the tool wear rate.

The main conclusions drawn from the research are as follows:

- the optimal (minimum) level of the factors for the response Ra is obtained for the values of I = 4 A and Ton = 4 µs. The value of the roughness Ra increases proportionally with the increase in the discharge current I;
- the optimal (maximum) level of the factors for the MRR response is obtained for the values of I = 10 A and Ton = 12 µs. The value of MRR increases proportionally with the discharge current I and the pulse time Ton;
- the optimal (minimum) level of the factors for the TWR response is obtained for the values of Ton = 12 µs and Toff = 3 µs. The value of TWR increases proportionally with increasing discharge current I, increasing rest time Toff and decreasing pulse time Ton.

The polynomial models developed for the three responses are evaluated and validated using the analysis of variance method on the one hand which has been found to be adjusted and on the other hand by the experimental validation tests, the comparison of experimental results with those of theoretical models are conclusive.

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Research Article

PANIC BUTTON MOBILE APPLICATION USABILITY STUDY

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PANIC BUTTON MOBILE APPLICATION USABILITY STUDY

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ABSTRACT: It is inevitable that technology, which enters all areas of our lives, is also used in disaster and emergency management. The frequent use of smartphones has led to the development of emergency applications for mobile phones. The usability of applications, which are vitally important to be used easily in emergency situations, should be at a high level. In this study, the “Panic Button” application, which was developed for use on smartphones in emergency situations, was subjected to heuristic evaluation and the evaluation results were shared. By applying the System Usability Scale with the help of heuristic evaluation, significant and fast feedback was received and this feedback was provided to increase the usability of the “Panic Button" application for emergency situations. It is aimed to prevent errors and to provide an environment where users can communicate quickly by recommending the help and documentation information of the “Panic Button” application.

Keywords: Usability, Emergency Mobile Application, Heuristic Evaluation, System Usability Scale.

1. INTRODUCTION

As in all fields of our lives, adaptation to an emergency is inevitable as well [1]. Applications that enable people to contact the person trapped under the rubble after an earthquake catastrophe or request a call for help for the evacuation of individuals trapped in a flood disaster can be demonstrated as an example.

Along with the use of emergency applications to be developed, many potential hazards can be prevented or the resulting damages can be minimized [1]. In today’s world where technology enters every field, the usage of smartphones has become an indispensable part of individuals' lives. Studies indicate that more than 90% of adults in Turkey use mobile phones, while more than 75% of them use smartphones [2-3]. Mobile-based emergency software will have augmented their usage when considering that mobile phones are widely used [4]. The fact that users can get the help they need swiftly by pressing a few buttons depends upon the ability of mobile applications to perform the expected function and to be easily used in emergencies, briefly, to have a high level of usability.

The set of attributes that measures quality based on how easy the user interface is to use is called usability [5]. ISO 9241-11:2018 standard; defines efficiency, satisfaction, and effectiveness as a consequence of the usage of a particular product as usability [6]. Measuring usability bridges over determining how usable the system is (e.g., effective, efficient, easy to learn) from the users' perspective, whether there are any issues to fix or not, and monitoring the performance of the system design over time [6-7]. The usability of a system can be measured through different measurement tools. As measurement tools, they can be used in different methods and models such as expert-based and user-based methods that are widely applied in the literature [8]. Studies with heuristic evaluation and user tests, which are usability evaluation tools, are escalating day by day. These studies provide information to software developers about the usability of interfaces. While there are many studies on usability in the literature, it is seen that there are fewer studies on applications used in emergencies [9]. With the increase in mobile applications used in our daily life, studies to evaluate the usability of these applications have also been made academically [10-11]. An investigation-based heuristic that defines usability principles was developed by Nielsen and Molish (1990) to examine the design interfaces of applications and evaluate their usability [11]. This developed method; is widely used due to its low cost, low resource consumption, efficiency, and accurate results [12].

In the literature, there are many studies conducted with the heuristic evaluation method to determine how easily and efficiently the applications are used [13]. Gómez et al. (2013) examine how more than 250 mobile applications that can be used in emergencies are used, by reviewing their innovation possibilities, functional features, and usability. In addition to this analysis, the “Citizen Emergency Management” mobile application is proposed for the functional design [14]. Sarlan et al. (2016) tested a mobile application by developing in which 10 heuristics of Nielsen were integrated, so that eyewitnesses could send accident warnings and notifications to the emergency call center in case of a traffic accident. As a result of the usability test, it has been observed that the prototype of the application complies with the usability principles, is easy to use, and gives positive results for the users [9]. Repanovici & Nedelcu (2020) evaluated three methods that can be used to communicate with field experts in emergency situations by addressing Voice Calls, SMS, and mobile applications. In the evaluation process, a multi-criteria analysis method was used. As a result of the findings obtained, they stated that mobile applications are the most ideal solutions for communicating in an emergency situation. Furthermore, the current status, future potentials and obstacles of mobile applications used for emergency notifications have been discussed [15]. In the literature, studies are discerned on application titles that will convey the correct information to the emergency center [9,14-15]. However, in the studies, it was seen that the evaluations made by the experts were not made together with Nielsen's heuristic evaluation and usability evaluation scales.

In this study, the Panic Button application developed by Pronet company for mobile devices was evaluated by taking the opinions of experts with the heuristic evaluation method suggested by Nielsen and Molich (1990) [16-17]. Besides, the usability of the application was measured with the help of the System Usability Scale (SUS), which was developed by Brooke (1996) and adapted to Turkish by Çağıltay (2011) [18-19]. In the studies that exist in the literature, evaluation is made using only Nielsen's heuristics or SUS. On the other hand, in this study, Nielsen's heuristic evaluation method and SUS were used together and evaluated by experts and more consistent results were obtained. In addition, while studies on mobile applications developed for emergencies usually present prototypes, in this study, a commercially developed and in-use mobile application was evaluated. Obtained results and expert opinions were compiled and presented.

2. METHOD

This study, which aims to evaluate the availability of the Panic Button application developed for mobile devices, was carried out as an expert-based assessment using expert opinions from heuristic evaluation methods and a SUS from usability scales. Within the scope of the study, an unaccustomed hybrid evaluation method was introduced in the literature by combining the steps of mapping the site of the Panic Button application, Nielsen's heuristics and system usability scale and obtaining expert opinions. It was preferred in this study to obtain expert opinions that constitute the first part of the proposed system given that it saves time and can be obtained in such a short time.

It is known that there should be at least 3 participants in the heuristic assessment made with expert opinion and that 5 participants may be adequate to detect an average of 75% of the problems [20]. Respectively, field specialists have heuristic evaluation methods made. Then, quantitative data were inference by applying the SUS to the experts [19].

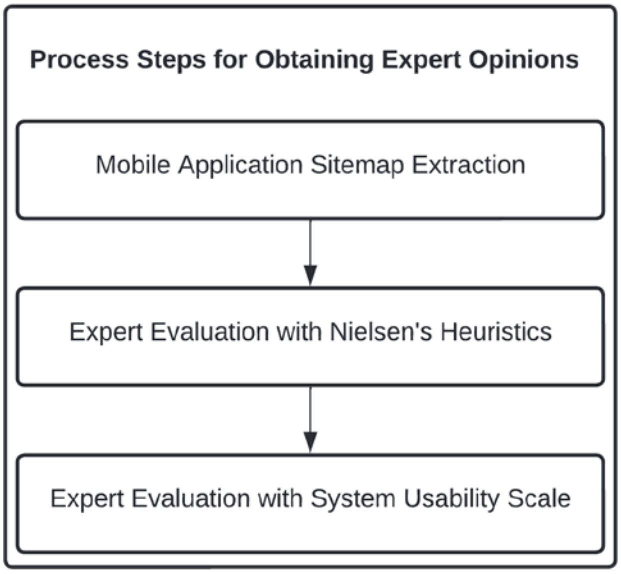

Figure 1. Process Steps for Obtaining Expert Opinions.

The process steps for obtaining expert opinions shown in Figure 1 are explained in detail in the following headings.

2.1. Mobile Application Site Map

The mobile application sitemap specified in Figure 2 is designed to provide a more comfortable view of the components/screens to be evaluated. Using Nielsen's Heuristics mentioned in Table 1, experts were able to evaluate the entire screens appropriately and thoroughly thanks to the prepared sitemap.

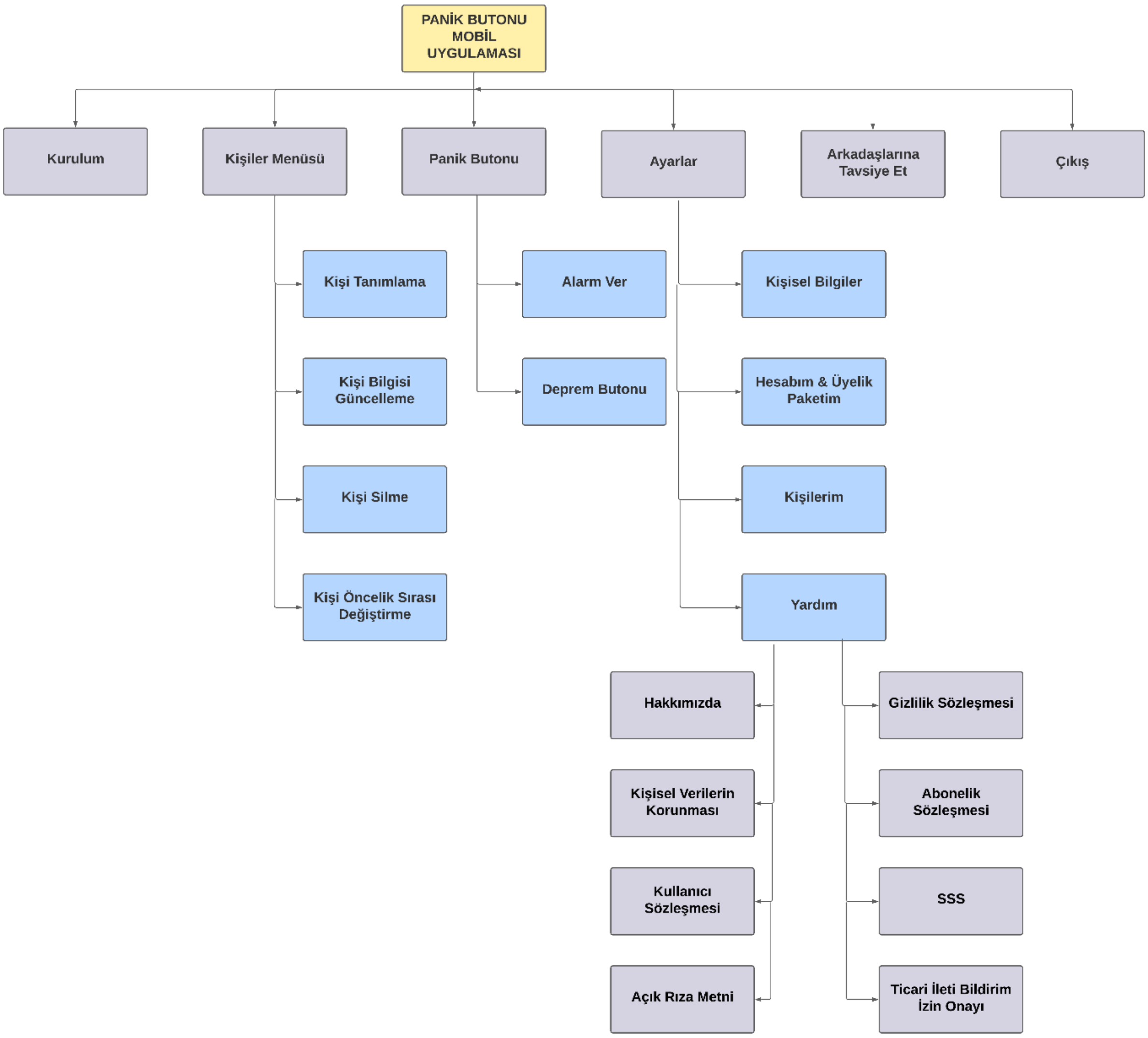

Figure 2. Mobile Application Site Map

2.2. Heuristic Evaluation and Expert Opinions

After the screens/components that should be mapped and evaluated were determined, the heuristic evaluation phase was established. During the heuristic evaluation phase, Nielsen's 10 heuristics, shown in Table 1, were used. It was reported by Nielsen (1994) that three or five specialists will be sufficient to assess the availability of a system [20].

