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CLEANING OF THE HEAT EXCHANGER FROM NaX ZEOLITE

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Abstract

In this study, the dissolution of NaX-type zeolite deposits from the surface of a heat exchanger was investigated using nitric acid solutions of varying concentrations. The main objective was to remove the zeolite layer without damaging the aluminum-based structure of the exchanger. Experimental results showed that a 42% nitric acid solution achieved complete dissolution of the zeolite within 30 minutes, without causing corrosion or damage to the metallic surface. In contrast, concentrations above 50% led to significant degradation of the aluminum surface. Post-dissolution analysis by Inductively Coupled Plasma Optical Emission Spectroscopy (ICPE-OES) confirmed the presence of aluminum (95.72%), sodium (2.44%), magnesium (1.17%), and calcium (0.67%) in the residual material, indicating effective removal of the zeolite phase and preservation of the heat exchanger material. These findings demonstrate that a controlled 42% nitric acid treatment provides an effective and safe method for restoring the operational capacity of aluminum-based heat exchangers fouled with NaX zeolite deposits.

Keywords: *Heat exchanger, NaX zeolite, nitric acid dissolution, ICPE-OES analysis, optimal acid concentration*

Introduction

Heat exchangers are an integral technological element of the oil and gas industry, enhancing the overall efficiency of production processes by effectively transferring energy from one medium to another. In particular, aluminum-based heat exchangers are widely used due to their lightweight nature, high thermal conductivity, and resistance to corrosion. However, the chemical sensitivity of aluminum—specifically its vulnerability to certain chemical reagents and mechanical impacts—requires careful handling during operation and maintenance.

Practical observations have shown that, over time, chemical residues accumulate on the surface of aluminum heat exchangers. This leads to a decrease in heat transfer efficiency, the formation of blockages that hinder the full circulation of gas flows, and, consequently, a significant reduction in the operational efficiency of the entire technological line.

Observations at the Muborak Gas Processing Plant have revealed that during the gas drying process, NaX-type zeolites degrade into fine powder and mix with the gas flow. In the subsequent stages, this powder accumulates on the internal surfaces of aluminum heat exchangers, negatively impacting their performance. The primary cause of the accumulation of solid particles in the heat exchangers is associated with the low chemical stability of NaX zeolites and the aggressive effects of acids, aldehydes, and ketones present in the gas on the zeolites.

Zeolites are natural and synthetic mineral compounds characterized by a high degree of porosity and a crystalline structure. They are widely used in the chemical and gas industries as adsorbents, catalysts, and ion-exchange materials. Their primary structure consists of $[SiO_4]^{4-}$ and $[AlO_4]^{5-}$ tetrahedra, which are interconnected through oxygen atoms to form a complex aluminosilicate framework. Within this framework, pores and channels are designed for ion exchange and molecular adsorption. The internal stability of zeolites is maintained by cations such as Na^+, K^+, Ca^{2+}, and water molecules.

The raw gas supplied to the Muborak Gas Processing Plant primarily consists of methane (92.312%), along with additional components such as ethane, propane, butane, pentane, and other heavier hydrocarbons, as well as inert components (nitrogen, carbon dioxide) and reactive compounds (water, aldehydes, acids, ketones).

These components, particularly acids and carbonyl compounds, weaken the chemical structure of zeolites by degrading their molecular framework, leading to the loss of hardness in the NaX zeolite. As a result, the degraded zeolite particles move in powder form through the heat exchangers and accumulate on aluminum surfaces, causing blockages.

This article scientifically analyzes the causes of NaX zeolite degradation, the mechanism of clogging in aluminum heat exchanger equipment, and technological approaches to prevent or mitigate these problems.

Material and methods

In this study, a SHIMADZU ICPE-9800 model Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) instrument was used to determine the inorganic elements in the samples. This method allows the simultaneous and highly accurate detection of multiple elements within a material. ICP technology operates based on argon gas: a high-frequency radiofrequency (RF) field ionizes the argon, creating a high-temperature plasma reaching approximately 10,000 K.

