Optimization of Leaching Parameters of Copper from Malachite Ore Using Multi Attribute Utility Theory

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Abstract
In this study, leaching parameters were optimized the recovery copper from malachite ore using Multi Attribute Utility Theory (MAUT) which is a Multi Criteria Decision Method (MCDM). TAGUCHI method was used to obtain decision matrix. In MAUT method five different attributes; time, temperature, agitation rate, concentration of solid/liquid ratio in five levels were used. The criteria weights, means relative importance of criteria to each other, were obtained by Analytic Hierarchy Process (AHP). After leaching experiments, 25th experiment condition was the most effective experiment for percentage recovery of copper. Similarly after the application of MAUT method to process, the 25th experiment condition was also found the most effective experiment condition. Experiment and MAUT method results were good agreement for rank for percentage recovery of copper from malachite ore. It was seen that the MAUT method was applicable for any leaching process.

Key words: Leaching, malachite, optimization, MAUT, MCDM

1. Introduction

Copper is used mostly in the areas of construction, transport, and all kinds of electrical and electronic applications, because of its malleability, ductility, conductivity of both heat and electricity [1]. Copper reserves are mostly present in the form of oxide and sulfide minerals such as malachite, azurite, bornite, chalcopyrite [2]. Hydrometallurgical process is generally preferred to extract copper from low grade ores, especially copper oxide since most of the copper ores contain only a very small percentage of copper minerals. It is complicated to optimize the any leaching process since it is affected simultaneously various conditions such as concentration of leaching agent, leaching temperature, leaching time, agitation rate and solid/liquid ratio.

In this work, we present an approach related to the optimization leaching parameters of copper from malachite ore in ammonium nitrate solution by using MAUT method from multi criteria methods.

2. Materials and Method

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The malachite ore was supplied from Yozgat region in Turkey. The ore was dried, crushed, grounded and sieved. The chemical composition and X-ray diffraction (XRD) pattern are shown in Table 1 and Figure 1, respectively. All chemical reagents used in this experiment were of analytical grade. The copper content was determined using by the volumetric method.

Table 1. Chemical analysis of malachite ore used in the experiments [3].

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

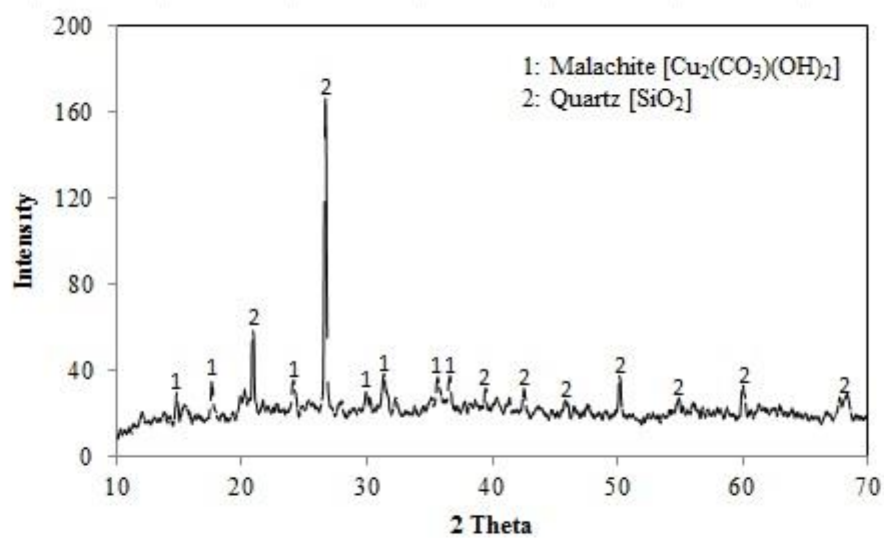

Figure 1. XRD patterns of malachite ore used in this study [3]

2.1. Multi Criteria Decision Making Methods

Multi Decision Making Methods (MCDM) are frequently used to determine the optimum process parameters for several engineering applications [4-6]. A study about leaching process with MCDM method is limited. Different kinds of MCDM methods used for engineering applications. Some of these are TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) [7-10], VIKOR (VlseKriterijumskaOptimizacijaKompromisnoResenje, means Multicriteria Optimization and Compromise Solution) [11, 12], ELECTRE (Elimination and Choice Expressing The Reality) [13], PROMETHE (preference ranking organization method for enrichment evaluation) [14], COPRAS (complex proportional assessment) [15], COPRAS-G (complex proportional assessment with Gray) [16]

2.1.1. Criteria Weighting with AHP Method

There are two methods commonly are used for calculation of criteria weights. One of these, a subjective compromised ranking method is widely used Analytic Hierarchy Process (AHP) [17], and the other one is Entropy method [18].