Table 1. Nielsen's Heuristics [27]

Name of Heuristics
Visibility of system status
Matching between system and the real world
User control and freedom
Consistency and standards
Error prevention
Recognition rather than recall
Flexibility and efficiency of use
Aesthetic and minimalist design
Recognize, diagnose, and recover from errors
Help and documentation

- Visibility of system status: Evaluation of keeping users informed of what is happening uninterruptedly within a reasonable time using appropriate notifications.
- Matching between system and the real world: Evaluating the existence of concepts, words, and phrases that the last user can simply understand.
- User control and freedom: It is the reversal of unintentional actions or the evaluation of the control of the actions that can be conducted within the system.
- Consistency and standards: It is the assessment of the consistency of different situations, actions, or words within the system.
- Error prevention: It is the evaluation of preventing the occurrence of errors and providing a mechanism to approve actions, rather than the error messages that should be shown to the user.
- Recognition rather than recall: It is the evaluation of presenting all the options and information required for the relevant action, instead of waiting for users to remember an action on the application.
- Flexibility and efficiency of use: Evaluating that novice users experience as comfortable and efficient as expert users.
- Aesthetic and minimalist design: It is the evaluation of being visually beautiful and free from unnecessary details.
- Recognize, diagnose, and recover from errors: Evaluating that the errors that occur are clearly expressed in plain language.
- Help and documentation: Evaluation of user guidance when it is necessary.

2.3 System Usability Scale and Its Application to Experts

The System Usability Scale (SUS) is used to evaluate the usability of different types of products, such as websites, software, or hardware [19,23-26]. SUS, which is a 5-point Likert type scale, consists of 10 items. In SUS, each question scales from 1 (strongly disagree) to 5 (strongly agree). The SUS score, which is calculated with the formula shown in equation 1, is subtracted from 1 for odd-numbered items, and 5 for even-numbered items. Then, the sum of the items is multiplied by 2.5 to get a total score.

In this way, it makes it easier for inexperienced people to understand the (SUS) scores scaled between 0 and 100 [25]. Brooke (1996) showed that high scores obtained as a result of the implementation of the SUS have positive effects on system usability. SUS scores can be thought of as a 100-point rating scale used in academic evaluations. For example, the 90–100 range in SUS is mapped to the A grade, and the 80–89 range to the B grade [24,26].

$$SUS = \left(\sum_{\substack{\mathrm{i}=1 \\ i \bmod 2=1}}^{10} (si - 1) + \sum_{\substack{\mathrm{i}=1 \\ i \bmod 2=0}}^{10} (5 - si) \right) * 2.5 \qquad (1)$$

In practice, 7 experts have been provided to evaluate by using the SUS. The scoring of the importance levels of the heuristics stated in Table 2 has been made out on the 5-point Likert scale. By emphasizing the degree of importance in the scoring, it has ensured that the heuristics that needed to be solved first have been determined. The site map in Figure-2 has been shared with experts so that the menus of the heuristics where the problems are identified can be easily seen. In Table 3, the evaluation of the system usability scale has been made over 100 points, and the SUS score is obtained. In line with the results obtained as a result of the scoring of the seven experts, the heuristics that the experts had different opinions have been examined.

3. RESULTS

In the study conducted by Brooke (1996), it was stated that when an evaluation is made with 5 experts, it would reach 75% of usability problems. In this study, the heuristic assessment and the SUS were applied to a group of 7 experts consisting of 6 men and 1 woman, aged between 25 and 45. The computer skills of the experts are at an ultimate level and their field knowledge experiences appear in the academic and private sectors. Experts made their examinations on mobile devices running the Android operating system.

3.1. Heuristic Evaluation Results

Findings obtained by taking expert opinions are summarized by considering Nielsen's heuristic titles in Table 1 [11].

Visibility of system status: Stated by experts that the visibility of the system status is sufficient, there is no delay on the screens, and sufficient information is provided to the user.

Matching between system and the real world: In general, experts claim that "*The language used in the application is simple and clear, the symbols used are associated with actions, the language for the last user is simple and understandable, and the system is related to the real world."* An expert stated that a technical error message was given on the error screen, unlike the error codes that were meaningful to software developers it was not purposeful to the last user.

User control and freedom: For user control, all experts gave negative feedback. All experts, *"It can not be entered on the settings page with the back button. A button to revert this status when the alarm button is accidentally pressed, etc. is not available. But if the earthquake button is pressed again, the button becomes passive or while you can exit the share location menu with a cross, this is not available in other menus."* stated their negative judgments. Another expert on this situation, *"A notification of accidental pressing may be received from the user within 30 seconds."* By offering a solution proposal in the form of a solution, the user was informed about the possibilities to be provided for control and independence.

Consistency and standards: On consistency and standards, experts gave different opinions. It was observed that three experts found the rules appropriate. On the other hand, it is seen that giving access to the same page from more than one screen is shown as an inconsistency. All experts also stated that the correct symbols are used in terms of the standard.

Error prevention: An expert states that error prevention mechanisms should be checked as*"Despite the registration by requesting subscription information during registration to the system, requesting confirmation from the user again after registration creates a problem in terms of error prevention"* Another expert stated that the "*User ID can not be 0*" message received after entering the TR ID number on the subscription information screen is a technical error and that this error should be prevented.

Recognition rather than recall: There is a dominant opinion that expressions that require sufficient recognition but are not recalled are used in the mobile application. However; *"The information about application usage in the help menu is not sufficient." opinion stated by 3 experts.*

Flexibility and efficiency of use: Six experts stated that the application was sufficient in terms of flexibility. Besides an expert is to provide flexibility to the last user in a better way, menu etc. stated that it would be beneficial for the screens to be customizable.

Aesthetic and minimalist design: As the design and content are compatible, it has been stated by the experts that the application looks aesthetically pleasing. It has been stated that conspicuous components such as the "Panic Button" are positioned correctly, and similar screens or tools can be enriched.

Recognize, diagnose, and recover from errors: The general opinion of the experts on error recognition is positive. However, it has been stated that the error with the message "User ID cannot be 0" after entering the TR ID number does not give the user sufficient information about the diagnosis.

Help and documentation: It was criticized negatively by all experts. It was stated that the content of the help menu is complex and needs improvement. It was stated that it would be beneficial to enrich the content of the frequently asked questions menu.

Table 2. Obtaining expert opinions – Scoring the importance of heuristics

Expert Number Heuristic Assessment Headline	E1	E2	E3	E4	E5	E6	E7	IMPORTANCE SCORE
Q1-Visibility of system status	5	5	3	3	4	3	5	4,00
Q2-Matching between system and the real world	5	4	5	5	5	5	5	4,86
Q3-User control and freedom	1	4	5	5	5	5	1	3,71
Q4-Consistency and standards	5	3	5	5	5	4	2	4,14
Q5-Error prevention	4	4	1	5	1	1	2	2,57
Q6-Recognition rather than recall	5	5	4	4	4	3	5	4,29
Q7-Flexibility and efficiency of use	5	4	2	2	3	2	5	3,29
Q8-Aesthetic and minimalist design	5	5	5	5	5	5	4	4,86
Q9-Recognize, diagnose, and recover from errors	4	5	4	4	4	4	3	4,00
Q10-Help and documentation	3	4	4	4	4	4	3	3,71

In the evaluations of the experts, the error prevention heuristic should be resolved in the first place with 2.57 points. 3 out of 5 experts reported that screen designs should be enriched to prevent the user from making mistakes. This is the first issue that software developers should review from the point of view of the “Error Prevention” heuristic. Help and documentation, user control and independence heuristics both scored 3.71, with negative feedback from all experts. It has been stated that the "Frequently Asked Questions" section shown on the site map has been criticized by experts and should be improved. It was seen that the average score of 3.94 (78.8 out of 100) obtained from the evaluations of the Panic Button application was sufficient [24].

3.2. System Usability Scale Results

Table 3 shows the distribution of the scores given by the 7 experts who evaluated the application to the 10 questions in the system usable scale.

Table 3. Expert Evaluations with System Usability Scale

Expert Number	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	SUS SCORE
E1	4	2	5	1	3	2	4	2	5	2	80
E2	3	1	4	2	5	3	4	1	3	5	67,5
E3	4	2	4	1	4	2	4	2	5	1	82,5
E4	3	1	5	1	4	1	5	1	4	1	90
E5	4	2	4	2	4	1	3	1	5	1	82,5
E6	4	2	4	1	4	1	4	1	5	1	87,5
E7	2	1	5	1	4	1	5	1	1	1	80

As can be seen in Table 3, the highest SUS score obtained is 90, and the lowest SUS score is 67.5. A score of 82.5 appears like the peak value (mode) given by more than one expert. Overall, the average score of the evaluation by 7 experts is 81.16. This average score was found in the Bangor et al. (2008) scale that corresponds to the "B" grade. An average score of 81.16 from expert reviews indicates that users can have a good usability experience. According to Sauro(2011), another evaluation study, it states that 68 points are an average score in the SUS evaluation. When the app's 81.16 scores are compared with Sauro (2011)'s average score, it shows that the usability level of the Panic Button application is well developed [25, 26]. While it is seen that the scores given to the experts in all heuristic evaluations between Q1 and Q8 are close to each other, the scores given to the 9th and 10th questions of the scale difference between the two experts, even though the scores given by E2 and E7 do not pose a problem in terms of the SUS score.

It was seen that the scores given by the experts to all questions in the heuristic evaluation were close to each other. This supports the fact that experts have a similar view on the usability of the application.

4. CONCLUSION AND DISCUSSION

It is recommended by experts to improve the application by making the necessary updates regarding the negative situations in heuristic evaluations. In the future, continuous improvement of the mobile-based interface can improve the user experience. Moreover, it is predicted that the use of different mobile operating systems (Android, iOS, etc.) in the evaluation phase of mobile usability may contribute to the solution of more problems. In the literature, usability evaluation is made using either Nielsen's heuristics or SUS, but in this study, both methods were used hybridity together and evaluated by experts and more consistent results were obtained.

Our experts, emphasizing the importance of time for emergency notifications given within the scope of the study, also stated that the user needs quick access with a few clicks. In this context, as a result of our research, it is recommended to consider the following items in the development and evaluation of emergency mobile applications.

- Using Widget in Emergency Applications
- Application Responding in a Certain Time
- Reporting the Location Information Accurately and Swiftly to the Other Party

Nielsen heuristics are used extensively throughout the topics where usability evaluation is made [11], but they cannot fully satisfy the special needs of software types that require special work (mobile device applications). In the usability evaluation of software types that require special work such as mobile device applications, heuristic development studies specific to usability problems are carried out in very few studies [7,25-26]. With the increase of these studies, the usability problems that need to be evaluated within the software serving special subjects will swell. In this case, it reveals the need that new heuristic evaluation methods can also be developed.

