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**Research Article**

# APPLICATION OF MULTI CRITERIA DECISION MAKING METHODS TO LEACHING PROCESS OF COPPER FROM MALACHITE ORE

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**ABSTRACT**

This study concerns with optimization of the leaching conditions of copper from malachite ore in the presence ammonium nitrate solution. In order to select the effective parameter from available dissolution process, all experiments were performed using $L_{25}$ orthogonal experimental design by Taguchi method and the temperature was found as a more effective parameter. Then multi-criteria decision making (MCDM) method was applied to experimental results and it was found that the process is in concordance with MCDM values. Based on the results, the highest copper extraction value (99.4%) was reached under optimum leaching conditions are as follows: time, 60 min; temperature, 75°C; stirring speed, 450 rpm; concentration of leaching reagent, 4 mol/L and solid/liquid ratio, 8 g/mL. In conclusion, Taguchi and MCDM method can be used effectively for optimization of various hydrometallurgical processes.
**Keywords:** Leaching, malachite, ammonium nitrate, optimization, Taguchi, TOPSIS, MCDM.

## 1. INTRODUCTION

In nature, the ores with copper content are available such as malachite, azurite, tenorite, covellite, chalcopyrite and bornite [1]. Metallic copper production from these ores generally can be performed by pyrometallurgical and hydrometallurgical methods at the present time [2]. Hydrometallurgical method has numerous advantages over pyrometallurgical method; less costly, more environmentally friendly and acceptable economically reported to be most appropriate method [2-6]. For these reasons, hydrometallurgical method was preferred in this study.

The strong acids are commonly utilized in the conventional dissolution process as the leaching reagents. However, the acids may cause some problems such as excessive acid consumption because of in presence of gangue minerals and dissolving the impurities in the ore matrix during leaching reaction. Therefore, leaching reagents including ammonia were utilized in leaching process of oxidized copper ores in previous works [2, 3, 5-9]

It is complicated to optimize any leaching process since it is affected simultaneously various conditions such as concentration of leaching agent, temperature, time, stirring speed and solid/liquid ratio. Several experiments are necessary to determine the simultaneous effects with

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correctly approach of all parameters on leaching, which means also highly cost and time consuming. Therefore, instead of classical experimental design, Taguchi method was used to find optimum leaching conditions. Multi criteria decision making (MCDM) method was also used to verify optimum leaching condition which was validated with experiment. The stages were detailed in Figure 1.

In this work, we were presented an approach related to the optimization leaching parameters of copper from malachite ore in ammonium nitrate solution by proposed methods.

