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# Alunite processing method selection using the AHP and TOPSIS approaches under fuzzy environment

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ABSTRACT

Alunite is the most important non bauxite resource for alumina. Various methods have been proposed and patented for processing alunite, but none has been performed at industrial scale and no technical, operational and economic data is available to evaluate methods. In addition, selecting the right approach for alunite beneficiation, requires introducing a wide range of criteria and careful analysis of alternatives. In this research, after studying the existing processes, 13 methods were considered and evaluated by 14 technical, economic and environmental analyzing criteria. Due to multiplicity of processing methods and attributes, in this paper, Multi Attribute Decision Making methods were employed to examine the appropriateness of choices. The Delphi Analytical Hierarchy Process (DAHP) was used for weighting selection criteria and Fuzzy TOPSIS approach was used to determine the most profitable candidates. Among 13 studied methods, Spanish, Svoronos and Hazan methods were respectively recognized to be the best choices.



## 1. Introduction

There is a wide range of processing methods for alunite that are created in order to access the maximum recovery of alumina and its peripheral products, using various operation units such as pre-concentration, calcination, leaching, and crystallization, utilizing different reagents including acids and bases. The only processing plant built for recovering alumina and potassium sulfate from alunite, was established in Soviet Union in the mid-1960s [1]. Some other investigations in this area were conducted in 1976 by Alumni Consortium on Utah alunite ore reserve at pilot scale [2]. Therefore, lack of technical, operational and economic data makes it hard for researchers to choose the most appropriate processing method. On the other hand, selecting the right process to recover alumina, is a complex subject, requiring complete analysis of technical, economic and environmental factors. The purpose of all these methods is to recover aluminum and potassium complexes and to remove impurities such as silica and iron. Also if the reagents used in a method, for example sulfuric acid, is able to be reused in the process stages, this is considered as an advantage of the method. Every processing method has some advantages and disadvantages. Containing fewer steps, flexibility to turn into a continuous process, requiring less reagents and lower temperature, are among advantages of a method. In a case that technical and economic data is insufficient, it is a difficult challenge to analyze advantages and disadvantages of different methods and to compare preferences. According to the characterization of alunite ore, selecting the right processing method involves various criteria analyzing with different levels of importance, such as process products (alumina and potassium sulfate), flow sheet operational complexity, operating and investing costs and environmental effects especially sulfur dioxide ($SO_2$) emission. Due to the lack of quantitative data on alunite processing, selection of the best approach has to be done using qualitative data. Since there are variety of factors with different impact areas, advanced multiple criteria decision making approaches have to be utilized. Otherwise, selecting the most appropriate method would not have enough accuracy and speed.

Multi criteria decision making approaches have been used in many engineering and economic research areas, for instance, they are utilized when choosing the optimum mining method, which is one of the most critical stages of mine design. The best possible mining method was selected with Monte Carlo Analytical Hierarchy Process for Jajarm bauxite mine in Iran by Ataei and associates [3]. Additionally, Karimnia and Heydar determined the most appropriate mining method for Qapiliq, a salt mine in Iran, using Fuzzy Analytical Hierarchy Process, in 2015 [4].

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But these techniques have been rarely utilized for selecting the best process, having a significant rule in technical, economic and environmental issues. In 2008, multiple criteria decision making approaches were used by Ding and associates in order to control critical roasting process on iron-containing ore in cylinder furnaces [5]. In 2009, these approaches were utilized to select Distributed Control System for controlling chemical processes in order to maximize equipment purchasing speed and minimizing investing costs [6]. The research on renewable energy resources to reduce carbon gas emission, which is part of energy policy, was conducted by Doukas and associates using Fuzzy TOPSIS, in 2009 [7]. In 2010, the location for the mineral processing plant at the Sangan iron ore mine was selected utilizing the Analytical Hierarchy Process (AHP) considering eight criteria [8]. In addition, a decision for selection of the best primary among available primary crushers was made using Multi-Criterion Decision Making (MCDM), in 2014 [9].

In this research, after preliminary considerations, evaluating criteria were determined and different processing methods were listed. These criteria were weighted using paired comparisons in Delphi Analytical Hierarchy Process (DAHP) and then different processing methods were considered utilizing Fuzzy TOPSIS.

Finally, sensitivity was analyzed on changing criteria weights and the best methods were introduced.

