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MODELLING OF THE PRECIPITATION PROCESS OF ALUMINIUM HYDROXIDE FROM ALUMINATE SOLUTIONS BASED ON FUZZY LOGIC THEORY

G.I. Alyshanly, A.A. Geidarov, A.N. Mammadov, S.Kh. Kalantarova

Acad. M. Nagiyev Institute of Catalysis and Inorganic Chemistry
National Academy of Sciences of Azerbaijan
e-mail: alishanova91@mail.ru

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Abstract: *The article deals with the application of the fuzzy logic approach to the stage of precipitation of aluminum hydroxide from sodium aluminate solutions obtained from the alkaline solution of raw alunite by hydrogen peroxide as an eco-friendly reagent. Factors influencing the precipitation of aluminum hydroxide in the presence of H_2O_2 from poor aluminate solutions include the concentration of hydrogen peroxide, the volume of hydrogen peroxide, and other parameters. The application of fuzzy logic to this process allows calculating the probabilities that the parameters can occur not only in one value but in a wide range as well, to find the optimal conditions for obtaining high-yield aluminum hydroxide. Based on the results of the experiments, it is possible to precipitate aluminum hydroxide with a yield of 92% using 15.5 ml of 17% hydrogen peroxide at 25 °C using fuzzy sets suitable for low, medium and high levels, and this figure can be increased or decreased by changing the parameters. The simulation of process control through a fuzzy logic controller is compiled using membership functions in Matlab.*

Keywords*: aluminum hydroxide, hydrogen peroxide, fuzzy logic, precipitation*
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Introduction

Fuzzy logic theory is a new approach used to imitate human thought using calculations and operations with fuzzy sets and linguistic variables, and its application to various fields of science has been growing rapidly in recent years. Fuzzy logic is not fixed or precise, but an approximate form of thinking. Traditional binary sets have a value of truth such as 0 or 1, which is true or false, and fuzzy logic can take any value between 0 and 1 [1].

It is not possible to model processes in fuzzy and uncertain systems using ordinary mathematical equations (eg. differential equations). Mandani's fuzzy logic control [2] and Lutfi-Zadeh's [3] fuzzy set theory are relevant research topics in the process automation and control theory.

Several studies on the application of the fuzzy logic approach to various chemical processes are also being studied [4], for example, the optimization of the pH in the environment [5]. Moreover, this theory was applied to the process of processing alunite. After studying the existing processes, authors of [6] evaluated 13 methods of processing alunite on 14 criteria of technical, economic, and environmental parameters, and which methods are more effective have been studied through fuzzy logic theory.

In the production of alumina during the processing of alunite ore, firstly, the ore is dissolved in an alkaline solution, the aluminate solution separates from the insoluble residue, desilication [7-8] and then aluminum hydroxide is precipitating from this solution, mainly using the carbonization method. A variety of other chemicals (e.g., ethanol [9], hydrogen peroxide [10], ammonia [11]) may also be used as a precipitant agent at this stage. As this process is a major step in the alunite ore processing for the production of the target product, process management matters as well.

This paper presents the application of fuzzy logic theory to the stage of precipitation of aluminum hydroxide from aluminate solutions obtained on the basis of new alunite technology [12]. This technology allows to exploit both poor and rich alunite deposits, simply, cheaply, efficiently and eco-friendly.

Since the main factors influencing the precipitation of aluminum hydroxide are the concentration and volume of the precipitator, the optimization of these parameters is one of the main objectives to find the appropriate conditions [13], so fuzzy logic control was to optimize the process. The fuzzy logic theory has been applied to determine the optimum conditions that make it possible to achieve maximum results, and the main purpose of the work is to increase the yield of aluminium hydroxide by controlling the conditions. Parameter simulation was performed by using the MATLAB's Fuzzy Logic toolbox.

Experimental part

Fuzzy logic is a systematic and mathematical approach to imitate human thought and logical reasoning. It provides an instinctive or promising way to implement decision-making, diagnostic, and monitoring system. The two key components of fuzzy logic are linguistic variables and membership functions. Linguistic variables are beings used to represent qualities that span a certain spectrum. Membership functions are user-defined values for linguistic variables [14]. Thus, a person's ability to think logically can be realized through a fuzzy logic approach to the management complex real-world systems.