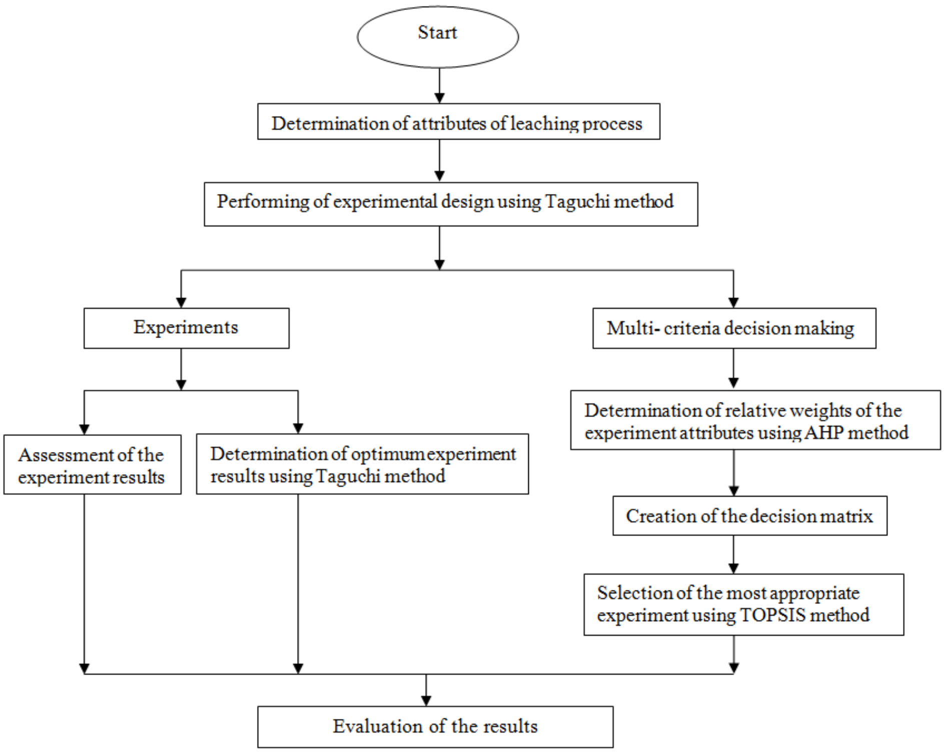


**Figure 1.** Flow diagram for proposed algorithm using Taguchi and MCDM methods

## 2. EXPERIMENTAL METHOD

Oxidized copper ore ($CuCO_3Cu(OH)_2$) utilized in the experiments was sieved using ASTM standard sieves to obtain certain particle fractions, after crushed and ground operations.

All experiments were carried out 1000 mL. a jacketed glass reactor at atmospheric pressure. The reactor contents a mechanical stirrer, a temperature probe and a condenser to prevent the volume reduction of the leaching solution by evaporation. The temperature of ammonium nitrate solution in reactor was adjusted to desired value, sample was added to the solution, and mixtures were stirred for the required reaction time and filtered. Then, amount of copper in the supernatant was measured using an Atomic Absorption Spectrophotometer (Perkin Elmer AAnalyst-400).

## 3. EXPERIMENTAL DESIGN AND OPTIMIZATION OF PROCESS PARAMETERS

### 3.1. Taguchi Method

Taguchi method is a powerful design and reduced the number of tests by using orthogonal arrays in engineering analysis. The quality of any experimental design can be described by basic philosophy of Taguchi method. In this way, the experiment time can be shortened and the process cost can be minimized in the any engineering application [21, 22].

Deviation experimental values and desired values are calculated by Taguchi method as a loss function. Thereafter, this loss function is converted into a signal-noise (S/N) ratio. Normally there are three kinds of quality characteristics in analysis of the S/N ratio.

- The lower the better
- The higher the best
- The nominal the better

S/N ratio is calculated based on the S/N analysis for each level of the process parameters. The higher the best signal to noise ratio was preferred since we plan to obtain the maximum copper extraction value in this process.

### 3.2. TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) Method

The MCDM methods are generally preferred to determine the optimum process parameters for numerous engineering applications at the present time [10]. There are various types of MCDM methods such as TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) [11-14], VIKOR (VlseKriterijumskaOptimizacijaKompromisnoResenje, means Multicriteria Optimization and Compromise Solution) [15, 16], ELECTRE (Elimination and Choice Expressing The Reality) [17], PROMETHE (preference ranking organization method for enrichment evaluation) [18], COPRAS (complex proportional assessment) [19], COPRAS-G [20]. Although there are only a few studies for dissolution process in literature, a study regarding to selection the best experiment conditions for a leaching process is not available in the literature [13]. TOPSIS method is used to find a solution which is nearest ideal solution and farthest non-ideal solution [14, 23].

### 3.3. Criteria Weighting

**Table 1.** Chemical analysis of malachite ore used in the experiments.

| Component | $SiO_2$ | CuO | $Al_2O_3$ | PbO | $Fe_2O_3$ | Ignition loss | Other oxides |
|---|---|---|---|---|---|---|---|
| Value, % | 40.52 | 22.86 | 14.53 | 1.28 | 1.01 | 16.80 | 3.00 |

The criteria weights are calculated with analytic hierarchy process (AHP) method which is a compromised weighting method [24]. AHP method was proposed first by Saaty (1977,1980) to model subjective decision making processes based on multiple attributes in a hierarchical system [25]. The method has three main steps to calculate the weights of attributes: First, structure of hierarchical system; second, comparative judgment of the alternatives and the criteria; third, synthesis of the priorities [11, 23].In order to compare a set of "*n*" criteria pairwise according to their relative importance weights, pairwise comparison matrix is used and it can be represented as [23] and relative importance of between two criteria is determined using Table 2.

