

DISSOLUTION KINETICS OF SEPIOLITE IN HYDROCHLORIC ACID AND NITRIC ACID

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Abstract—The dissolution kinetics of sepiolite in hydrochloric acid and nitric acid were studied in a batch reactor. The effects of reaction temperature, acid concentration, particle size and solid-to-liquid ratio on the dissolution process were investigated. Experimental studies were carried out in the ranges of 25–75°C for reaction temperature, 0.25–1.00 mol/L for acid concentration, 0.00755–0.05020 cm for average particle size and 2.5 to 12.5 g of solid/100 mL of acid for solid-to-liquid ratio. It was determined that the dissolution process is controlled by resistance of the diffusion through the product layer. The activation energies of the process were determined to be 40.8 and 38.3 kJ/mol for hydrochloric and nitric acid, respectively. The apparent rate constants were expressed as a function of reaction temperature, acid concentration, particle radius and solid-to-liquid ratio: $k\alpha e^{-49.10(1/T)}Cr^{-0.6}(s/l)^{-1}$ and $k\alpha e^{-46.06(1/T)}Cr^{-0.5}(s/l)^{-1}$ for hydrochloric and nitric acid, respectively; k is the apparent rate constant in min^{-1} ; T , the reaction temperature (K); C , the acid concentration (mol/L); r , the initial particle radius (cm); s/l , the solid-to-liquid ratio (g of solid/100 mL of acid).

Key Words—Dissolution Kinetics, Hydrochloric Acid, Nitric Acid, Sepiolite.

INTRODUCTION

Sepiolite is a fibrous clay mineral comprising tetrahedral and octahedral sheets of oxides. The chemical formula is $\text{Mg}_8\text{Si}_{12}\text{O}_{30}(\text{OH})_4(\text{H}_2\text{O})_4 \cdot 8\text{H}_2\text{O}$. It has molecular-sized channels (0.37×1.06 nm), oriented along the longitudinal direction of the fiber (Brauner and Preisinger, 1956). For N_2 gas, its BET surface area ranges from 230 to 380 m^2/g . There are active adsorption centers on sepiolite surfaces, oxygen atoms in the tetrahedral sheet, water molecules coordinated with the Mg^{2+} ions at the edge of the structure, and silanol groups which occurred through break-up of Si–O–Si bonds. For these reasons, sepiolite has a wide range of adsorption and catalytic applications (Galán, 1996).

The surface area and surface activity can be modified by acid treatment which increases the specific surface area, the number of active sites and the porosity, *e.g.* by disaggregation of clay particles, elimination of several mineral impurities, removal of metal-exchange cations and proton exchange (Vicente *et al.*, 1996). Studies of the acid activation of Spanish sepiolite have been carried out to improve the surface area and porosity and the amount of the surface acidity, to determine the structural changes in the sepiolite and to obtain good-quality products for use as adsorbents, filling materials and catalysts (Jimenez-Lopez *et al.*, 1978; Rodriguez-Reinoso *et al.*, 1981; Bonilla *et al.*, 1981; Corma *et al.*, 1984; Corma *et al.*, 1986; Gonzalez-Hernandez *et al.*, 1986; Aznar *et al.*, 1996; Myriam *et al.*, 1998; Dekany *et al.*, 1999; Radojevic *et al.*, 2002; Yebra-Rodriguez *et al.*, 2003).

There are some studies on the acid activation of Turkish sepiolite. Ceylan *et al.* (1989), for example, investigated the effects of HNO_3 activation and heat treatment on the surface activity of sepiolite. Balcı (1996) studied the thermal decomposition of sepiolite and the variations in pore structure with and without acid pre-treatment. Kara *et al.* (2003) investigated the effect of activation conditions on the adsorption of Co from aqueous solutions onto sepiolite. Furthermore, studies of dissolution of Mg from sepiolite by acids were carried out. In the first study concerning kinetics of dissolution, Abdul-Latif and Weaver (1969) found that the reaction was first-order with respect to the Mg, Al and Fe components in sepiolite, and also hydrochloric acid concentration. Çetişli and Gedikbey (1990) and Kıpçak (1999) studied the dissolution kinetics of sepiolite at various temperatures and particle sizes using dilute hydrochloric and nitric acids as solvents. They determined that the dissolution process was controlled by product layer diffusion.

The effects of various parameters on Mg dissolution from sepiolite by acids has been studied extensively but no work has been found in the literature related to a quantitative relationship between solid-to-liquid ratio and reaction rate. The solid-to-liquid ratio is an important parameter in reducing solvent volume and thus, costs. This parameter, in particular, is important in industrial-scale applications. The aim of this study is to investigate the dissolution kinetics of sepiolite in

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Table 1. Chemical composition of sepiolite.