The fuzzy logic controller is based on expert knowledge that provides tools to transform the control strategy for linguistic variables into an automatic control strategy.

Fuzzy inference systems are also referred to as fuzzy controllers when used as fuzzy rule-based systems, fuzzy patterns, fuzzy associative memory, and controllers. Fuzzy inference systems are primarily made up of functional blocks (Fig.1) [15].

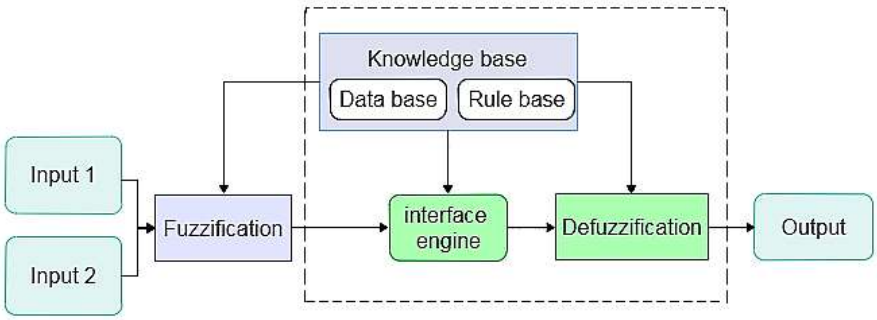


Fig. 1. Fuzzy inference system

To summarize this schematic diagram, it ought to be noted that the overall system consists of a rule base made up of several fuzzy rules; a database that defines the membership functions of fuzzy sets used in fuzzy rules; a knowledge base in conjunction with a database and a rule base; a decision-making unit in charge of the rule-summarization process (interface engine); a fuzzy interface that converts explicit input parameters to matching degrees of linguistic variables (fuzzification); a fuzzy interface that converts the fuzzy results of the interface into a clear output [16].

Fuzzy If-Then Rules, also known as fuzzy conditional terms, are labels of If A then B, where A (input) and B (output) are fuzzy characters characterized by the corresponding membership functions. In its short form, fuzzy if-then rules are used to make vague judgments that play an important role in a person's ability to make decisions in terms of uncertainty [17]. A basic note: if the concentration of a solution is high, the volume is low. Concentration and volume are linguistic variables with high and low membership functions [18].

Results and discussion

During the study, an aluminate solution of the following composition obtained from the solution of alunite ore in alkali (NaOH) was used: 52.3 g/l NaOH; 40.8 g/l Al_2O_3; 1.85 g/l KOH; 1 g/l SO_2; 0.39 g/l SiO_2. Experiments weren carried out under certain conditions (concentration of hydrogen peroxide 5-20%; temperature = 25ºC, $V_{H_2O_2}$:V_{sol} = (5-20) ml: 20 ml, with pH control and constant stirring (300 rpm). X-ray analysis and scanning electron microscopy (SEM) of the precipitated aluminum hydroxide are performed on Fig.2.