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Research Article

UPSCALING RESULTS FROM OPTIMUM SALINITY WATERFLOODING AT THE CORE SCALE TO A 3D DYNAMIC GRID

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UPSCALING RESULTS FROM OPTIMUM SALINITY WATERFLOODING AT THE CORE SCALE TO A 3D DYNAMIC GRID

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ABSTRACT: In order to fully quantify the volumes in place, capture the dynamics of fluid flow, production forecast and consequently economic potentials of oil and gas reservoirs, 3-dimensional (3D) models filled with relevant rock, fluid parameters and well information are built. This work carried out Optimum Salinity core flooding (OPTSWF) with progressive dilution of the invading brine at the laboratory scale. Next, the relative permeability curves for oil and water for the initial and final salinity conditions were obtained using Corey's estimation. These curves were then loaded into a 3D dynamic model and the model was run under different salinity conditions to quantify the incremental oil recovery from Optimum Salinity Waterflooding and to visualize the process in 2D. Interestingly, the impact of optimizing the salinity was visibly seen in the 3D grid results and helped to visually explain the observed additional recovery from the OPSWF experiment.

Keywords: Core Flooding, Optimum Salinity Water Flooding, 3D Reservoir Model, Low Salinity Waterflooding, Corey, Improved Oil Recovery

1. INTRODUCTION

Ensuring energy security for the future generations is a critical topic in the continuously growing world as the global population continuously grows. According to [1], the petroleum reserves in the Niger Delta has peaked due to limited or highly reduced exploration activities which is occasioned by multiple factors which are not limited to; low oil price, global Covid-19 pandemic, political instability, and uncertainty surrounding the passage of the Petroleum Industry Bill, PIB. An interesting scheme which has recently gained steam in literature is the low salinity water flooding which [1] refers to as OPTSWF. The OPTSWF which entails the injection of diluted brine with significantly lower salinity than the connate water, has resulted in reduction in residual oil saturation and consequently increase in recoveries from multiple experiments from different authors around the world [2], [3].

To capture the potentials from OPSWF, several authors have carried out laboratory studies using progressively diluted brines to flood cores saturated with crude oil [3]. The tests usually monitor the recovered oil, brine and pressure drop across the core with time during the experiment. To assess the potential gains of the OPTSWF scheme in an oilfield, a sector model from the field is built and then, the results from the tests are integrated into the model and then the results are quantitatively assessed.

2.THEORETICAL ANALYSIS

The relative permeability which is a measure of the relative ease with which a fluid moves in a porous medium in the presence of another fluid and is a composite function which is affected by several rock parameters including pore throat geometry, capillary pressure, burial and saturation history, rock and fluid composition etc. [4], [5]. [6]. Corey proposed a method for the determination of relative permeability by making use of fixed oil and water end points, exponents, residual oil and connate water saturation [7].

$$k_{rw} = \left[\frac{S_w - S_{wi}}{1 - S_{wi} - S_{or}}\right]^{nw} \tag{1}$$

$$k_{ro} = \left[\frac{S_o - S_{wi}}{1 - S_{wi} - S_{or}}\right]^{no} \tag{2}$$

By keeping all other parameters constant and changing the residual oil saturations from the pre-OPTSWF to the post-OPTSWF core flood results, relative permeability curves for different salinity levels can be derived. These curves can then be entered into a simulator to model the reservoir performance for comparison over a given duration. The key upscaling method used from laboratory to the field sector scale is the relative permeability curves which is derived from the core flooding experiment. The relative permeability curve is a composite rock-fluid property and is a function of interfacial tension, wettability, capillary pressure, pore size structure, mineralogy, salinity [1]. It is this composite property which is used to upscale the results from the core scale to the field scale. It is important to point out that fluid and rock properties are the same both at the core and field scale. However, at the field scale, there may be a higher level of heterogeneity in the rock properties. To manage the heterogeneity at the field scale, the reservoir is divided into flow units or rock types and for each rock type or flow unit, a corresponding core plug is obtained, and the experiments are run on such core plugs and then transferred to the field model.

3.MATERIALS AND METHODS

The input data for this study was sourced from [8], these are presented in Table 1 - Table 3 and Figure 1 - Figure 2.

Table 1. Core Plug Properties

Experiment Number	Core Length	Diameter	PV	PHI	Swi	SorHS	SorLS
EXPERIMENT 7	2.50	3.80	5.80	20%	12%	38%	16%

Table 1. Oil-Water Relative Permeability Tables for High Salinity and Low Salinity Core Flooding

HS				
Sw	**SWC**	**SOC**	**KRW_HS**	**KRO_HS**
12.07%	0.00%	100.00%	0.00	0.85
14.57%	5.00%	95.00%	0.00	0.75
17.07%	10.00%	90.00%	0.00	0.65
19.57%	15.00%	85.00%	0.00	0.57
22.07%	20.00%	80.00%	0.00	0.49
24.57%	25.00%	75.00%	0.01	0.41
27.07%	30.00%	70.00%	0.01	0.35
29.57%	35.00%	65.00%	0.02	0.29
32.07%	40.00%	60.00%	0.03	0.24
34.57%	45.00%	55.00%	0.04	0.19
37.07%	50.00%	50.00%	0.05	0.15
39.57%	55.00%	45.00%	0.07	0.12
42.07%	60.00%	40.00%	0.09	0.09
44.57%	65.00%	35.00%	0.11	0.06
47.07%	70.00%	30.00%	0.14	0.04
49.57%	75.00%	25.00%	0.17	0.03
52.07%	80.00%	20.00%	0.20	0.02
54.06%	85.00%	15.00%	0.25	0.01
57.07%	90.00%	10.00%	0.29	0.00
59.57%	95.00%	5.00%	0.34	0.00
62.07%	100.00%	0.00%	0.40	0.00

LS				
Sw	**SWC**	**SOC**	**KRW_HS**	**KRO_HS**
12.07%	0.00%	100.00%	0.00	0.85
14.57%	3.45%	96.55%	0.00	0.78
17.07%	6.91%	93.09%	0.00	0.71
19.57%	10.36%	89.64%	0.00	0.65
22.07%	13.81%	86.19%	0.00	0.59
24.57%	17.26%	82.74%	0.00	0.53
27.07%	20.72%	79.28%	0.00	0.48
29.57%	24.17%	75.83%	0.01	0.43
32.07%	27.62%	72.38%	0.01	0.38
34.57%	31.07%	68.93%	0.01	0.34
37.07%	34.53%	65.47%	0.02	0.29
39.57%	37.98%	62.02%	0.02	0.26
42.07%	41.43%	58.57%	0.03	0.22
44.57%	44.88%	55.12%	0.04	0.19
47.07%	48.34%	51.66%	0.05	0.16
49.57%	51.79%	48.21%	0.06	0.14
52.07%	55.24%	44.76%	0.07	0.11
54.06%	58.69%	41.31%	0.08	0.09
57.07%	62.15%	37.85%	0.10	0.07
59.57%	65.60%	34.40%	0.11	0.06
62.07%	69.05%	30.95%	0.13	0.05
64.57%	72.50%	27.50%	0.15	0.03
67.07%	75.96%	24.04%	0.18	0.02
69.57%	79.41%	20.59%	0.20	0.02
72.07%	82.86%	17.14%	0.23	0.01
74.57%	86.31%	13.69%	0.26	0.01
77.07%	89.77%	10.23%	0.29	0.00
79.57%	93.22%	6.78%	0.32	0.00
82.07%	96.67%	3.33%	0.36	0.00
84.40%	99.89%	0.11%	0.40	0.00

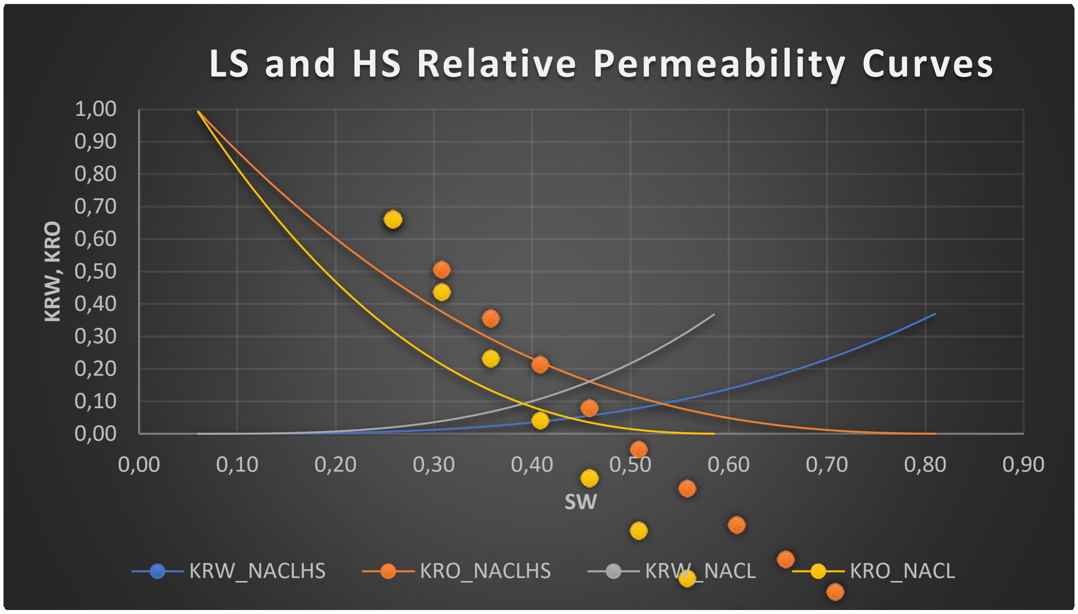

Figure 1. Oil-Water Relative Permeability Curves for HS and LS Core Flooding

3.1. Synthetic Grid

A synthetic cartesian grid was also built using a black oil simulator. The grid properties are summarized in Figure 2 and Table 3. A homogenous grid with uniform properties has been selected for this study as enumerated in Table 3. This assumption can be validated in upper shoreface depositional environment reservoirs where bulky sands with generally uniform properties are dominant.

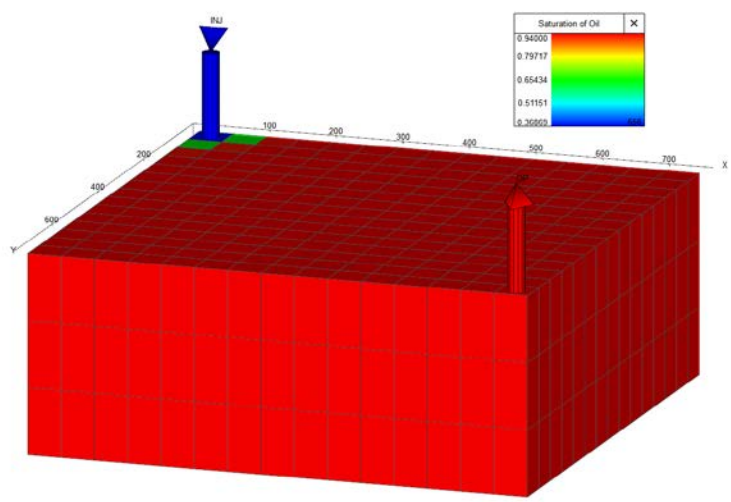

Figure 2. Synthetic Grid Used for Study

Table 2. Properties of Synthetic Cartesian Grid

Property	Value
Dimensions (X*Y*Z)	15*15*3
STOIIP, mmSTB	67
Porosity, %	27
PermX=PermY, md	1000
PermZ, md	100
Oil Producer(s)	1
Water Injectors(s)	1
Oil Production Rate, stb/d	12,580
Water Injection Rate, sbt/d	12,580
Simulation Start Date (dd.mm.yyyy)	01.01.1990
Simulation End Date (dd.mm.yyyy)	31.12.2015
Oil Water Contact, ftss	2700
Pay Thickness, ft	25
Oil FVF, rb/stb	1.2
Oil Viscosity, cp	0.47

3.2. Cases Considered

The following cases were simulated and using the synthetic grid.

i. Secondary Mode: HS Flooding (10,000 ppm NACL)
ii. Secondary Mode: HS Flooding (5,000 ppm NACL)
iii. Secondary Mode: HS Flooding (2,500 ppm NACL)
iv. Secondary Mode: HS Flooding (1,250 ppm NACL)
v. Secondary Mode: HS Flooding (625 ppm NACL)

Secondary water injection with 10,000 ppm NACL is the base case. This is the conventional water injection mode. In this base case mode, the initially oil saturated cartesian grid shown in Figure 2 was flooded with HS brine (10,000 ppm). For the subsequent cases, the salinity of the invading brine is reduced by half.