Component	SiO ₂	MgO	Al ₂ O ₃	Fe ₂ O ₃	CaO	TiO ₂	Na ₂ O	K ₂ O	LOI*
%, w/w	57.51	27.52	0.09	0.03	0.90	0.01	0.02	0.01	13.90

* loss on ignition

hydrochloric acid and nitric acid, and to determine the effects of reaction temperature, acid concentration, particle size and solid-to-liquid ratio on the dissolution process. The dissolution kinetics of sepiolite were examined according to heterogeneous reaction models, and the best fitted equation to the experimental data was determined.

MATERIALS AND METHODS

The sepiolite used in this study was obtained from Eskişehir, in Central Anatolia. It was crushed, ground and then sieved using ASTM standard sieves. The chemical composition of the sepiolite used is given in Table 1. The chemical analysis was performed by the classic gravimetric analysis method in which silicates are dissolved with sodium carbonate.

The parameters used in the experiments were reaction temperature, acid concentration, particle size and solid-to-liquid ratio. The values of experimental parameters were selected according to the ranges of the parameters used in the literature studies for comparison, and according to the results of preliminary experimental studies. The values of these parameters are given in Table 2. In the experiments, while the effect of one parameter was studied, the values of the other parameters were kept constant under the following conditions: reaction temperature 75°C (55°C for particle-size parameter); acid concentration 1 mol/1000 mL; average particle size, 0.00755 cm; solid-to-liquid ratio, 2.5 g of solid/100 mL of acid.

Dissolution experiments were carried out in a batch heater-jacketed reactor of 150 mL capacity. The reactor was kept at the desired temperatures by circulating water from a MGW Lauda model constant-temperature bath with ±0.1°C sensitivity. The reactor was also fitted with a condenser to prevent loss through evaporation. A Heidolph MR 3001 model magnetic stirrer was used for constant stirring.

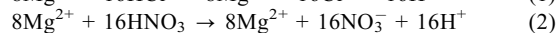
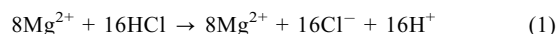
In the experiments, firstly, a definite volume of hydrochloric acid was added to the reactor which was then heated to the reaction temperature. Then, a given

amount of sepiolite was fed into the reactor. The reactor content was stirred at 1250 rpm for a certain reaction period. Samples (2 mL) of solution were taken at fixed time intervals and filtered. The Mg²⁺ in the filtrates was analyzed by volumetric analysis using EDTA solution. In case the filtrate was very acidic, it was coarsely neutralized with NaOH. One Indicator-Buffer tablet was added and, after its dissolution, 1 mL of ammonia solution. Then titration was performed using 0.1 mol/L of EDTA solution until the distinctive color change from red to green occurred (Gülensoy, 1984). For each experimental condition, the experiment was repeated twice, and the arithmetic average of the results of the two experiments was used in the kinetic analysis. The data obtained were calculated as X = the amount of dissolved Mg/the amount of Mg in the original mineral.

RESULTS AND DISCUSSION

Reactions and kinetics models

According to Gonzalez-Hernandez *et al.* (1986), the possible chemical reaction that occurs during Mg dissolution from sepiolite with hydrochloric acid and nitric acid is written as follows:



The heterogeneous reaction process may involve the following individual steps (Wadsworth and Miller, 1979): (1) mass transfer of reactants and products between the bulk of the fluid and the external surface of the solid particle; (2) diffusion of reactants and products within the pores of the product layer; and (3) surface chemical reaction between the reactants in the fluid and in the solid.

The rate equations related to heterogeneous reactions are represented according to the steps controlling the rate of process and the shape of the particles.

Under steady-state conditions and constant liquid reactant concentration for spherical geometry, the general rate expression may be given by the following rate equation:

Table 2. Parameters employed in the experiments.

Parameter	Values			
Reaction temperature (°C)	25	55	65	75
Acid concentration (mol/L)	0.25	0.50	0.75	1.00
Average particle size (cm)	0.05020	0.02535	0.01795	0.00755
Solid-to-liquid ratio (g of solid/100 mL of acid)	2.5	4.0	8.0	12.5

Table 3. The apparent rate constants and R^2 values of heterogeneous models for hydrochloric acid.