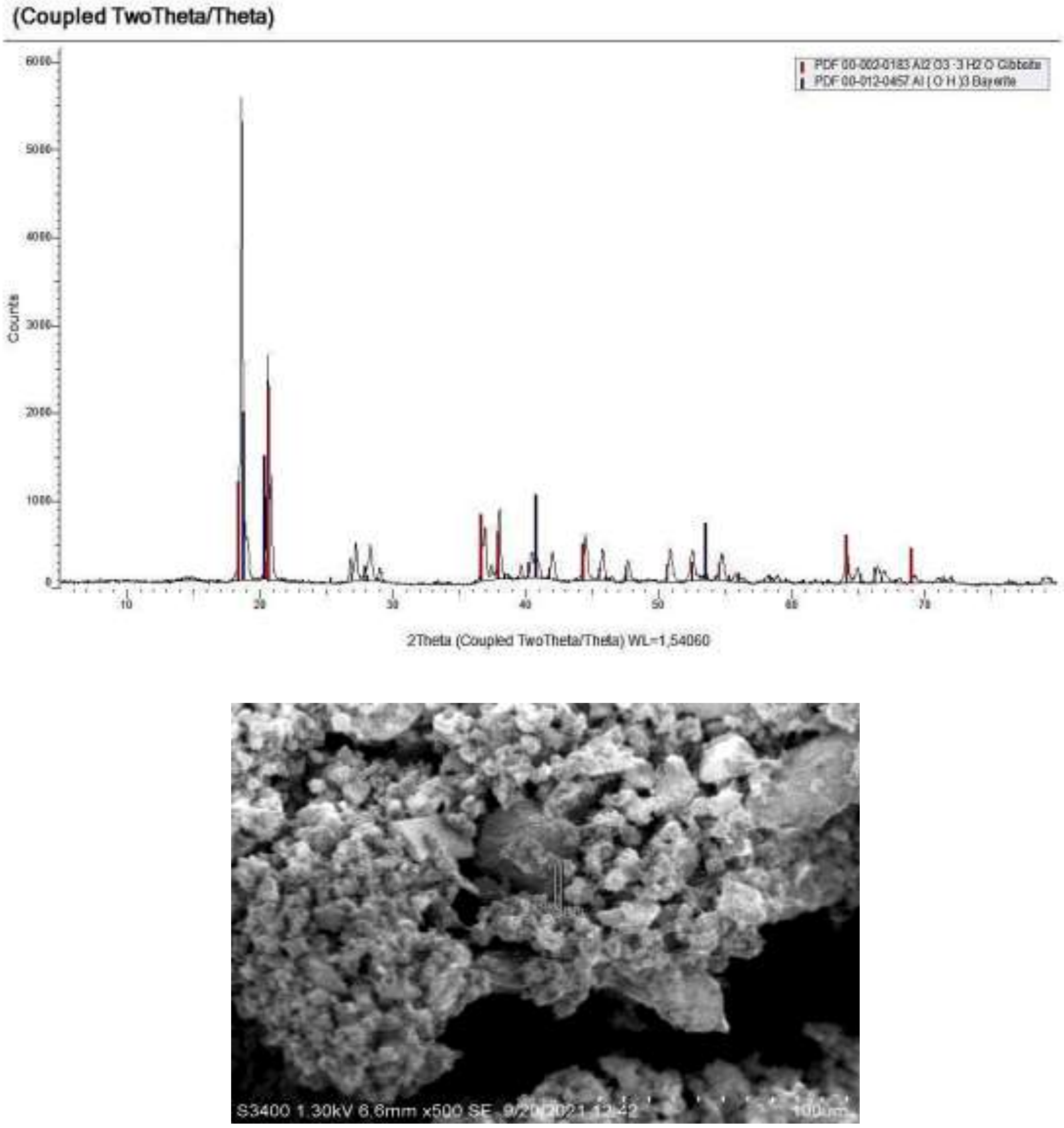


Fig. 2. X-ray analysis and SEM microscopy of precipitated $Al(OH)_3$ (concentration of hydrogen peroxide (10%); volume of hydrogen peroxide (10ml)

The membership functions were selected based on these predetermined conditions and testing outcomes. Initially, the input parameters (concentration and volume of hydrogen peroxide) and the output parameter (precipitation rate of aluminum hydroxide) were entered using the Gaussian and triangular membership functions, respectively. The 9 fuzzy sets based on the if-then rules and used to find the optimal condition, are shown in Tab. 1, and Fig.3 which depict the fuzzy sets created with the Fuzzy Logic Toolbox's rule editor tool.

Table 1. Input membership functions (concentration of hydrogen peroxide (5-20%) 0-5% less than 5-15% average; 15-20% more; volume of hydrogen peroxide (5-20 ml): 0- 5 ml less; 5-15 ml medium; 15-20 ml 15-20.