**Table 2.** Ratio Scale in the AHP method [25]

| Intensity | 1 | 3 | 5 | 7 | 9 | 2,4,6,8 |
|---|---|---|---|---|---|---|
| Linguistic | Equal | Moderate | Strong | Demonstrated | Extreme | Intermediate value |

## 4. RESULTS AND DISCUSSION

### 4.1. Analysis of Signal to Noise (S/N) Ratio

Time ($l_c$), temperature (T), stirring speed ($A_r$), leaching reagent of concentration (C), solid/liquid ratio ($SL_r$) were considered as leaching process parameters. The leaching process parameters and their levels were given in Table 3. Experimental design for five parameters of leaching process (time, temperature, stirring speed, leaching reagent of concentration, solid/liquid ratio) with five levels organized by Taguchi's $L_{25}$ orthogonal array was shown in Table 4.

**Table 3.** Leaching parameters and levels

| Symbol | Leaching Parameters | Level 1 | Level 2 | Level 3 | Level 4 | Level 5 |
|---|---|---|---|---|---|---|
| A | Time (*minute*) | 15 | 30 | 60 | 90 | 120 |
| B | Temperature (*℃*) | 35 | 45 | 55 | 65 | 75 |
| C | Agitation rate (*rpm*) | 150 | 250 | 350 | 450 | 550 |
| D | Concentration (*mol/L*) | 1 | 2 | 3 | 4 | 5 |
| E | Solid/Liquid Ratio (*g/mL*) | 1 | 2 | 4 | 6 | 8 |

**Table 4.** Full factorial design with orthogonal array of Taguchi $L_{25}$

| Experiment No | A (Time) | B (Temperature) | Agitation rate (rpm) | D (Concentration) | E (Solid/liquid) |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 | 3 |
| 4 | 1 | 4 | 4 | 4 | 4 |
| 5 | 1 | 5 | 5 | 5 | 5 |
| 6 | 2 | 1 | 2 | 3 | 4 |
| 7 | 2 | 2 | 3 | 4 | 5 |
| 8 | 2 | 3 | 4 | 5 | 1 |
| 9 | 2 | 4 | 5 | 1 | 2 |
| 10 | 2 | 5 | 1 | 2 | 3 |
| 11 | 3 | 1 | 3 | 5 | 2 |
| 12 | 3 | 2 | 4 | 1 | 3 |
| 13 | 3 | 3 | 5 | 2 | 4 |
| 14 | 3 | 4 | 1 | 3 | 5 |
| 15 | 3 | 5 | 2 | 4 | 1 |
| 16 | 4 | 1 | 4 | 2 | 5 |
| 17 | 4 | 2 | 5 | 3 | 1 |
| 18 | 4 | 3 | 1 | 4 | 2 |
| 19 | 4 | 4 | 2 | 5 | 3 |
| 20 | 4 | 5 | 3 | 1 | 4 |
| 21 | 5 | 1 | 5 | 4 | 3 |
| 22 | 5 | 2 | 1 | 5 | 4 |
| 23 | 5 | 3 | 2 | 1 | 5 |
| 24 | 5 | 4 | 3 | 2 | 1 |
| 25 | 5 | 5 | 4 | 3 | 2 |

Optimization of leaching parameters is the most critical step in hydrometallurgical processes as it is considered process costs. Therefore, the influence of each factor level on process conditions was analyzed by signal to noise (S/N) ratio. S/N ratios and level values were calculated with the condition of "*the higher the best*" criteria. For each level, average S/N ratio is calculated on the basis of the recorded value in Table 5. It demonstrates optimum levels of control factors for the highest percentage extraction values of copper from malachite ore. S/N ratio values and graphics are seen in Figure 3. Optimum leaching parameters of control factors for the maximum percentage recovery values of copper from malachite ore can be easily determined from Figure 2. According to Figure 2, the levels and S/N ratios for the factors giving the best percentage recovery value of copper were determined as a factor A (Level 3, S/N= -0.8207), factor B (Level 5, S/N=-1.2899), factor C (Level 4, S/N= -1.4538), factor D (Level 4, S/N=-1.5851), factor E (Level 5, S/N=-1.4629). In other words, optimum leaching conditions in this situation is $A_3B_5C_4D_4E_5$. S/N response table for efficiency is seen Table 6. Bold values of control factors of S/N ratios are represented optimum parameters of process.