4. RESULTS AND DISCUSSION

The results for all cases considered are presented in Figure 3 to Figure 16. It is to be noted that as the salinity of the brine is reduced, additional oil is mobilized as seen from the relative permeability curves in Figure 1. This additional oil recovered is obtained because of a reduction in the residual oil saturation from the higher salinity flood. [3] Pointed out that as the salinity of the invading brine is reduced below that of the connate brine, an initial equilibrium which exists between the crude-brine-rock is destabilized, and this leads to the mobilization of some residual oil.

Key Findings

1. The comparative performance plot shown in Figure 15 reveals that the plateau life and cumulative oil is improved as the salinity of the flooding brine is reduced. This is very interesting to note as many brown fields can potentially benefit from this scheme.
2. Also, the saturation profile shown in Figure 16 depicts the improved sweep efficiency as the salinity is reduced. The flood front moves slower through the model and the hydrocarbon saturation behind the flood is observed to be lower with reducing water salinity.
3. Optimum salinity water flooding can be employed in the secondary mode to brown fields right from the onset of development to enhance the additional recoveries producible from the field.

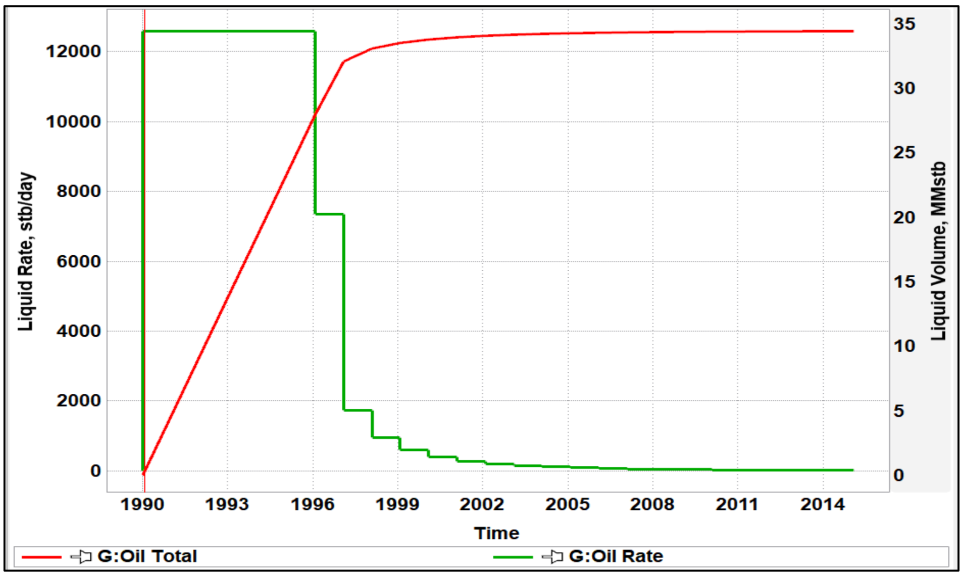

Figure 3. Production Performance - Secondary Mode: HS Flooding (10,000 ppm NACL)

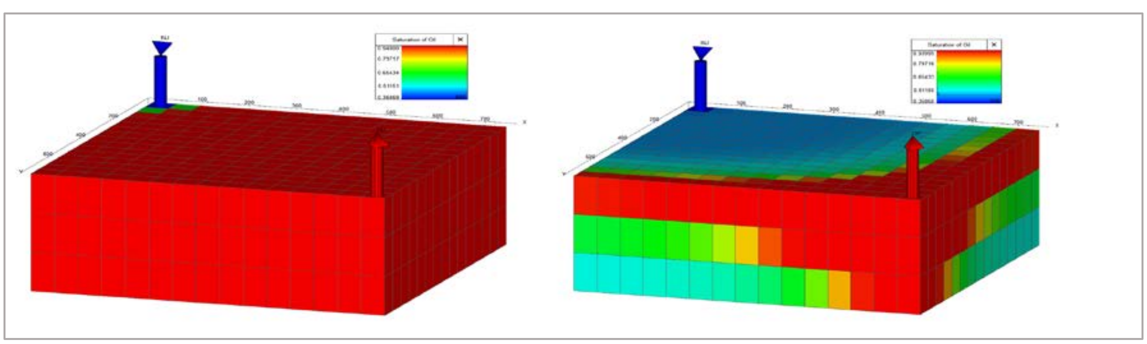

Figure 4. Pre (left) and Postproduction (Right) Saturation Distribution - Secondary Mode: HS Flooding (10,000 ppm NACL)

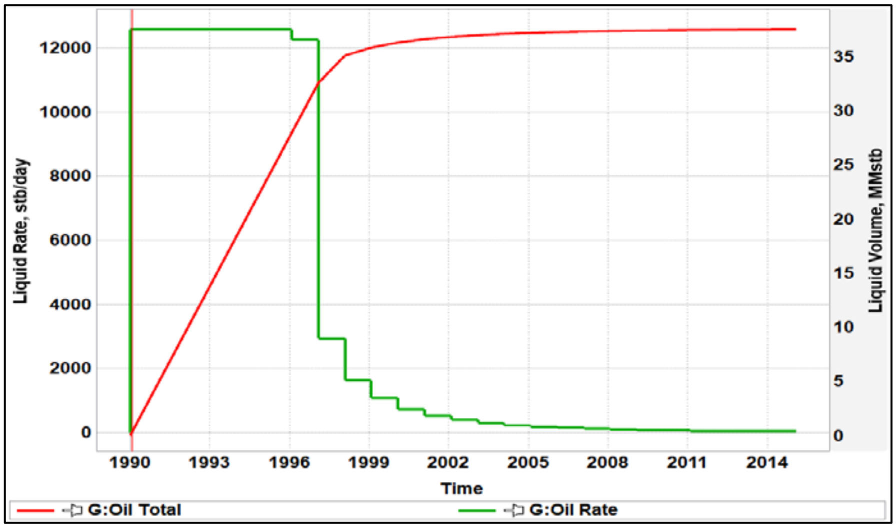

Figure 5. Production Performance - Secondary Mode: HS Flooding (5,000 ppm NACL)

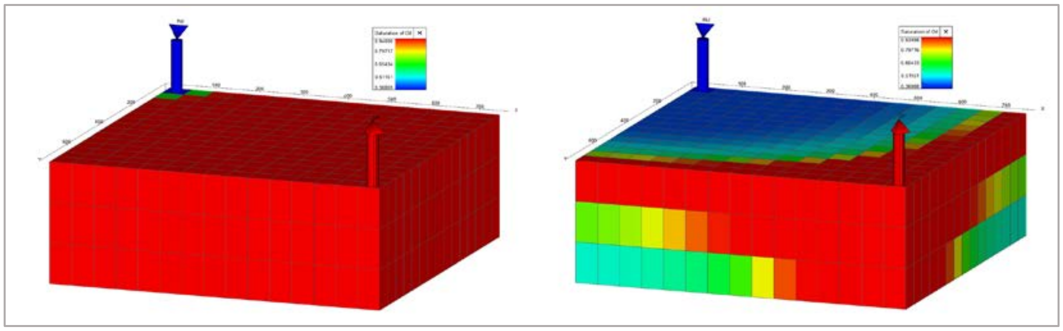

Figure 6. Pre (left) and Postproduction (Right) Saturation Distribution - Secondary Mode: HS Flooding (5,000 ppm NACL)

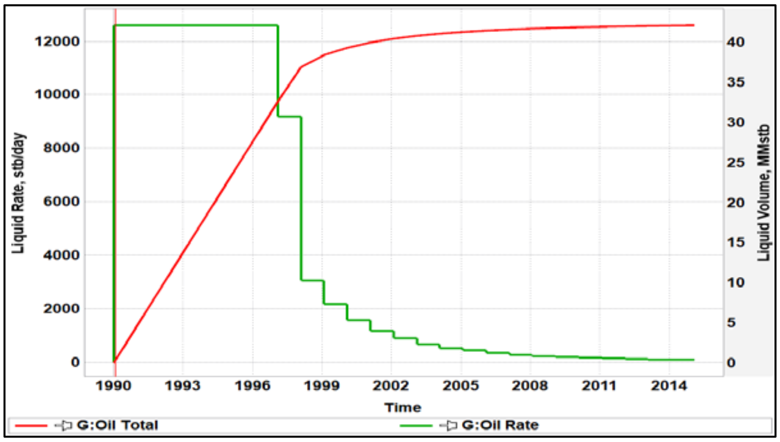

Figure 7. Production Performance - Secondary Mode: HS Flooding (2,500 ppm NACL)

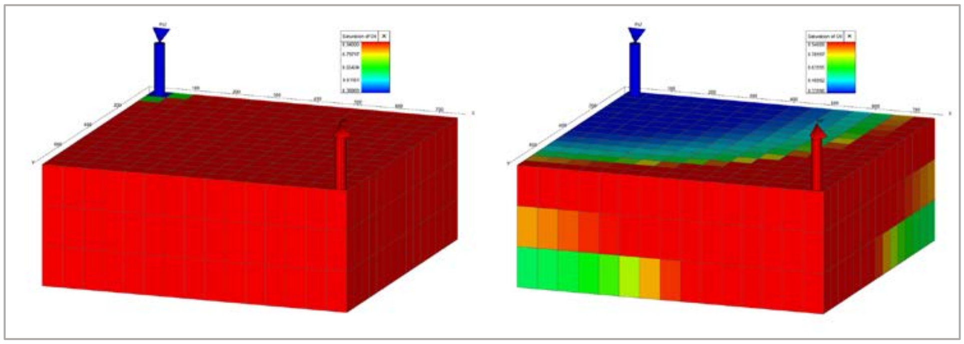

Figure 8. Pre (left) and Postproduction (Right) Saturation Distribution - Secondary Mode: HS Flooding (2,500 ppm NACL)

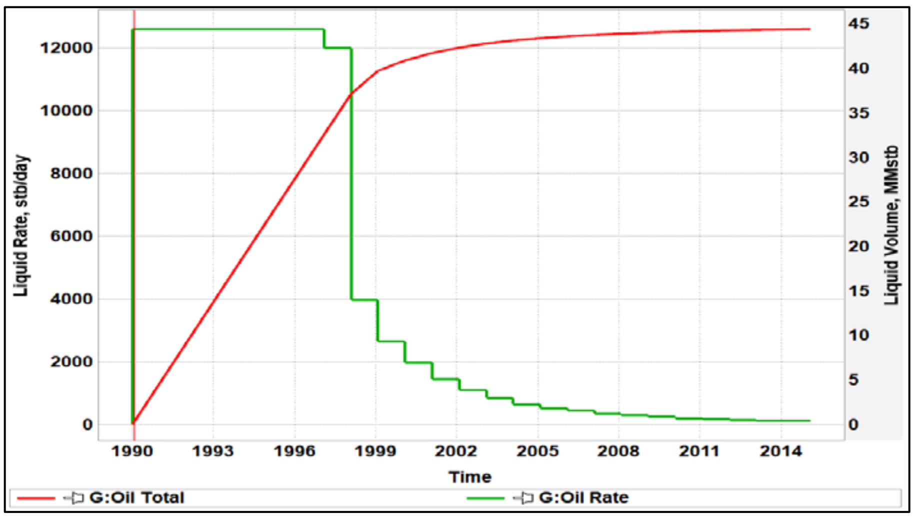

Figure 9. Production Performance - Secondary Mode: HS Flooding (1,250 ppm NACL)