	Input parameters	Low	Medium	High
1.	Concentration of hydrogen peroxide	+	-	-
	Volume of hydrogen peroxide	+	-	-
2.	Concentration of hydrogen peroxide	+	-	-
	Volume of hydrogen peroxide	-	+	-
3.	Concentration of hydrogen peroxide	+	-	-
	Volume of hydrogen peroxide	-	-	+
4.	Concentration of hydrogen peroxide	-	+	-
	Volume of hydrogen peroxide	+	-	-
5.	Concentration of hydrogen peroxide	-	+	-
	Volume of hydrogen peroxide	-	+	-
6.	Concentration of hydrogen peroxide	-	+	-
	Volume of hydrogen peroxide	-	-	+
7.	Concentration of hydrogen peroxide	-	-	+
	Volume of hydrogen peroxide	+	-	-
8.	Concentration of hydrogen peroxide	-	-	+
	Volume of hydrogen peroxide	-	+	-
9.	Concentration of hydrogen peroxide	-	-	+
	Volume of hydrogen peroxide	-	-	+

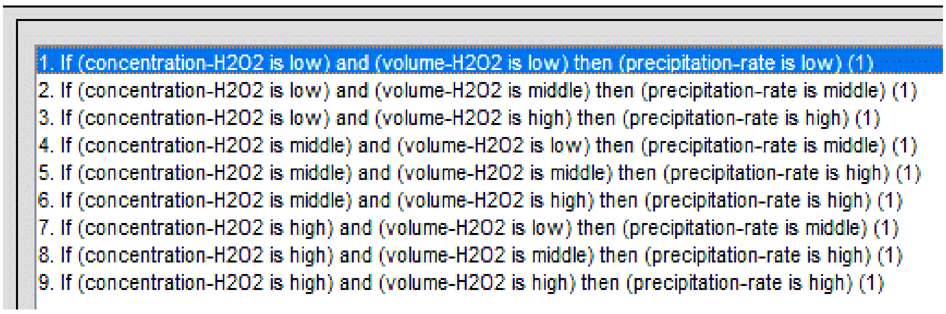
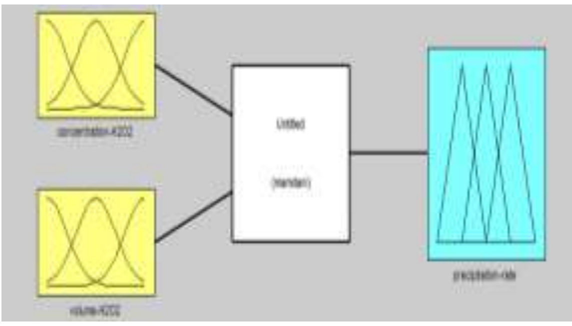
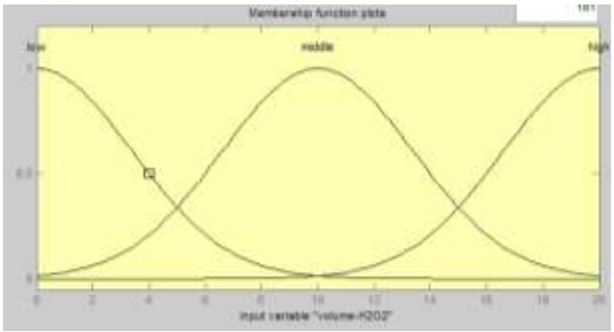


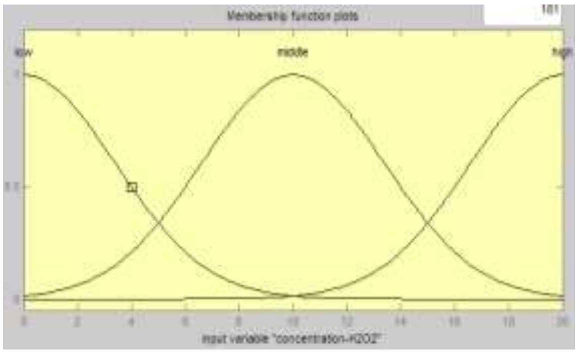
Fig. 3. Fuzzy sets derived from the if-then rules