**Table 5.** The experiment results and S/N ratios

| Experimental Number | Control Factors | | | | | % Cu | S/N Ratios |
|---|---|---|---|---|---|---|---|
| | A Time (*minute*) | B Temperature ($^OC$) | C Agitation Rate (*rpm*) | D Concentration (*mol/L*) | E Solid/Liquid Rate (*g/mL*) | | |
| 1 | 15 | 30 | 100 | 0.1 | 1 | 0.513 | -5.798 |
| 2 | 15 | 40 | 150 | 0.3 | 1.5 | 0.625 | -4.082 |
| 3 | 15 | 45 | 200 | 0.5 | 2 | 0.695 | -3.16 |
| 4 | 15 | 50 | 250 | 0.7 | 3 | 0.758 | -2.407 |
| 5 | 15 | 55 | 300 | 0.9 | 4 | 0.789 | -2.058 |
| 6 | 30 | 30 | 150 | 0.5 | 3 | 0.711 | -2.963 |
| 7 | 30 | 40 | 200 | 0.7 | 4 | 0.762 | -2.361 |
| 8 | 30 | 45 | 250 | 0.9 | 1 | 0.752 | -2.476 |
| 9 | 30 | 50 | 300 | 0.1 | 1.5 | 0.761 | -2.372 |
| 10 | 30 | 55 | 100 | 0.3 | 2 | 0.709 | -2.987 |
| 11 | 60 | 30 | 200 | 0.9 | 1.5 | 0.856 | -1.351 |
| 12 | 60 | 40 | 250 | 0.1 | 2 | 0.894 | -0.973 |
| 13 | 60 | 45 | 300 | 0.3 | 3 | 0.928 | -0.649 |
| 14 | 60 | 50 | 100 | 0.5 | 4 | 0.933 | -0.602 |
| 15 | 60 | 55 | 150 | 0.7 | 1 | 0.941 | -0.528 |
| 16 | 90 | 30 | 250 | 0.3 | 4 | 0.861 | -1.3 |
| 17 | 90 | 40 | 300 | 0.5 | 1 | 0.853 | -1.381 |
| 18 | 90 | 45 | 100 | 0.7 | 1.5 | 0.889 | -1.022 |
| 19 | 90 | 50 | 150 | 0.9 | 2 | 0.855 | -1.361 |
| 20 | 90 | 55 | 200 | 0.1 | 3 | 0.916 | -0.762 |
| 21 | 120 | 30 | 300 | 0.7 | 2 | 0.831 | -1.608 |
| 22 | 120 | 40 | 100 | 0.9 | 3 | 0.873 | -1.18 |
| 23 | 120 | 45 | 150 | 0.1 | 4 | 0.892 | -0.993 |
| 24 | 120 | 50 | 200 | 0.3 | 1 | 0.936 | -0.574 |
| 25 | 120 | 55 | 250 | 0.5 | 1.5 | 0.987 | -0.114 |

**Table 6.** S/N response table for efficiency factor

| Levels | Control Factors | | | | |
|---|---|---|---|---|---|
| | Efficiency | | | | |
| | A | B | C | D | E |
| Level 1 | -3.5011 | 2.6027 | -2.3178 | -2.1796 | -2.1514 |
| Level 2 | -2.6317 | -1.9955 | -1.9853 | -1.9186 | -1.7882 |
| Level 3 | **-0.8207** | -1.6599 | -1.6417 | -1.644 | -2.0179 |
| Level 4 | -1.1651 | -1.4633 | **-1,4538** | **-1,5851** | -1,592 |
| Level 5 | -0.8937 | **-1.2899** | -1.6138 | -1.685 | **-1.4629** |
| Delta | 2.6804 | 1,3138 | 0.8639 | 0.5945 | 0.6885 |