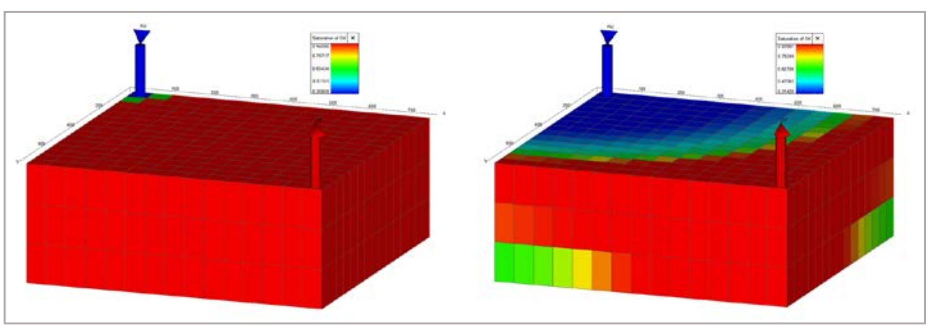

Figure 10. Pre (left) and Postproduction (Right) Saturation Distribution - Secondary Mode: HS Flooding (1,250 ppm NACL)

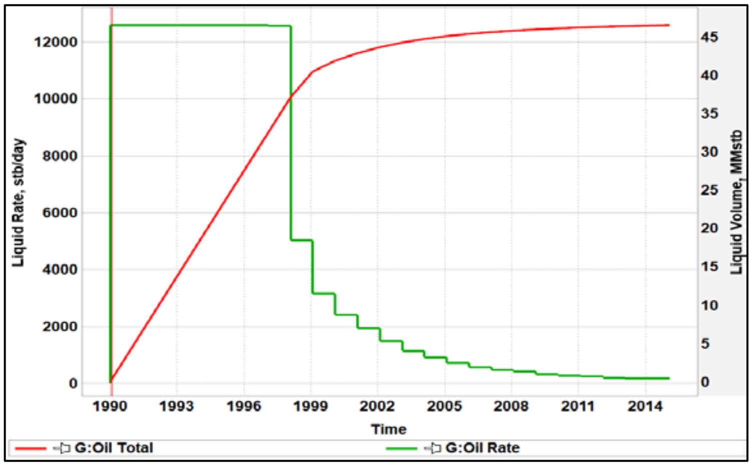

Figure 11. Production Performance - Secondary Mode: HS Flooding (625 ppm NACL)

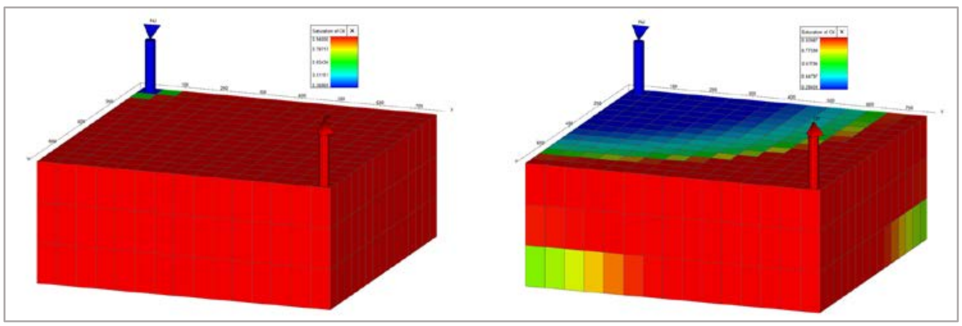

Figure 12. Pre (left) and Postproduction (Right) Saturation Distribution - Secondary Mode: HS Flooding (625 ppm NACL)

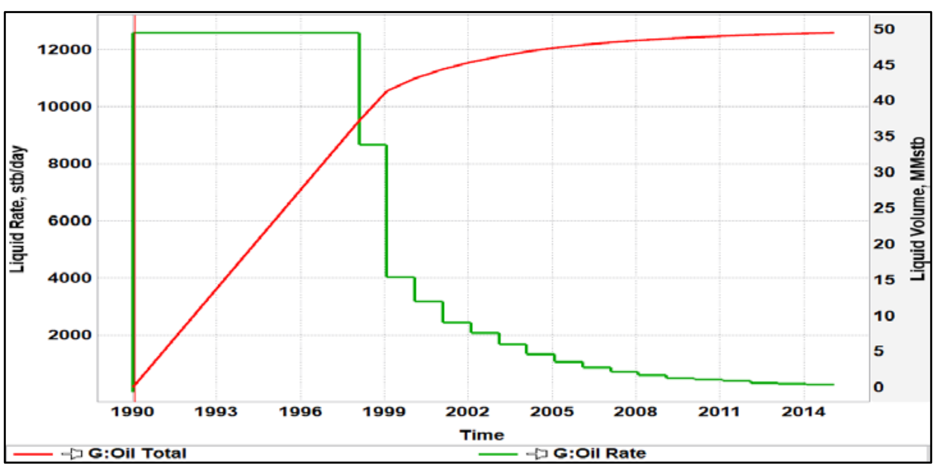

Figure 13. Production Performance - Secondary Mode: HS Flooding (0 ppm NACL)

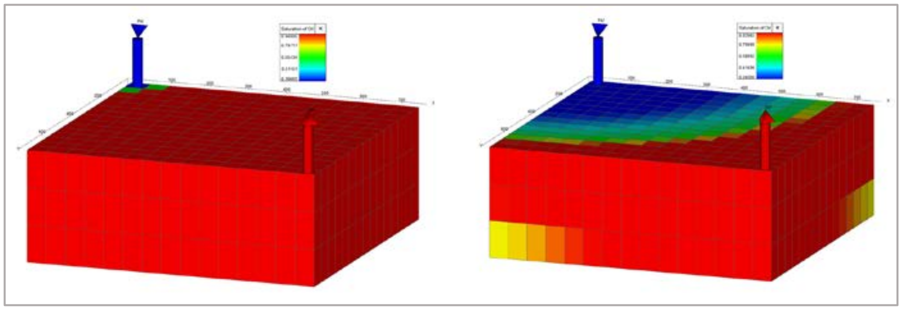

Figure 14. Pre (left) and Postproduction (Right) Saturation Distribution - Secondary Mode: HS Flooding (0 ppm NACL)

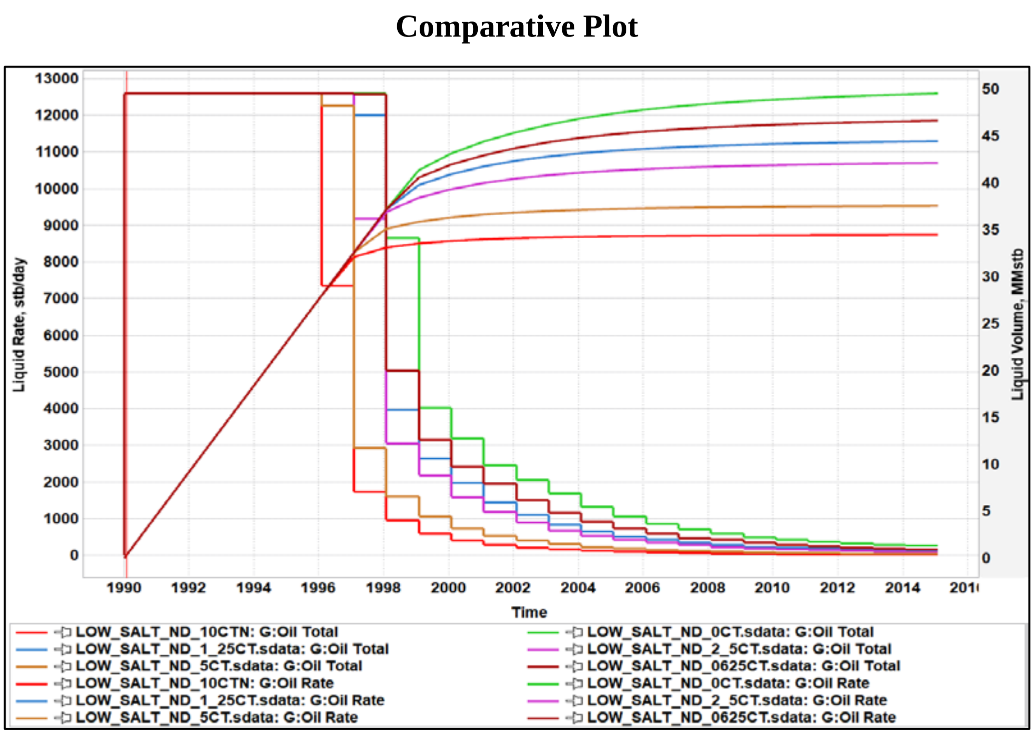

Figure 15. Production Performance - Secondary Mode: HS Flooding (All Cases)

5. CONCLUSION

This work has integrated the results from core flooding experiments with a synthetic 3D grid to visualize and quantify the performance of progressively reducing salinity waterflooding employed in the secondary mode.

I. Additional oil recoveries ranging from 3 mmstb to ~9mmstb were produced in the 5000 ppm and 0 ppm flooding mode compared to the 10,000-ppm secondary flooding mode Figure 15.

II. Also, the water breakthrough time is increased due to the improved sweep efficiency, thus resulting in increased well and field life. The field life is enhanced by an additional 1-2 years Figure 15.

III. Again, the result from this work also enables the visualization of the movement of the flood front and the sweep efficiency Figure 16. This implies that the microscopic sweep efficiency is enhanced as the residual oil saturation to water is further reduced.

Additional areas which can be explored for further studies include.

a) Exploring the performance of low salinity waterflooding in the tertiary mode to demonstrate potential application to brown fields
b) Carry out detailed economic analysis to sense check the cost/benefit analysis from implementing the low salinity water flooding scheme in a typical offshore environment. This will give a sense of required additional unit operating costs and CAPEX, breakeven crude oil price, NPV, IRR, pay back time and other economic indicators.

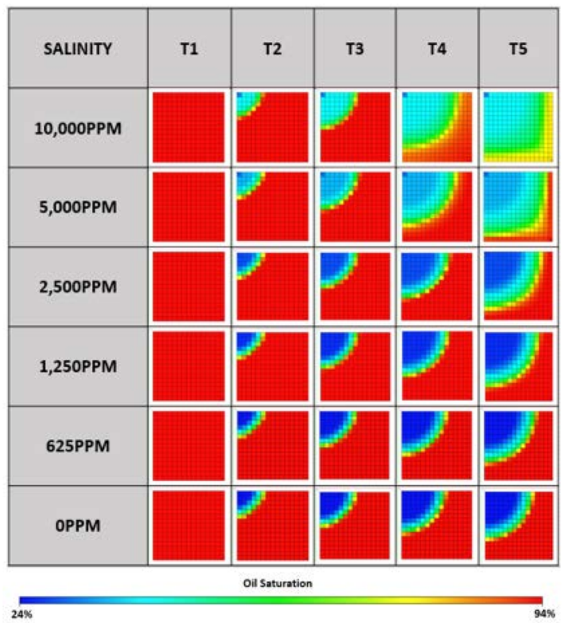

Figure 16. Pre (left) and Postproduction (Right) Saturation Distribution - Secondary Mode: All Cases

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Nomenclature

2D:	Two Dimensional
3D:	Three Dimensional
CAPEX:	Capital Expenditure
HS:	High Salinity
HSWF:	High Salinity Waterflooding
IRR:	Internal Rate of Return
Kro:	Relative Permeability to Oil
Krw:	Relative Permeability to Water
LS:	Low Salinity

LSWF:	Low Salinity Waterflooding
No:	Oil Corey Exponent
NPV:	Net Present Value
Nw:	Water Corey Exponent
OPEX:	Operational Expenditure
OPSWF:	Optimum Salinity Waterflooding
PHI:	Effective Porosity
PV:	Pore Volume
Soc:	Normalized Corey Oil Saturation
Sorw:	Residual Oil Saturation
Sorw_HS:	Residual Oil Saturation under High Salinity
Sorw_LS:	Residual Oil Saturation under Low Salinity
Swc:	Normalized Corey Water Saturation
Swi:	Connate Water Saturation
mmSTB:	Million Stock Tank Barrels
STOIIP:	Stock Tank Original Oil in Place

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Research Article

NEW EXPANSIONS IN THE ECONOMIC PRODUCTION QUANTITY MODEL CONTAINING DEFECTIVE PRODUCTS

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NEW EXPANSIONS IN THE ECONOMIC PRODUCTION QUANTITY MODEL CONTAINING DEFECTIVE PRODUCTS

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ABSTRACT: The basic assumption in classical production quantity models is that all of the products produced are free of defect. But in real life, this assumption is not always valid. EPQ models were examined for the situation where the proportion of defective products is a random variable and fits a certain probability distribution. When the literature reviewed, it is seen that the scanning speed of defective products is accepted as equal to the production rate. In this study, a model was developed under the condition that the scanning speed is smaller than the production rate. In addition, a sample problem solution was made with the assumption that the defective product ratio is random variable and corresponds to the normal distribution and uniform distribution.

