STUDY OF HYDROCHLORIC ACID LEACHING OF UZBEK ALUMINOSILICATES FOR ALUMINUM CHLORIDE AND POLYCHLORIDE PRODUCTION

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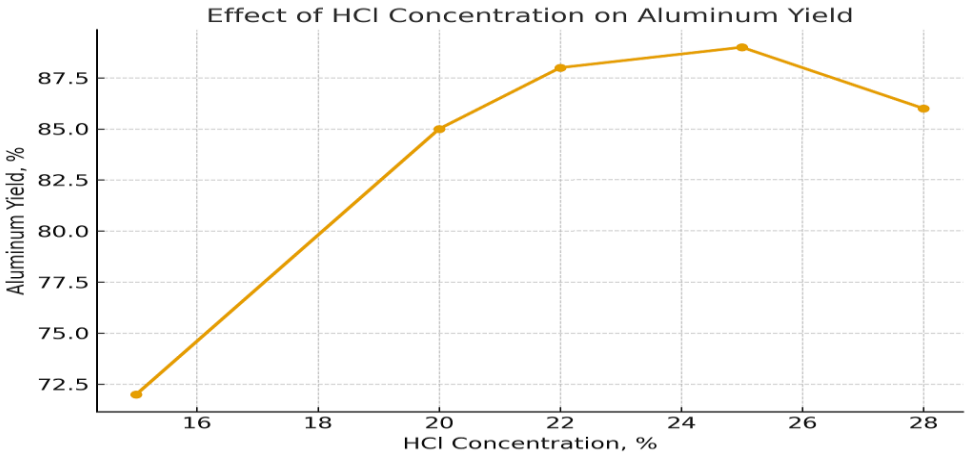
Aluminosilicates are complex minerals primarily composed of aluminum oxide (Al_2O_3) and silicon dioxide (SiO_2), widely distributed across Uzbekistan, particularly in the Fergana Valley, Kashkadarya, Jizzakh, and Navoi regions. These minerals are valuable raw materials for the aluminum industry as well as for water purification, catalyst synthesis, and pigment production. The growing global emphasis on environmentally friendly and economically viable technologies has driven the need for sustainable aluminum extraction methods. Conventional hydrothermal and hydrometallurgical processes are energy-intensive and produce substantial waste. Therefore, hydrochloric acid leaching offers a promising alternative due to its relatively mild conditions, high extraction efficiency, and adaptability to industrial implementation. Processing local aluminosilicates to produce aluminum chloride ($AlCl_3$) and polymeric aluminum chloride (PAC) enables Uzbekistan to utilize domestic raw materials effectively, reduce dependence on imported reagents, and support sustainable development in the national chemical industry. Several studies have examined acid leaching as a viable technique for aluminum recovery from silicate minerals [1–3]. Hydrochloric acid (HCl) leaching has received particular attention due to its strong reactivity with aluminosilicates, forming soluble $AlCl_3$ that can be further processed into PAC and other valuable compounds [4,5]. The leaching efficiency depends on acid concentration, temperature, and reaction duration. Reports indicate that 20–25% HCl solutions at 95–100 °C for 2–3 hours achieve 85–90% aluminum recovery [6]. Higher acid concentrations slightly reduce reaction rates due to increased solution viscosity. PAC, obtained through controlled hydrolysis and polymerization of $AlCl_3$, exhibits excellent coagulation capacity for removing suspended solids, organic contaminants, and heavy metal ions from wastewater [7]. Thus, producing PAC from domestic aluminosilicates presents both economic and ecological benefits for Uzbekistan.

Aluminosilicate raw materials were obtained from deposits located in the Fergana, Kashkadarya, and Jizzakh regions. Each sample was crushed, dried at 105 °C, and ground to a particle size below 0.1 mm. The chemical composition was analyzed using X-ray fluorescence (XRF), revealing an average content of 48–52% SiO_2, 24–28% Al_2O_3, and minor oxides of Fe, Ti, and Ca. Leaching experiments were performed using analytical-grade hydrochloric acid (10–30% w/w) at temperatures ranging from 70 °C to 100 °C. The solid-to-liquid ratio was maintained at 1:5 g/mL, and reaction durations varied between 1 and 4 hours under continuous stirring. After leaching, the slurry was filtered to remove insoluble residues.

To visualize the influence of hydrochloric acid concentration on the aluminum extraction efficiency, the experimental results presented in Table 1 were plotted as a concentration–yield relationship. The obtained data clearly demonstrate how variations in acid concentration affect the leaching behavior of aluminosilicate materials. The corresponding dependence is shown in Figure 1.



As illustrated in Figure 1, the aluminum yield increases steadily with the rise in HCl concentration up to 25%, reaching a maximum of 89%. Beyond this point, a slight decline is observed at 28%, which can be attributed to the formation of secondary silica gel and the partial reprecipitation of aluminum compounds. This trend confirms that an optimal acid concentration of around 25% ensures efficient leaching and prevents excessive side reactions, indicating favorable process conditions for aluminum chloride production.

The influence of acid concentration, temperature, and leaching time on aluminum yield was systematically studied. It was observed that aluminum recovery increased with higher acid concentrations up to 25%, beyond which the efficiency slightly decreased due to elevated viscosity and diffusion limitations. Optimal leaching conditions were determined to be 20–25% HCl, 95–100 °C, and 2–3 hours of treatment, providing aluminum yields between 85–89%. Under these conditions, the obtained $AlCl_3$ exhibited 98% purity with Fe impurity ≤0.1% and moisture content of 1.6%.

The influence of hydrochloric acid concentration on the aluminum yield during the leaching process was studied under different experimental conditions. The results are summarized in Table 1.

Table 1.

Relationship between acid concentration and aluminum yield

HCl concentration, %	Temperature, °C	Time, h	Aluminum yield, %
15	95	2	72
20	95	2	85
22	100	2.5	88
25	100	2.5	89
28	100	3	86

As shown in Table 1, increasing the HCl concentration from 15% to 25% significantly enhances the aluminum yield, reaching a maximum of 89%. However, a

further increase to 28% results in a slight decrease, which can be attributed to the formation of secondary silica gel or partial reprecipitation of aluminum compounds. These results indicate that an optimal acid concentration of around 25% ensures the most efficient leaching process under the studied conditions.

The subsequent hydrolysis and polymerization of $AlCl_3$ resulted in the formation of PAC with high coagulation efficiency. Laboratory testing of PAC solutions on simulated wastewater confirmed their strong flocculation capacity, reducing turbidity and metal ion concentrations effectively [8,9]. The results emphasize the potential of Uzbekistan's aluminosilicates as an alternative source for the production of $AlCl_3$ and PAC, reducing reliance on imported coagulants and advancing sustainable industrial chemistry. This research confirms that local aluminosilicate deposits in Uzbekistan can be effectively processed through hydrochloric acid leaching to obtain high-purity aluminum chloride and polymeric aluminum chloride. The optimal technological parameters (20–25% HCl, 95–100 °C, 2–3 h) yield up to 89% aluminum extraction and 98% $AlCl_3$ purity. The proposed method provides an environmentally friendly and cost-effective approach to producing coagulants and catalytic materials domestically, supporting the country's transition toward sustainable and import-substituting chemical production.

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