The sample is introduced into the plasma in solution form using a specialized nebulizer. At such high temperatures, atoms and ions within the sample become excited and, upon returning to their ground state, emit light at characteristic wavelengths. Since each element has a unique emission spectrum, the qualitative and quantitative composition of the elements in the sample can be determined by measuring the intensity of the emitted radiation.

This method is particularly sensitive for detecting the concentrations of aluminum, sodium, silicon, calcium, iron, and other metal ions. Additionally, the ICP-OES technique is distinguished by its speed, accuracy, wide dynamic range, and low background noise.

X-ray Diffraction (XRD) Analysis

To assess the crystallinity, phase composition, and morphological changes of the zeolite powders, X-ray Diffraction (XRD) analysis was employed. This method is a universal physical-analytical technique used to determine the internal crystalline structure of materials. X-rays are a part of the electromagnetic spectrum with short wavelengths (0.01–10 nm) and high energy, and they are diffracted by the atomic arrangements in crystalline materials.

The diffraction patterns are interpreted according to Bragg's Law ($n\lambda = 2d \sin\theta$), where λ is the X-ray wavelength, d is the interplanar spacing, θ is the diffraction angle, and n is an integer. Each phase has distinct diffraction peaks, which can be identified on the XRD pattern (plotted against the 2θ angle). The intensity and position of these peaks allow for the determination of the phase composition, degree of crystallinity, and disorder within the zeolite sample.

Through XRD analysis, valuable information was obtained regarding the extent of degradation of NaX zeolite powders, the transition from crystalline to amorphous states, and the transformation into other phases (such as amorphous aluminosilicates or weakened skeletal structures).

Result and discussion

Initially, a sample was taken from the heat exchanger, and XRD analysis was performed. The results are presented in Table 1.

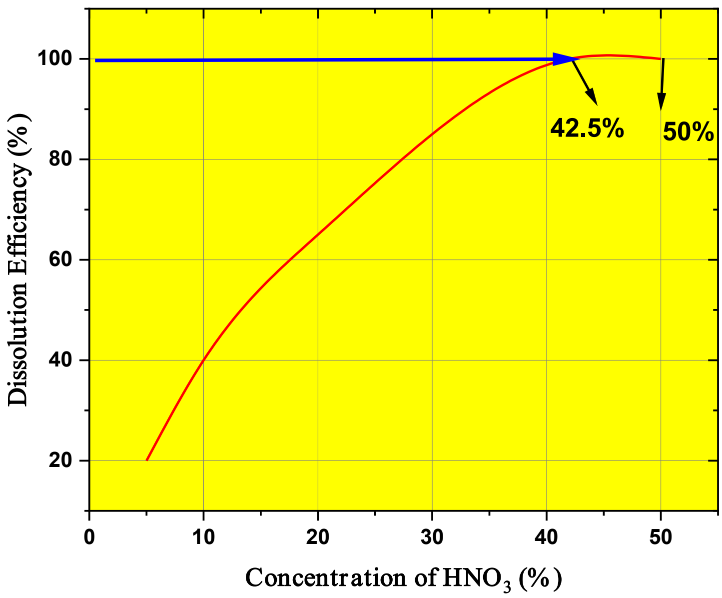
Table 1. *XDR peak data table*

Peak no.	2 Theta (°)	d-spacing (Å)	Relative Intensity (I/I1 %)	FWHM (°)	Intensity (counts)	Integrated Intensity
1	17.8684	4.96007	5.0	0.7142	99.0	2445.0
2	20.7108	4.28531	3.0	1.6222	57.0	1649.0
3	21.1097	4.20523	5.0	0.0	91.0	0.0
4	21.9077	4.05382	5.0	0.0	102.0	0.0
5	23.0051	3.86287	4.0	2.1834	79.0	4360.0
6	38.1852	2.35497	8.0	0.7876	150.0	3041.0
7	39.2644	2.29269	99.0	0.5441	1889.0	21349.0
8	42.3197	2.13397	15.0	0.5431	289.0	3539.0
9	78.5834	1.21639	56.0	0.4755	1069.0	11122.0
10	45.4323	1.99474	100.0	0.5608	1913.0	23080.0