Keywords: EPQ, Defective product, Scan rate

1. INTRODUCTION

Inventory models have been developed to meet the ever-evolving challenges of real-world applications. The economic production quantity model is the most common model that is used to find the optimum production quantity for each cycle, taking into account the production, preparation, inventory and stock-free costs in general [1]. Traditional economic order/production quantity (EOQ/EPQ) models assume that all products are excellent. However, in case that defective products are often present in manufacturing processes, free of defect manufacturing cannot accurately reflect real-life problems. Forwhy in any production system, the defect caused by the different difficulties that arise in the production process is a natural phenomenon. Part of the manufactured goods is defective for many reasons, such as malfunctions of the facilities, worker errors and poor-quality material. Therefore, detecting defective products is one of the most important problems faced by production units. As a natural consequence of the assumption that defective products can be produced in a production process, the necessity of inspection, scanning, control, etc. concepts in production systems have emerged. Defective items may also be sold at the same starting price after rework in case that they can be repaired. Repairable items need to be reworked, and they are usually kept in a warehouse until the time of their reworking process. The reworking process can take place after the normal production process or when the inventory of excellent products drops to zero. Due to the difference between the maintenance costs of defective and free of defect products, the time it takes to start the reworking process is crucial given the impact of the inventory system on the total cost. Customer satisfaction and retention of defective products, as well as the costs associated with the return of defective products and after-sales services, need to be considered. However, this activity should be optimally organized, because there is a cost sanction on top of the screening and reworking costs of a defective product, and that is the cost of reputational damage or punishment. [2].

This study will help managers to choose the best policy for the economic production quantity-reprocessing process based on production system conditions.

2. LITERATURE REVIEW

The first studies involving the rework of defective products [3] include the study in which the system produces excellent products up to a certain point and comes out of control and started to produce defective products until the end of production. It is assumed that the period that has passed until the end of system getting out of control fits the exponential distribution and no pre-purchase is allowed. In this study, time needed to perfect the defective products by reworking has not been taken into consideration. (they are considered zero) [3-4]. Salameh and Jaber discuss a realistic situation where defective products are identified through a scanning process and sold with discount after the cycle. That is why model presented by Salameh and Jaber attracted attention in literature since its wide applicability on scanning and quality control in model inventory systems [5]. Hayek and Salameh developed an economic production quantity model for situations in which defective product rate fits to uniform distribution. It is assumed that defective products are reworked with a fixed rate when production stops. Not having stock is allowed in the model [6]. Chiu et. al. deal with defining an optimum working time for economic production quantity (EPQ) model with scrap, rework and stochastic machine malfunctions in this article. It formulates production-stock cost statements, machine malfunction scenarios and scenarios in which no malfunction occurs. They combine two functions and find the optimum cycle duration [7]. Eroğlu and Özdemir developed Salameh and Jaber model for conditions allowing not having stock [8]. Eroğlu et alia developed an economic production model for condition when a fixed measurable feature of the products is present in normal distribution and defective products are grouped as repairable, low quality and scrap in their study [1]. Maddah and Jaber worked over the model of Salameh and Jaber and calculated optimum expected annual profit using Renewal Reward Theory (RRT) [9]. Khan et al. expanded the model of Salameh and Jaber to involve the condition where defective products are sold or changed. They take Type 1 and Type 1 malfunctions deriving from misgrading of units during scanning [10]. Wee et al., worked on EPQ models for defective products allowing scanning rate to be slower than or equal to production speed [11]. Haydar et al. designed a scanning process carried out in production process, during production and end of production in their model. Defective products produced are grouped as discounted sale and rework. In each condition demand during production are provided solely from flawless products. This means that system scans products while selling. Thus, scanning rate is the same as demand rate before the end of production. After the production ends, a scanning process will begin for all remaining products [12]. Kumar et al. expands traditional EPQ model with a defective product inventory that has a demand rate depending on advertisement. In this model, production speed is considered as a decision variable. This article also handles the issue of sale of defective products after 100% elimination process with discount in single batch. Scanning speed is considered different than production speed and changed proportionally to production speed [13]. Al-Salamah used an EPQ model that has defective quality and random machine malfunction depending on heuristic artificial bee colony and put optimal batch size by calculating multivariate expected average cost function [14].

Most of the production quantity models that have defective production a rework processes reviewed in literature ignore scanning effect. A study adopting the approach in which scanning speed is equal to or slower than production speed and higher than demand rate has been found [11]. Additionally, defective product production rate is considered as a function of production speed.

A gap in literature has been identified regarding to the review of the relationship between scanning rate and production rate.

3. MATHEMATICAL MODEL

Inventory models involving defective products attracted great attention in literature. Most of the existing studies ignored the relationship between scanning speed and production speed within production cycle and considered speed as equal. Products are produced in single line and a specific amount of these products are defective. Defective product rate is a random variable and considered as suitable to a specific probability distribution. Repairable products are repaired through rework process.

3.1. Functionality of Process and Related Necessary Considerations

[1] Demand rate of manufactured products are known and fixed.
[2] Production of manufactured products are known and fixed.
[3] Raw materials and unit holding cost of the manufactured products are known and fixed.
[4] Raw materials and installation cost of the manufactured products are known and fixes.
[5] Examination and repair costs are fixed.
[6] Inspections are faultless.
[7] α units of production is made within production unit of time and defect rate of the production is p. Defect rate is a random variable and density function is $f(p)$.
[8] Demand for flawless products is β in unit of time and at least $\beta/1-p$ products need to be inspected to meet the demand an meet the demand with flawless products. Ignoring the fact that the scanning speed needs to be higher than $\beta/1-p$ rate, demand cannot be covered with flawless products.
[9] Not having stock is not allowed.
[10] Quality control cost through the production period is higher than the quality control cost after production period, $d1$ >$d2$.

3.2. Model Parameters

a: Production speed in a unit of time
α_1: Repair speed in a unit of time
β: Demand speed in a unit of time
c: Unit production cost
c_r:Unit rework (repair) cost
d_1:Scanning cost during production
d_2: Scanning cost of the defective product after production stops
h: Holding cost in a unit of time
h_1: Holding cost of defective products in a unit of time
p: $f(p)$probability density function and defective product probability
$f(p)$: Probability density function of P
K: Production establishment cost (fixed)

x: Scanning speed in a unit of time (quantity of separating defective and flawless products from each other)
y: Optimum product quantity produced during a production cycle
T: production cycle $T = t_1 + t_2 + t_3 + t_4$
TC : total cost in a production cycle
$ETC(y)$ expected total cost in a production cycle
$ETCU(y)$ expected total cost in a unit of time

3.3. Model Functionality Under $\boldsymbol{\beta/1-p \leq x \leq \alpha}$ Consideration

If scanning rate x is lower than production rate a, whole products that are manufactured at_1 will not scanned during production period. t_1x of the y products will be scanned during production period and remaining $y - t_1x$ will be scanned during scanning period t_2. Defective products will be stocked with px speed during production and scanning periods. After the scanning period, defective products will be repaired with a_1 speed and added to solid products inventory. Change of inventory

Level over time is provided on figure (1) and (2).

Figure 1. Change of Produced Product Inventory a Cycle Over Time

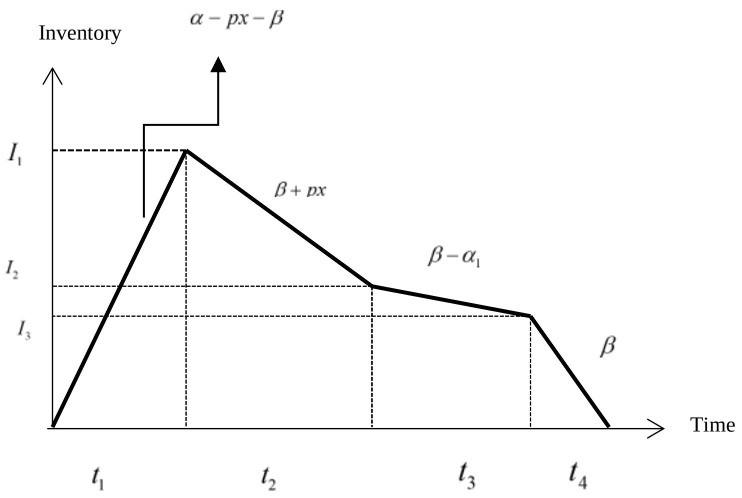
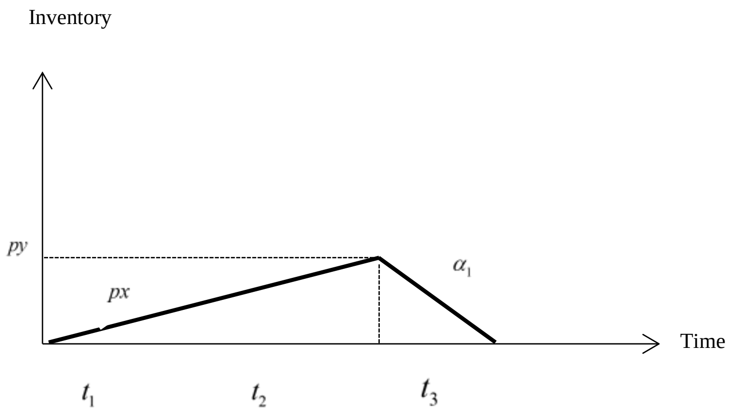


Figure 2. Change of Defective Product Inventory for a Cycle Over Time



Products are produced during t_1 with α speed and products are examined with x speed to separate defective and flawless products. As a result of examination with x speed, defective products that are produced with px speed are taken out of inventory on image 1 and added to defective product inventory on image 2. Since y products are produced through t_1 with α speed;

Taking Image (1) and (2) into consideration;

Production time is,

$$t_1 = y/\alpha \tag{1}$$

and from image 1

$$t_1 = \frac{I_1}{\alpha - px - \beta} \tag{2}$$

The following is obtained from Equation (1) and (2)

$$I_1 = \left(1 - \frac{\beta}{\alpha} - \frac{px}{\alpha}\right) y \tag{3}$$

In t_1, the amount of unexamined product is $y - xt_1 = \left(1 - \frac{x}{\alpha}\right) y$.