Firstly Saaty (1977,1980) proposed AHP method for calculation of relative importance of criteria to each other. Saaty model a subjective decision making processes based on multiple attributes in a hierarchical system [19]. AHP has three main steps to evaluate the relative importance: creating hierarchical structure of different criteria, comparative judgment of the alternatives and the criteria, synthesis of the precedence, respectively [4, 7]. The pairwise comparison matrix "A" is used in order to compare a set of "n" criteria pairwise according to their relative importance weights. The pairwise comparison matrix can be represented as [18];

$$A=\begin{bmatrix} a_{11} & \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & & \vdots & & \vdots \\ a_{i1} & \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & & \vdots & & \vdots \\ a_{n1} & \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix}, a_{ii}=1, a_{ij}=1/a_{ji}, a_{ji}\neq 0 \quad (1)$$

Where the criteria is denoted $a_1, a_2, \ldots, a_n$ and $w_1, w_2, \ldots, w_n$ are denoted the relative importance of criteria. The relative importance of between two criteria is determined using Table 2. In real situation w_i/w_j is unknown, with AHP method it will find such that $a_{ij} \cong w_i/w_j$.

Table 2. Ratio Scale in the AHP method [19]

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

A weight matrix is shown as;

$$W=\begin{matrix} & w_1 & & w_j & & w_n \\ w_1 & w_1/w_1 & \cdots & w_1/w_j & \cdots & w_1/w_n \\ \vdots & \vdots & & \vdots & & \vdots \\ w_i & w_i/w_1 & \cdots & w_i/w_j & \cdots & w_i/w_n \\ \vdots & \vdots & & \vdots & & \vdots \\ w_n & w_n/w_1 & \cdots & w_n/w_j & \cdots & w_n/w_n \end{matrix} \quad (2)$$

2.1.1. Multi Attribute Utility Theory

Multi Attribute Utility Theory (MAUT) allows one to systematically consider value judgments of multiple, competing objectives is an analytical method used for decision making problems.

Utility functions are used by MAUT for to model criteria measures. Utility function represents the attributes of desirability on a scale from 0 (desirable) to 1 (undesirable) [20].

Main steps of application of multi attribute utility theory for a decision matrix is described below [21];

(a) The normalization of the decision matrix is performed using Eq. (3). Dimensionless values of different experiment condition are obtained by normalization step.

$$x_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \quad j = 1,2, \ldots, n; i = 1,2, \ldots, m \quad (3)$$

(b) Weighted normalized decision matrix obtained by using Eq. (4)

$$V_{ij} = w_j * x_{ij} \quad (4)$$

(c) Beneficial values of decision matrix obtained by Eq. (5)

$$B_i = \sum_{i=1}^{m} V_{ij}$$

Calculated B_i values are rank from 0 to 1.

3. Results

3.1. Criteria Weighting

The selection of leaching parameters of copper from malachite ore was considered in the light of MAUT in this section. Criteria weights were calculated by AHP method. The criteria was compared with pairwise based on experience of the author about leaching process using scale Table 1. A pairwise comparison matrix for criteria was compiled Table 3 for criteria of time, temperature, agitation rate, concentrations of solid/liquid ratio. Table 4 shows that the criteria weights of leaching parameters were obtained by AHP method.

Table 3. 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 4. Criteria weights

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

3.2. Multi Attribute Utility Method

The decision matrix is used in the application of the MAUT (Table 5). Five criteria, five level decision matrix was designed with Taguchi method. The B_i values were obtained with MAUT by Eqs. (3), (4), (5) seen in Table 6.

Table 5. 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 6. B_i values

	Time	Temperature	Agitation rate	Concentration	Solid/Liquid ratio	B_i	Rank
1	0,0146	0,0345	0,0159	0,0024	0,0049	0,0723	**25**
2	0,0146	0,0444	0,0265	0,0048	0,0098	0,1001	**24**
3	0,0146	0,0542	0,0371	0,0073	0,0195	0,1327	**23**
4	0,0146	0,0641	0,0477	0,0097	0,0293	0,1654	**17**
5	0,0146	0,0739	0,0583	0,0121	0,0390	0,1980	**11**
6	0,0293	0,0345	0,0265	0,0073	0,0293	0,1268	**22**
7	0,0293	0,0444	0,0371	0,0097	0,0390	0,1594	**18**
8	0,0293	0,0542	0,0477	0,0121	0,0049	0,1482	**20**
9	0,0293	0,0641	0,0583	0,0024	0,0098	0,1638	**16**
10	0,0293	0,0739	0,0159	0,0048	0,0195	0,1435	**21**
11	0,0585	0,0345	0,0371	0,0121	0,0098	0,1520	**19**
12	0,0585	0,0444	0,0477	0,0024	0,0195	0,1725	**15**
13	0,0585	0,0542	0,0583	0,0048	0,0293	0,2052	**9**
14	0,0585	0,0641	0,0159	0,0073	0,0390	0,1848	**12**
15	0,0585	0,0739	0,0265	0,0097	0,0049	0,1735	**14**
16	0,0878	0,0345	0,0477	0,0048	0,0390	0,2139	**7**
17	0,0878	0,0444	0,0583	0,0073	0,0049	0,2026	**10**
18	0,0878	0,0542	0,0159	0,0097	0,0098	0,1773	**13**
19	0,0878	0,0641	0,0265	0,0121	0,0195	0,2100	**8**
20	0,0878	0,0739	0,0371	0,0024	0,0293	0,2305	**4**
21	0,1171	0,0345	0,0583	0,0097	0,0195	0,2390	**3**
22	0,1171	0,0444	0,0159	0,0121	0,0293	0,2187	**6**
23	0,1171	0,0542	0,0265	0,0024	0,0390	0,2392	**2**
24	0,1171	0,0641	0,0371	0,0048	0,0049	0,2279	**5**
25	0,1171	0,0739	0,0477	0,0073	0,0098	0,2557	**1**

3.3. Experimental Results

Experimental results obtained percentage recovery of copper from malachite ore (Table 7).