According to table 1, Based on the XRD analysis results, peaks numbered 10, 7, and 29 were identified as having the highest diffraction intensities. Peak 10, located at 2θ = = 45.4323°, exhibited maximum intensity (100%) with a d-spacing of 1.99474 Å; this peak corresponds to the (111) plane of metallic aluminum. Peak 7 was detected at 2θ = = 39.2644°, showing 99% intensity and a d-spacing of 2.29269 Å, corresponding to the NaX-type zeolite phase accumulated in the heat exchanger. Peak 29 appeared at 2θ = = 78.5834°, recorded with 56% intensity and a d-spacing of 1.21639 Å; this peak corresponds to the higher-order crystallographic planes of the high-angle aluminum phase. Thus, the XRD results confirmed the presence of metallic aluminum and NaX zeolite as the main phases in the heat exchanger.

In the next stage of the study, to dissolve the zeolites accumulated in the heat exchanger, different concentrations of nitric acid ranging from 10% to 50% were used, and the results are presented in Figure 1.

Figure 1. *The Relationship Between Nitric Acid Concentration and the Dissolution Efficiency of NaX Zeolite*



According to Figure 1, when analyzing the graph showing the relationship between nitric acid concentration and dissolution efficiency, it was observed that the dissolution efficiency increased steadily with the rise in acid concentration. At a concentration of 42.5%, the dissolution efficiency reached its maximum level (100%), enabling the complete dissolution of the zeolite layer without causing any damage to the metallic surface of the equipment.

However, although the dissolution efficiency remained at 50% concentration, damage to the metallic surface was detected as indicated by the decline in the blue line on the graph. Based on this observation, it can be concluded that the optimal nitric acid concentration for the effective and safe cleaning of the heat exchanger is around 42–43%. Higher concentrations may negatively affect the metallic components of the equipment.

After determining the optimal concentrations of the nitric acid solution, ICPE analysis of the heat exchanger was performed. The results are presented in Table 2.

Table 2. *ICPE-OES Analysis Results of Heat Exchanger Surface after NaX Zeolite Dissolution*

Element	Wavelength (nm)	Concentration (%)	Comment
Na	589.592	2.44	Main ion from NaX seolite
Mg	285.213	1.17	Detected after dissolution
Ca	422.673	0.67	Minor contamination
Al	396.153	95.72	Main component of heat exchanger

The ICPE analysis results obtained from the NaX zeolite solution showed that the primary element detected from the heat exchanger was aluminum (Al), with a concentration of 95.72%, confirming that aluminum is the dominant material of the equipment. Sodium (Na) was found at a concentration of 2.44%, resulting from the dissolution of NaX zeolite in nitric acid. Magnesium (Mg) and calcium (Ca) were detected at concentrations of 1.17% and 0.67%, respectively, likely originating either from the zeolite structure or from minor impurities introduced during the dissolution process. Overall, the analysis results indicate that after the dissolution process, the material primarily consists of aluminum, while the main ions from the NaX zeolite have been transferred into the solution.

Conclusion

In this study, different concentrations of nitric acid were tested to dissolve the NaX-type zeolite layer hardened inside the heat exchanger without causing damage to the equipment. The dissolution experiments revealed that a 42% nitric acid solution provides optimal conditions for completely dissolving the zeolite layer while preserving the metallic surface of the heat exchanger. The dissolution efficiency and the extent of impact on the metal surface were evaluated based on concentration and time parameters. At concentrations higher than 50%, signs of corrosion were observed on the aluminum surface.

After the dissolution process, samples taken from the device surface were analyzed using ICPE-OES. According to the analysis results, aluminum (95.72%), sodium (2.44%), magnesium (1.17%), and calcium (0.67%) were identified, confirming that the primary metallic material—aluminum—was largely preserved, while the structural ions of the zeolite had migrated into the solution. The XRD and ICPE results, along with the evaluation of the dissolution conditions, enabled the determination of an optimal dissolution technology.

Overall, the study recommends the use of a 42% nitric acid solution to dissolve NaX zeolite layers without damaging the heat exchanger. This technological approach plays an important role in extending the operational life and reducing the need for maintenance of such equipment.

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