Screening time after production as unexamined products will be examined at x rate in t_2 (screening time after production) is as follows:

$$t_2 = \frac{\left(1 - \frac{x}{\alpha}\right) y}{x} = \left(\frac{1}{x} - \frac{1}{\alpha}\right) y \tag{4}$$

In t_2, the defective products detected with px rate as a result of examination are deducted from the inventory in figure 1 and added to the inventory of defective products in figure 2. The defective and excellent products are completely separated at the end of this process. The following is obtained from Figure 1;

$$t_2 = \frac{I_1 - I_2}{px + \beta} \tag{5}$$

And the following is obtained from equation (4) and (5);

$$I_2 = \left(1 - p - \frac{\beta}{x}\right) y \tag{6}$$

In $t_1 + t_2$, the defective products accumulate at px rate and reach to the amount of py as $py = (t_1 + t_2)px$.

In t_3, the defective products are repaired at α_1 rate and become excellent. Then;

Rework Time (rework time) is as follows;

$$t_3 = \frac{py}{\alpha_1} \tag{7}$$

$$t_3 = \frac{I_2 - I_3}{\beta - \alpha_1} \quad \text{is obtained from figure 1.} \tag{8}$$

And the following is obtained from equation (7) and (8)

$$I_3 = \left(1 - \frac{\beta}{x} - \frac{p\beta}{\alpha_1}\right) y \tag{9}$$

As the I_3 amount of product will meet the demand within t_4, The equation of $t_4 = \frac{I_3}{\beta} = \left(\frac{1}{\beta} - \frac{1}{x} - \frac{p}{\alpha_1}\right) y$ (10)

is obtained.

As all defective products are repaired and become excellent, the amount of excellent product in a cycle is equal to the production amount y in the cycle. As it will be obtained by proportioning the amount of excellent product to the demand rate if the cycle time is t ,the following applies;

$$t = \frac{y}{\beta} \tag{11}$$

As the total cost TC in a cycle will be the sum of the purchase cost, repair cost, examination cost, ordering cost, and inventory cost, the following applies:

$$TC = cy + c_r py + d_1 x t_1 + d_2(y - x t_1) + K + h\left[\frac{t_1 I_1}{2} + \frac{t_2(I_1+I_2)}{2} + + \frac{t_3(I_2+I_3)}{2} + \frac{t_4 I_3}{2}\right]$$
$$+h_1\left[\frac{(t_1+t_2+t_3)py}{2}\right]$$
$$= \left[c + c_r p + (d_1 - d_2)\frac{x}{\alpha} + d_2\right] y + K + \left\{\frac{h}{2}\left(\frac{1}{\beta} - \frac{1}{\alpha}\right) + \frac{(h_1-h)}{2}\left(\frac{p}{x} + \frac{p^2}{\alpha_1}\right)\right\} y^2 \tag{12}$$

As $E[.]$ is the expected value operator, the expected total cost ETC per cycle is as follows;

$$ETC = \left[c + c_r E[p] + (d_1 - d_2)\frac{x}{\alpha} + d_2\right] y + K + \left\{\frac{h}{2}\left(\frac{1}{\beta} - \frac{1}{\alpha}\right) + \frac{(h_1-h)}{2}\left(\frac{E[p]}{x} + \frac{E[p^2]}{\alpha_1}\right)\right\} y^2 \tag{13}$$

The below expected total cost per unit time $ETCU$ is obtained by proportioning the expected value of the cycle time $\left(E[t] = \frac{y}{\beta}\right)$ to the expected total cost per cycle ETC;

$$ETCU = \frac{ETC}{E[t]} = \left[c + c_r E[p] + (d_1 - d_2)\frac{x}{\alpha} + d_2\right]\beta$$
$$+\frac{K\beta}{y} + \left\{\frac{h}{2}\left(\frac{1}{\beta} - \frac{1}{\alpha}\right) + \frac{(h_1-h)}{2}\left(\frac{E[p]}{x} + \frac{E[p^2]}{\alpha_1}\right)\right\}\beta y \tag{14}$$

If the $ETCU$ function is differentiated with respect to the y variable and set to zero to find the optimum order amount, the following equations are obtained.

$$\frac{dETCU}{dy} = -\frac{K\beta}{y^2} + \left\{\frac{h}{2}\left(\frac{1}{\beta} - \frac{1}{\alpha}\right) + \frac{(h_1-h)}{2}\left(\frac{E[p]}{x} + \frac{E[p^2]}{\alpha_1}\right)\right\}\beta = 0 \tag{15}$$

$$y = \sqrt{\frac{2K}{h\left(\frac{1}{\beta} - \frac{1}{\alpha}\right) + (h_1-h)\left(\frac{E[p]}{x} + \frac{E[p^2]}{\alpha_1}\right)}} \tag{16}$$

3.4 Illustrative Example

A factory produces a single item A. The number of daily demands for item A is 1200 and the production capacity is 5000 per day. There are defects in production for various reasons and it is considered that the defect rate complies with a certain probability distribution. The examination (inspection) is made during production and defective products are separated. Daily examination capacity is 4000 items. While the unit examination cost during production is 1.2 TRY, the unit examination cost after production is 1 TRY. All defective products are repaired and become excellent. The daily repair capacity is 600 items. Unit repair cost is 10 TRY and unit production cost is 50 TRY. The preparation cost is 16700 liras, and the stock cost of defective and excellent products is 3 and 2 liras, respectively.

Therefore, model parameters are as follows:

$\beta = 1200, \alpha = 5000, x = 4000, d_1 = 1.2, d_2 = 1, \ \alpha_1 = 600$

$c_r = 10, c = 50, K = 16700, h_1 = 3, h = 2.$

If normally distributed with an average of $\mu = 0.06$ and variance of $\sigma^2 = 0.0001$, the defect rate is $E[p] = \mu = 0.06, E[p^2] = \mu^2 + \sigma^2 = 0.0037$. Then, the economic production amount with the equation of (15) is y=5092.64 unit, while the expected total cost with the equation of (14) is $ETCU = 69982.17 \ lira$

The cycle time is *t=4.2439 days*. Also, t_1*=1.0185 day*, t_2*=0.2546 day*, t_3*=0.5093 day*, t_4*=2.4614 day*, I_1*=3625.96 unit*, I_2*=3259.29 unit*, I_3*=2953.73* is obtained.

If the defect rate complies with the uniform distribution and the probability density function is the following;

$$f(p) = \frac{100}{3}, \quad 0.04 \leq p \leq 0.07$$

It would be $E[p] = \mu = 0.055, E[p^2] = 0.0031$. Then, with the equation of (16) economic production amount is y=5097.10 unit, the expected daily total cost is $ETCU = 69915.30 \ lira$ and cycle time is *t=4.2476* with the equation of (15). Also t_1*=1.0194 day*, t_2*=0.2549 day*, t_3*=0.4672 day*, t_4*=2.5062 day*, I_1*=3649.52 unit*, I_2*=3287.63 unit*, I_3*=3007.29* is obtained.

4. RESULTS AND SUGGESTIONS

Screening is conducted at the end of the production to detect the defective parts in a production process of a single product likely to produce a defective product at a random rate. Once detected, the defective products are repaired at a fixed rate before being returned to inventory. The assumption of continuous screening during production complicates analysis and is not practical for most production systems especially with low probability of defective products and high production rate, thus making continuous screening during production quite expensive. The decisions about when and where to position screening stations have great importance in practice. The decision to position screening after or during production has importance. All the above-mentioned literature neglects the screening time required to identify defective components. Therefore, the study contributes to the literature. The efficiency of screening rises to prominence while lower screening costs suggest longer screening time. It has also been observed that reducing defect rates or return rates and increasing the customer satisfaction without a significant increase in system costs or new investments may be achieved by adjusting operational parameters. The model can be improved by adding screening errors related to the screening rate being greater than the production rate and the stockless production.

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Review Article

APPLICATIONS OF TAGUCHI EXPERIMENTAL DESIGN METHOD IN THE FIELD OF TEXTILE

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APPLICATIONS OF TAGUCHI EXPERIMENTAL DESIGN METHOD IN THE FIELD OF TEXTILE

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ABSTRACT: The aim of this study is to investigate the Taguchi experimental design method and the studies conducted in the field of textiles. Taguchi experimental design method is widely used in engineering field. Experiments are carried out in order to obtain the optimum values of the product designed or produced in the field of engineering. It is difficult to make the experiments because of the large number of parameters in the studies made. Therefore, with the Taguchi experimental design method, less experimentation can be done in shorter time and an accurate test strategy is being developed. Thus, saving is provided from time and cost, high quality and low cost production is achieved. In this study, information was given about Taguchi experimental design method and Taguchi applications in the field of textile.

Keywords: Taguchi, Experimental Design, Textile.

1. INTRODUCTION

In order for the product designed and produced in engineering studies to have the best performance, the features and factors affecting the performance should be determined, and experiments should be carried out to obtain the optimum values [1].

Experimental design methods were developed by Fischer for use in agricultural research in the 1920s [2,3]. In addition, the analysis of the data obtained as a result of experimental studies, the "Analysis of Variance (ANOVA)" method, which is widely used today, was used and developed [4].

Thanks to the experimental design methods, the quality of the products is increased, the cost is reduced, the product is used more efficiently, and the production process is controlled in the most efficient way [5].

Due to the inadequacy of classical methods in experimental design, full factorial, fractional factorial and Taguchi methods are used in statistical experiment design [6].

In the full factorial experimental design method, at least two or more parameters and the combination obtained by multiplying the levels of these parameters with each other are used. Blocking is used to prevent unknown and uncontrollable errors from affecting the experiment.

In this method, experimental analysis is performed using ANOVA (analysis of variance) and regression analysis. The effect of a parameter on the experiment can be calculated with this method [6].

Since all level combinations of the parameters are tried one by one with the full factorial experimental design method, there is an increase in cost and a loss of time. Therefore, with the fractional factorial experiment design method, in which the number of experiments is reduced fractionally, cost and time savings are achieved. When a two-level experiment with seven parameters is performed with the full factorial experiment design method, 27=128 experiments are performed, while in the fractional factorial experiment design method, it is up to the researcher to decide on the construction of the experiment as fractional and 64 experiments can be done with ½ fraction or 32 experiments with ¼ fraction [6].

Taguchi method is an experimental design method established to provide the optimum combination between different levels of different parameters. It is one of the most used experimental design [6].

Genichi Taguchi, using his own name, developed a method to reduce the number of experiments with the analyzes he made before the experiment [7]. In the 1960s, the Taguchi method was used in the manufacturing industry, and it was widely used in the field of engineering, contributing to new developments [8].

While all experiments are performed in the full factorial test method, the most suitable test combinations are determined by using orthogonal arrays in the Taguchi test method. The number of factors, the number of levels and their interactions determine orthogonal arrays [9]. Table 1 shows the comparison of the number of full factorial experiments with the number of Taguchi experiments. As can be seen in the table, the number of experiments is greatly reduced with the Taguchi method, thereby providing convenience. While the full factorial experimental design is based on all factors and combinations, the fractional factorial design uses some of the combinations. More time is spent on traditional designs. The cost of these methods is high and the results can be erroneous. The Taguchi method, on the other hand, overcame these problems and made fractional factorial design simpler [10].

Table 1. Comparison of the number of full factorial experiments with the number of Taguchi experiments [9]

Number of factors	Number of levels	Number of Full Factorial Experiments	Taguchi Number of Experiments
2	2	4 (2^2)	4
3	2	8 (2^3)	4
4	2	16 (2^4)	8
7	2	128 (2^7)	8
15	2	32768 (2^{15})	16
4	3	81 (3^4)	9

With the Taguchi experimental design method, it uses controllable factors before, during and after production in the best way and minimizes the variable against uncontrollable factors [4].

In this study, it is aimed to investigate the Taguchi experimental design method and studies in the field of textiles. When the literature is examined, factorial design, response surface method and Taguchi method are commonly used; It has been seen that the Taguchi method is preferred more because of less experiments, fast results and cost savings. It has been seen that this method makes significant contributions to the production process and product performance [11].