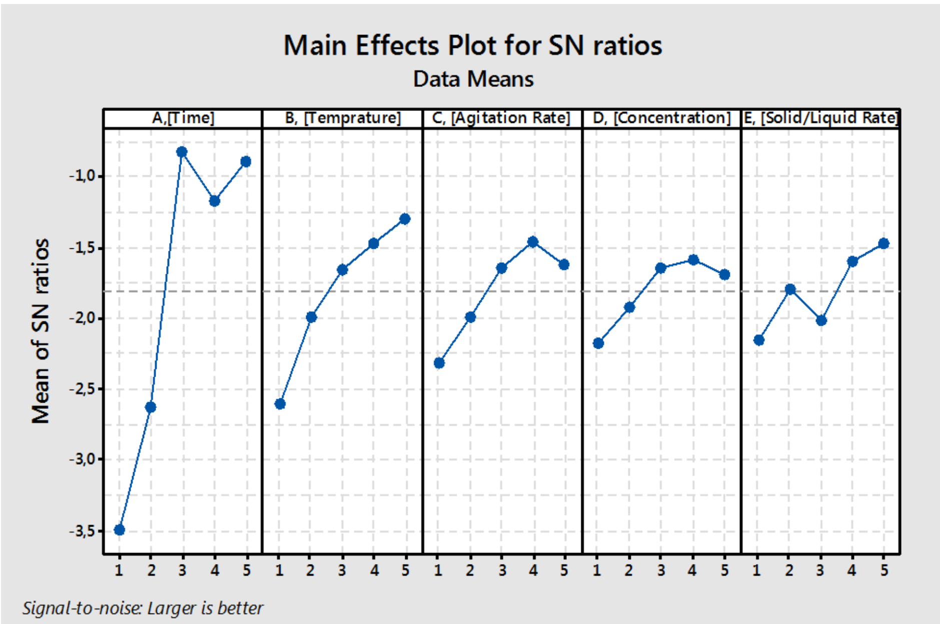


**Figure 2.** The graphics of mean S/N ratios versus factor levels (efficiency).

### 4.2. Confirmation Test

Confirmation test was performed with optimum parameters which were obtained by Taguchi method. Consequently, percentage extraction of copper from malachite ore is 0.994% which is higher than 25$^{th}$ experiment. It has been found that Taguchi method is a suitable method to determine the optimum parameters of process.

### 4.3. Analysis by TOPSIS method

The applicability of TOPSIS method was investigated in order to the most suitable experimental conditions. Criteria weightings were obtained by AHP method which was used in

TOPSIS. Based on Table 2, a pairwise comparison matrix was created in Table 7. Here as criteria the time is considered most important for leaching process. Other criteria are arranged according to their importance respectively; temperature, stirring speed, solid/liquid ratio, concentration. Table 8 shows that criteria weights of leaching parameters were obtained by AHP method.

**Table 7.** The pairwise comparison matrix for criteria

| | **A** | **B** | **C** | **D** | **E** |
|---|---|---|---|---|---|
| **A** | 1 | 1.286 | 1.8 | 9 | 3 |
| **B** | 0.778 | 1 | 1.4 | 7 | 2.334 |
| **C** | 0.556 | 0.715 | 1 | 5 | 1.667 |
| **D** | 0.112 | 0.143 | 0.2 | 1 | 0.334 |
| **E** | 0.334 | 0.429 | 0.6 | 3 | 1 |

**Table 8.** Criteria weights

| | **Time** | **Temperature** | **Agitation Rate** | **Concentration** | **Solid/Liquid Ratio** |
|---|---|---|---|---|---|
| $w_j$ | 0.360 | 0.280 | 0.200 | 0.040 | 0.120 |

The decision matrix which was needed for TOPSIS method was determined with Taguchi's $L_{25}$ orthogonal array which was used in leaching experiments (Table 9). The normalized decision matrix is seen from Table 10. It was multiplied by the relative importance in Table 8 and obtained the weighted normalized matrix is presented in Table 11. The ideal ($V_i^+$) and non-ideal solution ($V_i^-$) were obtained (Table 12). The Euclidean Distances and relative closeness to ideal solutions are presented in Table 13. The highest percentage value of extraction copper was assessed to be the 25$^{th}$ experiment by this method and it is also same the experiment results. The comparison of rankings obtained from the experiment and TOPSIS method is seen Figure 3. The test results and MCDM method is good agreement with each other.