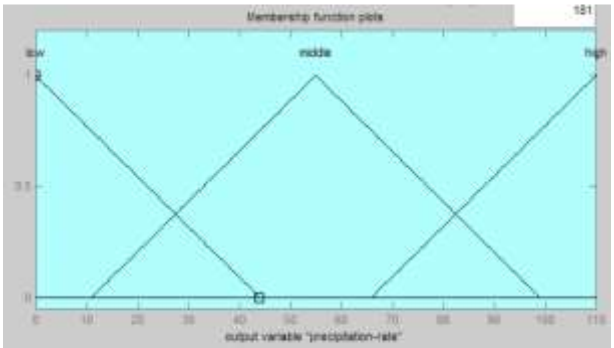
The use of fuzzy logic management to optimize the precipitation process is discussed in this research. The fuzzy rules are created using two input membership functions and an output membership function when the rule base and membership function are developed simultaneously. Fig.4 illustrates the input and output membership functions that had been chosen for the optimization of the process.





a) b)





c) d)

Fig. 4 Simulation of input and output membership functions (a): input - volume of hydrogen peroxide, ml (b), and concentration of hydrogen peroxide (c), %; output – the precipitation rate of aluminum hydroxide (d).

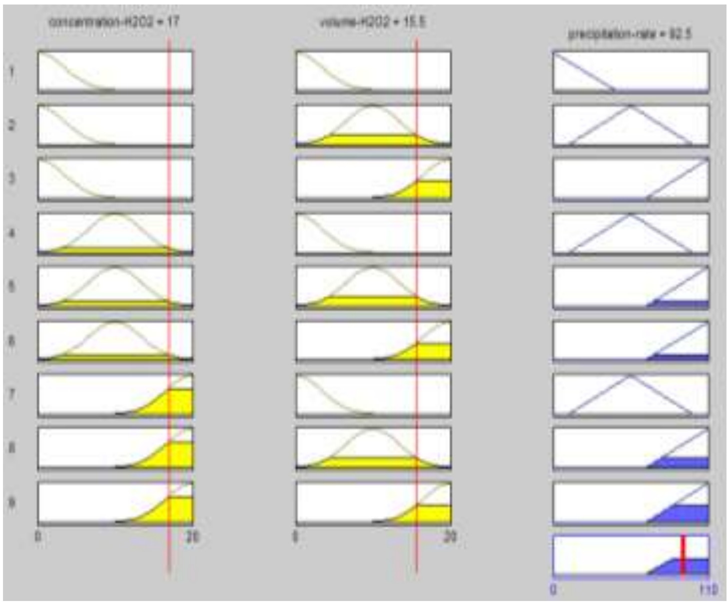


Fig. 5. One of the possible results

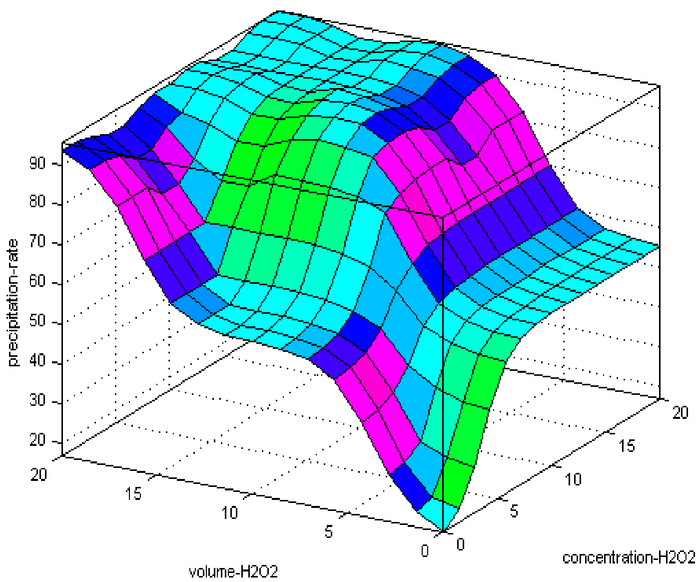


Fig. 6. Plot surface function

The application of fuzzy logic theory to the precipitation process allows us to conclude that it is possible to optimize the process and achieve high yields of aluminum hydroxide by changing the parameters that affect the precipitation in accordance with the purpose.