Table 7. The experiment results

Experiment Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
% Cu	0.513	0.625	0.695	0.758	0.789	0.711	0.762	0.752	0.761
Experiment Number	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	
% Cu	0.709	0.856	0.894	0.928	0.933	0.941	0.861	0.853	
Experiment Number	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	
% Cu	0.889	0.855	0.916	0.831	0.873	0.892	0.936	0.987	

4. Discussion

The percentage recovery of copper from malachite ore was rank by the MAUT method and experimental for different experiment conditions. Decision matrix was obtained using TAGUCHI method. Relative importance of weights was evaluated with AHP method. As seen the experimental results, the most efficient parameter is time which was achieved with AHP method. Similarly the results of experiment and MAUT method were good agreement for rank for percentage recovery of copper from malachite ore.

B_i values were calculated with MAUT method and the highest values were given the best rank for leaching process. According to the ranking of alternatives with MAUT method is 25-24-23-21-15-22-20-18-16-17-19-13-6-10-9-14-8-12-5-2-11-7-4-3-1 which indicates that the optimum leaching experiment condition was obtained as 25th and the worst experiment condition was obtained as 1th. The comparison of rankings obtained from MAUT method and experiment were given in Figure 2. The ranks of experimental condition MAUT method and experiment were good agreement. Most efficient experiment condition was obtained 25th for each other, and similarly the worst experiment condition was obtained 1th experiment condition each other too.

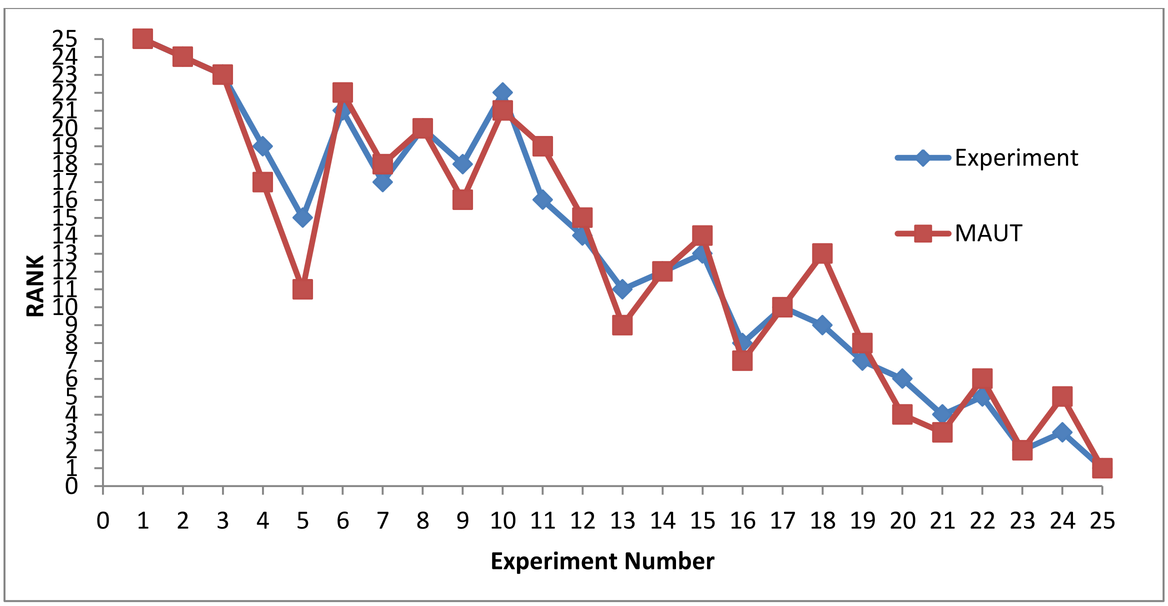

Figure 2. The comparison of rankings obtained from the experiment and MAUT method

5. Conclusions

In this study, the applicability of MAUT method for determine efficient leaching experiment parameters of malachite ore using only experimental design data without performing any experiments has been demonstrated. The efficient of experiment condition for leaching successfully evaluated using MAUT method. The 25th experiment condition; 120 minute, 55^{o}C, 250 rpm, 0.5 mol/L, 1.5 g/mL, the most efficient experiment condition for this leaching process obtained with MAUT method. After leaching experiments, 25th experiment condition was also the most effective condition according to MAUT method. Similarly the worst experiment condition was 1th experiment for experimental and MAUT method. Time parameter for this leaching process was obtained the most effective parameter. It was validated that the MCDM is extremely good approach for solving the complex leaching process. For future works, this process can be also extended with using various MCDM methods.

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