**Table 9.** The Decision Matrix

| **Experiment** | Time | Temperature | Agitation rate | Concentration | Solid/Liquid ratio |
|---|---|---|---|---|---|
| **1** | 15 | 35 | 100 | 0.1 | 1 |
| **2** | 15 | 45 | 150 | 0.3 | 1.5 |
| **3** | 15 | 55 | 200 | 0.5 | 2 |
| **4** | 15 | 65 | 250 | 0.7 | 3 |
| **5** | 15 | 75 | 300 | 0.9 | 4 |
| **6** | 30 | 35 | 150 | 0.5 | 3 |
| **7** | 30 | 45 | 200 | 0.7 | 4 |
| **8** | 30 | 55 | 250 | 0.9 | 1 |
| **9** | 30 | 65 | 300 | 0.1 | 1.5 |
| **10** | 30 | 75 | 100 | 0.3 | 2 |
| **11** | 60 | 35 | 200 | 0.9 | 1.5 |
| **12** | 60 | 45 | 250 | 0.1 | 2 |
| **13** | 60 | 55 | 300 | 0.3 | 3 |
| **14** | 60 | 65 | 100 | 0.5 | 4 |
| **15** | 60 | 75 | 150 | 0.7 | 1 |
| **16** | 90 | 35 | 250 | 0.3 | 4 |
| **17** | 90 | 45 | 300 | 0.5 | 1 |
| **18** | 90 | 55 | 100 | 0.7 | 1.5 |
| **19** | 90 | 65 | 150 | 0.9 | 2 |
| **20** | 90 | 75 | 200 | 0.1 | 3 |
| **21** | 120 | 35 | 300 | 0.7 | 2 |
| **22** | 120 | 45 | 100 | 0.9 | 3 |
| **23** | 120 | 55 | 150 | 0.1 | 4 |
| **24** | 120 | 65 | 200 | 0.3 | 1 |
| **25** | 120 | 75 | 250 | 0.5 | 1.5 |

**Table 10.** Normalized Decision Matrix

| Experiment | Time | Temperature | Agitation Rate | Concentration | Solid/Liquid ratio |
|---|---|---|---|---|---|
| 1 | 0.0407 | 0.1233 | 0.0795 | 0.0603 | 0.0407 |
| 2 | 0.0407 | 0.1585 | 0.1325 | 0.1206 | 0.0813 |
| 3 | 0.0407 | 0.1937 | 0.1854 | 0.1809 | 0.1626 |
| 4 | 0.0407 | 0.2289 | 0.2384 | 0.2412 | 0.2439 |
| 5 | 0.0407 | 0.2641 | 0.2914 | 0.3015 | 0.3252 |
| 6 | 0.0813 | 0.1233 | 0.1325 | 0.1809 | 0.2439 |
| 7 | 0.0813 | 0.1585 | 0.1854 | 0.2412 | 0.3252 |
| 8 | 0.0813 | 0.1937 | 0.2384 | 0.3015 | 0.0407 |
| 9 | 0.0813 | 0.2289 | 0.2914 | 0.0603 | 0.0813 |
| 10 | 0.0813 | 0.2641 | 0.0795 | 0.1206 | 0.1626 |
| 11 | 0.1626 | 0.1233 | 0.1854 | 0.3015 | 0.0813 |
| 12 | 0.1626 | 0.1585 | 0.2384 | 0.0603 | 0.1626 |
| 13 | 0.1626 | 0.1937 | 0.2914 | 0.1206 | 0.2439 |
| 14 | 0.1626 | 0.2289 | 0.0795 | 0.1809 | 0.3252 |
| 15 | 0.1626 | 0.2641 | 0.1325 | 0.2412 | 0.0407 |
| 16 | 0.2439 | 0.1233 | 0.2384 | 0.1206 | 0.3252 |
| 17 | 0.2439 | 0.1585 | 0.2914 | 0.1809 | 0.0407 |
| 18 | 0.2439 | 0.1937 | 0.0795 | 0.2412 | 0.0813 |
| 19 | 0.2439 | 0.2289 | 0.1325 | 0.3015 | 0.1626 |
| 20 | 0.2439 | 0.2641 | 0.1854 | 0.0603 | 0.2439 |
| 21 | 0.3252 | 0.1233 | 0.2914 | 0.2412 | 0.1626 |
| 22 | 0.3252 | 0.1585 | 0.0795 | 0.3015 | 0.2439 |
| 23 | 0.3252 | 0.1937 | 0.1325 | 0.0603 | 0.3252 |
| 24 | 0.3252 | 0.2289 | 0.1854 | 0.1206 | 0.0407 |
| 25 | 0.3252 | 0.2641 | 0.2384 | 0.1809 | 0.0813 |