2. TAGUCHI EXPERIMENTAL DESIGN STAGES

The Taguchi experimental design method consists of three basic concepts: system design, parameter design, and tolerance design.

System Design: In order to realize the best product design with the least cost by evaluating all the materials at hand, the current technological developments are researched and a feasibility study is carried out on the usability in the system [6].

Parameter Design: It is the most important step in process improvement and renewal. The improvement of the parameter is achieved by optimizing the product to be produced or developed. Uncontrollable parameters that negatively affect the quality of the product during production are determined and the effect of these parameters is minimized [6].

Tolerance Design: In cases where the desired target is not achieved, these deviations are reduced by making additional studies and finding the losses that deviate from the target value [6].

The following steps are followed in the implementation of the Taguchi experimental design method [12,13]:

Selection of factors affecting the experiment by using methods such as brainstorming and cause-effect diagram, determining the interaction between factors: There are controllable and uncontrollable factors in the Taguchi method. Designs and experiments are carried out according to the number of controllable factors.

Determination of experimental factor levels: Factor levels can be two, three or more.

Choosing orthogonal arrays: Many factors can be tested with the least number of orthogonal arrays, and it provides the opportunity to change factor levels.

Assignment of experimental factors to columns: Factors are assigned to columns according to orthogonal order by using linear graphics and triangular tables.

Performing the experiments: The data is analyzed according to the selected performance statistics. Therefore, performance statistics should be determined correctly.

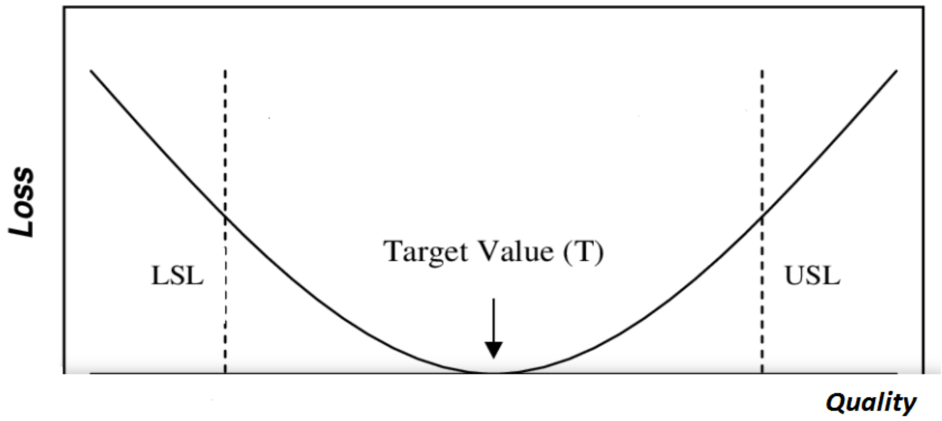
Analysis of the results: Analysis is made using methods such as analysis of variance, graphical representation of factor effects, spreadsheet method.

Confirmation of the experiments: When the factor obtained as a result of the experiment, the level combination reached the best performance characteristic, the experiment reached its goal.

By following these steps, the best experimental parameters are determined [13].

3. LOSS FUNCTION IN TAGUCHI EXPERIMENTAL DESIGN

In cases where there is a deviation from the target value, cost evaluation is made with the Taguchi loss function. In conventional quality control, if the value of the part is outside the specification limit, the part is reworked or scrapped. If the value of the part is within the specification limit, it is accepted. With the traditional method, there is either no loss or complete loss. Taguchi developed the Taguchi loss function, thinking that this method does not reflect the truth. In the Taguchi loss function shown in Figure 1., the horizontal axis represents the amount of deviation from the target, and the vertical axis represents the monetary loss that occurs after the product leaves the factory. In the formula shown below (1), it is seen that with the increase in the deviation from the target value, the loss increases in the ratio of the square of the deviation [4].



LTL: Lower Tolerance Limit
UTL: Upper Tolerance Limit

Figure 1. Taguchi loss function [4]

$$Loss=k.(Y-T)^2 \quad (1)$$

T: "Target value"
Y: "Measured value of quality variable"
k: "The coefficient that converts the deviation into currency" [4]

It is aimed to minimize the loss that may occur with the Taguchi loss function.

4. TEXTILE APPLICATIONS

Kuo and Fang (2006) determined the optimum dyeing conditions by using the Taguchi method in order to obtain the desired color during dyeing of the nylon-lycra mixed raw fabric, and it was observed that the optimum dyeing conditions obtained from the Taguchi method were compatible with the experiments [14].

20-40% of reactive dyes are mixed with waste water. Waste water needs to be treated because reactive dyes impair the aesthetic properties of waste water and reduce the amount of dissolved oxygen in nature. For this purpose, the most suitable test parameters were determined with the Taguchi method to ensure color removal from textile wastewater by using modified zeolite [15].

Taguchi and fully active experimental design methods were used to examine the effect of twist direction on the mechanical properties of cord fabric such as tensile strength, elongation at break, and force values at a certain elongation. The data obtained are compatible with each other in both experimental design methods, and it has been stated that it is more suitable than other experimental design methods because the least number of experiments can be done thanks to the Taguchi method [16].

Simulation method and Taguchi experimental design method were used to shorten the process of obtaining raw fabric used in contract manufacturing apparel enterprises. When the simulation model established with the obtained data is compared, the lead times of the fabrics are compatible with each other. It has been observed that the cost and lead time are reduced with the simulation system. The total stock amount variable was also minimized with the Taguchi method [17].

The properties affecting the bursting strength of knitted fabrics were optimized using the Taguchi experimental design method. The data obtained as a result of the experimental study were found to be compatible with the Taguchi method [18].

By using the Taguchi method, Mezarcıöz and Oğulata (2010) optimized the breaking strength values of single jersey fabrics. Contrary to the full factorial experimental design, which causes time and cost loss, the number of experiments is reduced with the Taguchi method [19].

Taguchi method was used to provide color removal of reactive dyes used in textile industry under appropriate conditions using Reactive Red 198 as reactive dye and pistachio shell as absorbent material. It has been seen that the appropriate experimental conditions are determined by the Taguchi method, the number of experiments is reduced by the Taguchi method, time and cost loss is prevented, and the pistachio shell is a good absorbent material [20].

Yazıcı (2010), in the dyeing process of staple acrylic fiber used in carpet production with cationic dyestuff, used the Taguchi method to obtain optimum values in the dyeing process, and a more efficient dyeing process was achieved, and cost savings were achieved [21].

Alhalabi and Sabır (2011) used the Taguchi method to examine the effect of the lubricant used to prevent static electricity in synthetic fiber spinning on the quality parameters of ring yarn obtained from polyester fiber. Optimum static electricity and lubricant amount were determined by Taguchi method [22].

Mutlay (2011) states that one of the accidents that pose the greatest threat to the environment and human health today is chemical and oil spills. Scattered liquid contaminants can be effectively cleaned using porous textile structures. The xylene and diesel fuel retention properties of absorbent textile fillers produced from expanded graphite-based fibrous structures were investigated. The highest absorption value of liquid pollutants in the literature was achieved with the Taguchi experimental design method [23].

Demirbaş and Yıldız (2012) used the Taguchi method for the optimization of adsorption experiments in the use of silica for the removal of textile dyestuff from wastewater. With the Taguchi method, fewer experiments were performed than with the traditional method, and time and cost savings were achieved [24].

Kocatüfek (2013) obtained thermoplastic composite by adding glass fiber at different rates to polyamide-based materials. The effect of this method, which is used in these composites obtained by using the hot plate method, on the plate temperature, welding time, heating time and joining stroke, was achieved by reducing the number of experiments with the Taguchi experimental design method. On the other hand, when the experimental and numerical data were compared, it was seen that the Taguchi method was successfully applied to polyamide 6 materials. On the other hand, it has been observed that the welding strength of the 30% glass fiber added polyamide 66 material is not compatible in experimental and numerical data due to thermal deterioration caused by time and temperature. Instead of Taguchi L9 orthogonal matrix used in the study, it is suggested to design Taguchi orthogonal matrix at new levels [25].

Özgür (2013) investigated the effects of texture structure, dye intensity and raising process on some quality properties of woven fabrics such as breaking strength, tear strength, pilling. The data obtained from the results were analyzed statistically and the compatibility of the results obtained from the full factorial experimental design with the Taguchi experimental design was examined. Except for the pilling process, all experiments were found to be compatible with the Taguchi experimental design [26].

The Taguchi method was used to optimize the experimental conditions in the electrocoagulation method used in the treatment of textile wastewater. The variables affecting the electrocoagulation method were optimized with the Taguchi method [27].

It was desired to remove acidic, basic and reactive dyes by using vegetable wastes and carbon. Optimum conditions in the experiment were determined using the Taguchi method [28].

Sabir and Özgür (2014) applied bending length test to fabrics produced in different knitting texture, dyeing ratio and raising process. When the results were analyzed, it was seen that the data obtained by the Taguchi method were largely compatible with the experimental results [29].

With the Taguchi method, the optimization of the sizing process in different yarn counts, delivery speeds and viscosity values of 100% cotton yarn was investigated. Thanks to the Taguchi method, fewer experiments were performed, resulting in cost savings [30].

Nano fiber production was carried out by electrospinning method using polymethyl methacrylate polymer. It was observed that the electrospinning process parameters were optimized by the Taguchi method [31].

Woven fabrics with twill weave structure were dyed in three different dye ratios and raised in two passages. In addition, tensile strength and elongation at break tests were applied to the fabrics [32].

The most suitable knit structure, dye ratio and raising type were determined for the optimization of breaking strength and elongation at break with the Taguchi method.

Özgen and Altaş (2016) determined that yarn count, slub thickness, slub length, slub distance control factors were determined in Taguchi L9 orthoganal design after weaving slub yarns with different properties as 1/3 twill fabric. The effect of the slub yarn structure produced with different properties on the air permeability of the woven fabric was investigated. The results of the analysis showed that the slub thickness is the most effective factor in the air permeability of the woven fabric [33].

Avcu (2017) used the Taguchi method to improve the wear performance of automotive seat upholstery produced using double-layered woven fabric. The mechanical properties such as thickness measurement, weight, tear strength, elongation, abrasion resistance of woven fabrics produced using polyester yarn were examined and the most suitable tissue structure in terms of mechanical properties was determined by Taguchi method [34].

Özmen (2017) determined the order of importance of the factors that may cause a change in yarn quality in a yarn production facility with the Taguchi method. Thus, time and cost savings were achieved by making fewer experiments [35].

The removal of Astrazon Black MBL (AB) dye, which is prepared synthetically with garden soil used as an adsorbent, was investigated by modeling with the taguchi method. After treatment, oxidation-reduction potential (ORP) and FTIR analyzes were carried out by working with the removal of both color and organic matter content in the synthetic dye solution, adsorption and Fenton processes under different operating conditions. It has been concluded that high rates of color can be removed with the soil used and organic materials can be held on the surface [36].

Üstündağ et. al., 2022, it is presented that the optimum levels of coating process parameters for the tear strength and hardness properties of cotton/elastane blended denim fabrics are determined by Taguchi method and Gray relational analysis [37].

5. CONCLUSIONS

Contrary to traditional methods, significant improvements are achieved in experimental performance with the Taguchi experimental design method. In the studies, it was seen that the test results were compatible with the Taguchi experimental design and the experimental process parameters were optimized by the Taguchi method. By making fewer experiments in a shorter time, cost savings are achieved not only for researchers in the field of textiles, but also for studies in other fields. The use of Taguchi experimental design method in studies in universities and industry provides great convenience in studies.

Conflict of Interest

No conflict of interest was declared by the authors.

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