## 2. Methods and patterns

### 2.1. Stages review

The evaluation process in this research is shown in Fig. 1. After determination of criteria and analyzing different alunite processing methods, "choices" were introduced. By creating a form, shown in Table 1, and asking experts and specialists to fill it out, the weights of each criterion were calculated using DAHP. In the next step, Expert Choice software was utilized to determine weights and also incompatibility factor. Then, by using Fuzzy TOPSIS, choices were scored with regard to the criteria, and were finally sorted. The explanation of main stages is provided in subsections.

### 2.2. Evaluation criteria

Fig. 2 shows a general view of alunite processing methods and peripheral products. Calcination and leaching are among the most important operating units to separate alumina from tailings. The critical difference of these methods is in the possible combinations of these units. Generally, alunite calcination is carried out in four ways; simple calcination, oxidizing, reducing, and calcination in the presence of some salts, such as potassium chloride and sodium chloride. Alunite calcination at high temperatures decreases solubility of alumina. To overcome this problem, calcination is carried out at lower temperatures with potassium chloride and sodium chloride. Therefore, alumina is leached without undesired solution of silica, in lower-cost circumstances i.e. pressure, temperature, and soluble concentrates [10].

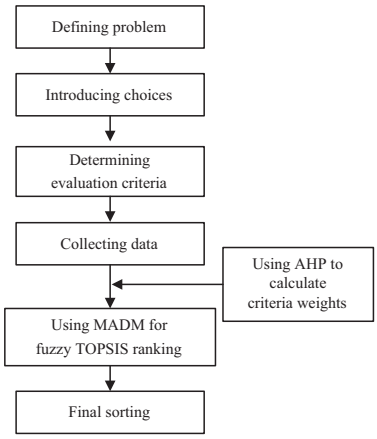


**Fig. 1.** Research procedure stages.

Next unit is leaching that can be performed either in acidic form or in alkaline form. In cases of alkaline leaching, calcination unit can be omitted in certain processes, for example Nasyrov and Hazen [11,12], which will cause changes in future units as well. But in processes containing acidic leaching, calcination unit is necessary before leaching. Leaching can be performed in one or two steps, depending on process type. In case of alkaline leaching, silica complexes of the ore turn into insoluble aluminosilicate and leave the circuit as tailing. As a result, the quantity of alumina and base decrease and recovery of alumina falls. Obviously, it is recommended to remove silica from the solution in alkaline leaching processes [11]. Acidic leaching on low-grade ore types faces some problems, for example, alumina contamination with iron oxide impurities existing in alunite; therefore, producing iron-free aluminum complexes is the aim in most methods [10–17].

According to preliminary researches on worldwide alunite processing methods, 13 different methods with certain technical and environmental circumstances were selected and mentioned in Table 2, by the researchers' names. Almost all alunite processing methods, obey these 13 methods, except in operational details. Concerning alunite processing methods, the most appropriate criteria can be categorized into 3 main groups, technical, economic and environmental criteria, with some sub criteria in each group (see Table 1). In Fig. 3, the relation between criteria is shown in a hierarchical structure in order to choose proper methods.

### 2.3. Decision making approaches

#### 2.3.1. Delphi Analytical Hierarchy Process (DAHP)

Analytical hierarchy process is one of the most comprehensive systems for multiple criteria decision making [18]. The method was first used by Saaty in 1980 [19]. AHP is a tool to combine qualitative and quantitative factors in selecting a process and to determine preferences in an unpredictable issue [20].

The main advantage of this approach is the ability to solve problems with complex structures on a paired comparison basis that cannot be solved with usual mathematical methods. With Fuzzy Delphi, in addition to the option of saving time and money, experts' opinions are known. Changing the weights of criteria according to experts' views is a basic feature in this approach [20,21].

#### 2.3.2. TOPSIS

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) can be used both as a weighting approach and as a MADM approach. TOPSIS is based on the fact that ideal choice is the highest priority for all criteria whereas negative ideal is a choice with lowest priority for all criteria. The principle of this approach is that the best choice should have the most similarity to the ideal and the most dissimilarity to the negative ideal, of a geometrical aspect. In this approach, it is assumed that all criteria have equal increasing or decreasing profit [22]. Considering all possible solutions simultaneously, simple calculation process and simple programming are amongst features of this approach.

#### 2.3.3. Fuzzy TOPSIS

In this section some important explanations and definitions are presented. It is usually challenging for decision makers to rank the operation on choices for criteria. The advantage of fuzzy theory is

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