**Table 11.** Weighted normalized decision matrix

| Experiment | Time | Temperature | Agitation Rate | Concentration | Solid/Liquid ratio |
|---|---|---|---|---|---|
| 1 | 0.0146 | 0.0345 | 0.0159 | 0.0024 | 0.0049 |
| 2 | 0.0146 | 0.0444 | 0.0265 | 0.0048 | 0.0098 |
| 3 | 0.0146 | 0.0542 | 0.0371 | 0.0073 | 0.0195 |
| 4 | 0.0146 | 0.0641 | 0.0477 | 0.0097 | 0.0293 |
| 5 | 0.0146 | 0.0739 | 0.0583 | 0.0121 | 0.039 |
| 6 | 0.0293 | 0.0345 | 0.0265 | 0.0073 | 0.0293 |
| 7 | 0.0293 | 0.0444 | 0.0371 | 0.0097 | 0.039 |
| 8 | 0.0293 | 0.0542 | 0.0477 | 0.0121 | 0.0049 |
| 9 | 0.0293 | 0.0641 | 0.0583 | 0.0024 | 0.0098 |
| 10 | 0.0293 | 0.0739 | 0.0159 | 0.0048 | 0.0195 |
| 11 | 0.0585 | 0.0345 | 0.0371 | 0.0121 | 0.0098 |
| 12 | 0.0585 | 0.0444 | 0.0477 | 0.0024 | 0.0195 |
| 13 | 0.0585 | 0.0542 | 0.0583 | 0.0048 | 0.0293 |
| 14 | 0.0585 | 0.0641 | 0.0159 | 0.0073 | 0.039 |
| 15 | 0.0585 | 0.0739 | 0.0265 | 0.0097 | 0.0049 |
| 16 | 0.0878 | 0.0345 | 0.0477 | 0.0048 | 0.039 |
| 17 | 0.0878 | 0.0444 | 0.0583 | 0.0073 | 0.0049 |
| 18 | 0.0878 | 0.0542 | 0.0159 | 0.0097 | 0.0098 |
| 19 | 0.0878 | 0.0641 | 0.0265 | 0.0121 | 0.0195 |
| 20 | 0.0878 | 0.0739 | 0.0371 | 0.0024 | 0.0293 |
| 21 | 0.1171 | 0.0345 | 0.0583 | 0.0097 | 0.0195 |
| 22 | 0.1171 | 0.0444 | 0.0159 | 0.0121 | 0.0293 |
| 23 | 0.1171 | 0.0542 | 0.0265 | 0.0024 | 0.039 |
| 24 | 0.1171 | 0.0641 | 0.0371 | 0.0048 | 0.0049 |
| 25 | 0.1171 | 0.0739 | 0.0477 | 0.0073 | 0.0098 |

**Table 12.** The Ideal and non-ideal solutions

| | **Time** | **Temperature** | **Agitation Rate** | **Concentration** | **Solid/Liquid ratio** |
|---|---|---|---|---|---|
| $V^+$ | 0.1171 | 0.0739 | 0.0583 | 0.0121 | 0.0390 |
| $V^-$ | 0.0146 | 0.0345 | 0.0159 | 0.0024 | 0.0049 |

**Table 13.** $S_i^+$ , $S_i^-$ and $C_i$

| $S_i^+$ | $S_i^-$ | $C_i$ | **Rank** |
|---|---|---|---|
| 0.0151 | 0 | 0 | 25 |
| 0.0133 | 0.0002 | 0.0177 | 24 |
| 0.0117 | 0.0011 | 0.084 | 22 |
| 0.0108 | 0.0025 | 0.19 | 18 |
| 0.0105 | 0.0046 | 0.3054 | 15 |
| 0.0104 | 0.0009 | 0.0834 | 23 |
| 0.009 | 0.002 | 0.1797 | 19 |
| 0.0094 | 0.0017 | 0.154 | 21 |
| 0.0088 | 0.0029 | 0.2494 | 17 |
| 0.0099 | 0.002 | 0.1668 | 20 |
| 0.0063 | 0.0025 | 0.284 | 16 |
| 0.0049 | 0.0032 | 0.3993 | 13 |
| 0.004 | 0.0047 | 0.5433 | 11 |
| 0.0053 | 0.004 | 0.4276 | 12 |
| 0.0056 | 0.0036 | 0.394 | 14 |
| 0.0026 | 0.0075 | 0.7452 | 7 |
| 0.0029 | 0.0073 | 0.7133 | 9 |
| 0.0039 | 0.0058 | 0.5984 | 10 |
| 0.0023 | 0.0066 | 0.7392 | 8 |
| 0.0015 | 0.008 | 0.8418 | 4 |
| 0.0019 | 0.0126 | 0.866 | 5 |
| 0.0028 | 0.0113 | 0.803 | 6 |
| 0.0015 | 0.0122 | 0.8906 | 2 |
| 0.0018 | 0.0118 | 0.87 | 3 |
| 0.001 | 0.0131 | 0.9296 | 1 |