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ALÜMİNİUM HİDROKSİDİN ALÜMİNAT MƏHLULLARINDAN ÇÖKDÜRÜLMƏSİ PROSESİNİN QEYRI-SƏLİS MƏNTİQ NƏZƏRİYYƏSİ ƏSASINDA MODELLƏŞDİRİLMƏSİ

G.İ. Alışanlı, A.A. Heydərov, A.N. Məmmədov, S.X. Kələntərova

AMEA-nın akad. M.Nağıyev adına Kataliz və Qeyri-üzvi Kimya İnstitutu
AZ 1143, Bakı, H.Cavid pr., 113; e-mail: alishanova91@mail.ru

Xülasə*: Bu işdə xam xam alunitin qələvidə həlledilməsindən alınan alüminat məhlullarından alüminium hidroksidinin ekoloji təmiz reagent olan hidrogen peroksidlə çökdürülməsi mərhələsinə qeyri-səlis məntiq yanaşmasının tətbiqi öyrənilmişdir. Kasıb aluminat məhlullarından H_2O_2 iştirakıyla alüminium hidroksidinin çökməsinə təsir edən amillərə hidrogen peroksidin qatılığı və həcmi kimi parametrlər daxildir. Qeyri-səlis məntiqin bu prosesə tətbiqi bu parametrlərin yalnız bir qiymətində deyil, həm də geniş diapazonda baş verə biləcək mümkün ehtimalları hesablamağa, alüminium hidroksidin yüksək çıxımını almaq üçün optimal şəraitin tapılmasına imkan verir. Təcrübələrin nəticələrinə əsasən, aşağı, orta və yüksək səviyyələr üçün uyğun qeyri-səlis dəstlər tətbiq etməklə 25°C-də 15.5 ml 17% hidrogen peroksiddən istifadə edərək 92% çıxımla alüminium hidroksidi çökdürmək mümkündür və bu rəqəm parametrləri dəyişdirməklə artılıb və ya azaldıla bilər. Qeyri-səlis məntiq vasitəsilə prosesə nəzarətin simulyasiyası Matlab proqramında üzvlük funksiyalarından istifadə etməklə tərtib edilir.*

Açar sözlər: *alüminium hidroksid, hidrogen peroksid, qeyri-səlis məntiq, çökdürmə.*

МОДЕЛИРОВАНИЕ ПРОЦЕССА ОСАЖДЕНИЯ ГИДРОКСИДА АЛЮМИНИЯ ИЗ АЛЮМИНАТНЫХ РАСТВОРОВ НА ОСНОВЕ ТЕОРИИ НЕЧЕТКОЙ ЛОГИКИ

Г.И. Алышанлы, А.А. Гейдаров, А.Н. Мамедов, С.Х. Калантарова

Институт катализа и неорганической химии им. акад. М.Нагиева
Национальной АН Азербайджана
AZ 1143 Баку, пр. Г. Джавида, 113; e-mail: alishanova91@mail.ru

Аннотация: *В данной работе изучено применение подхода нечеткой логики к стадии осаждения гидроксида алюминия из растворов алюмината натрия, полученного из щелочного раствора сырого алунита, перекисью водорода, являющимся экологически чистым реагентом. К факторам, влияющим на осаждение гидроксида алюминия в присутствии H_2O_2 из бедных алюминатных растворов, относятся концентрация, объем перекиси водорода и другие параметры. Применение нечеткой логики к этому процессу позволяет рассчитать вероятности того, что параметры могут встречаться не только в одном значении, но и в широком диапазоне, найти оптимальные условия для получения высокопродуктивного гидроксида алюминия. По результатам экспериментов можно осадить гидроксид алюминия с выходом 92 %, используя 15.5 мл 17 %-ной перекиси водорода при 25 °C с использованием нечетких наборов, подходящих для низкого, среднего и высокого уровней, и эту цифру можно увеличивать или уменьшать путем изменения параметров. Моделирование управления технологическим процессом через контроллер с нечеткой логикой компилируется с использованием функций принадлежности в Matlab.*

Ключевые слова: *гидроксид алюминия, перекись водорода, нечеткая логика, осаждение.*