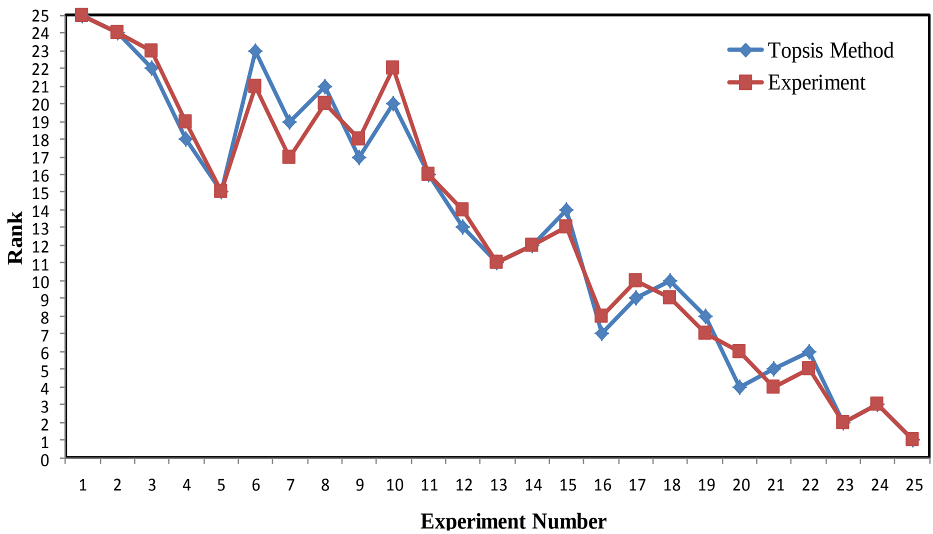


**Figure 3**. The comparison of rankings obtained from the experiment and TOPSIS method

## 5. CONCLUSIONS

There are several attributes which influence the optimization of leaching parameters of copper from malachite ore in the presence ammonium nitrate solution. Some of these conditions are time, temperature, stirring speed, concentration of leaching reagent, solid/liquid rate. The various process conditions have been defined, compared and ranked with the aid of Taguchi and MCDM methods, which will maximize the amount of copper passing into solution.

The results obtained from experiments were analyzed with Taguchi method. Taguchi analyses were clearly indicated that the most efficient experiment combination of attributes time, 60 min; temperature, 75$^o$C; stirring speed, 450 rpm; concentration of leaching reagent, 4 mol/L and solid/liquid ratio, 8 g/mL. This result was confirmed with a new experiment in above-mentioned conditions. Consequently, the result of the confirmation experiment was higher compared with performed by Taguchi $L_{25}$ orthogonal array previously. It can be inferred that the higher temperature and solid/liquid ratio were found to be highly ranked with better leaching performance. However, the acid concentration, stirring speed and time also play a significant role in order to achieved better leaching performance.

At the second part of this study, TOPSIS method was used for rank the experiment conditions for better to worst efficiency which was created with Taguchi $L_{25}$ orthogonal array without doing any experiment. It was clearly reveals that the results are good agreement with obtained TOPSIS method. Consequently, 25$^{th}$ experiment has the best efficiency compared to the obtained results of the experiments and TOPSIS method. It is determined that the highest percentage recovery of copper from malachite ore can be achieved using only experimental design data without performing any experiments. For future works, this process can be also extended with using various MCDM methods.

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