Reaction temperature (°C)	Acid concentration (mol/L)	Average particle size (cm)	Solid-to-liquid ratio (g of solid/100 mL of acid)	Kinetic equations			
				$[(1 - (1 - X)^{1/2})^2]$ k (min ⁻¹), 10 ⁻³	R^2	$[1 - \frac{2}{3}X - (1 - X)^{2/3}]$ R^2	$[1 - (1 - X)^{1/3}]$ R^2
25	1.00	0.00755	2.5	0.3	0.98	0.98	0.88
55	1.00	0.00755	2.5	1.4	0.97	0.96	0.32
65	1.00	0.00755	2.5	2.1	0.94	0.92	0.17
75	1.00	0.00755	2.5	3.2	0.97	0.95	0.52
75	0.25	0.00755	2.5	0.9	0.91	0.89	-0.27
75	0.50	0.00755	2.5	1.9	0.97	0.95	0.31
75	0.75	0.00755	2.5	2.6	0.98	0.97	0.51
55	1.00	0.05020	2.5	0.5	0.95	0.95	0.13
55	1.00	0.02535	2.5	0.6	0.94	0.93	0.14
55	1.00	0.01795	2.5	1.0	0.97	0.96	0.32
75	1.00	0.00755	4.0	1.8	0.94	0.93	0.22
75	1.00	0.00755	8.0	1.2	0.93	0.92	0.07
75	1.00	0.00755	12.5	0.5	0.92	0.91	-0.10

R^2 = regression coefficient

$$\frac{\sigma\delta}{D_s}X + \frac{3\sigma r}{2D_e} \left[1 - \frac{2}{3}X - (1 - X)^{2/3} \right] + \frac{3}{k_s} \left[1 - (1 - X)^{1/3} \right] = \frac{3MC}{\rho r} t \quad (3)$$

The first term on the left side of the equation represents film diffusion, the second term diffusion through product layer and the third term the surface chemical reaction. Here, X is fractional conversion (w/w); σ , the stoichiometry factor (the stoichiometric coefficient of the liquid/the stoichiometric coefficient of the solid); δ , the effective minimum thickness of a film layer (cm); D_s , the coefficient of film diffusion (cm²/min); D_e , the effective diffusion coefficient for diffusion through product layer (cm²/min); r , the initial particle radius (cm); k_s , the rate constant for the surface

chemical reaction (min⁻¹); M , the molecular weight of solid (g/mol); ρ , the density of solid (g/mL); C , the liquid reactant concentration (mol/1000 mL); t , the reaction time (min).

The step with the highest resistance is the rate-controlling step. According to the steps given above, a heterogeneous reaction may be controlled by the fluid-film diffusion (step 1), the product-layer diffusion (step 2), or the surface-chemical reaction (step 3). The rate equations for these three steps can be given as follows:

$$\text{Film-diffusion control: } [1 - (1 - X)^{1/3}] = kt \quad (4)$$

$$\text{Surface-chemical reaction control: } [1 - (1 - X)^{1/3}] = kt \quad (5)$$

$$\text{Product-layer diffusion control: } [1 - \frac{2}{3}X - (1 - X)^{2/3}] = kt \quad (6)$$

Table 4. The apparent rate constants and regression coefficients (R^2) of heterogeneous models for nitric acid.

Reaction temperature (°C)	Acid concentration (mol/L)	Average particle size (cm)	Solid-to-liquid ratio (g of solid/100 mL of acid)	Kinetic equations			
				$[(1 - (1 - X)^{1/2})^2]$ k (min ⁻¹), 10 ⁻³	R^2	$[1 - \frac{2}{3}X - (1 - X)^{2/3}]$ R^2	$[1 - (1 - X)^{1/3}]$ R^2
25	1.00	0.00755	2.5	0.3	0.98	0.98	0.89
55	1.00	0.00755	2.5	1.3	0.97	0.96	0.32
65	1.00	0.00755	2.5	1.7	0.93	0.90	-0.05
75	1.00	0.00755	2.5	2.9	0.95	0.94	0.53
75	0.25	0.00755	2.5	0.8	0.92	0.91	-0.27
75	0.50	0.00755	2.5	1.7	0.98	0.97	0.43
75	0.75	0.00755	2.5	2.3	0.98	0.92	0.50
55	1.00	0.05020	2.5	0.5	0.96	0.96	0.57
55	1.00	0.02535	2.5	0.6	0.95	0.95	0.23
55	1.00	0.01795	2.5	1.0	0.98	0.97	0.35
75	1.00	0.00755	4.0	1.7	0.93	0.91	0.06
75	1.00	0.00755	8.0	1.1	0.92	0.90	-0.05
75	1.00	0.00755	12.5	0.5	0.92	0.91	0.11

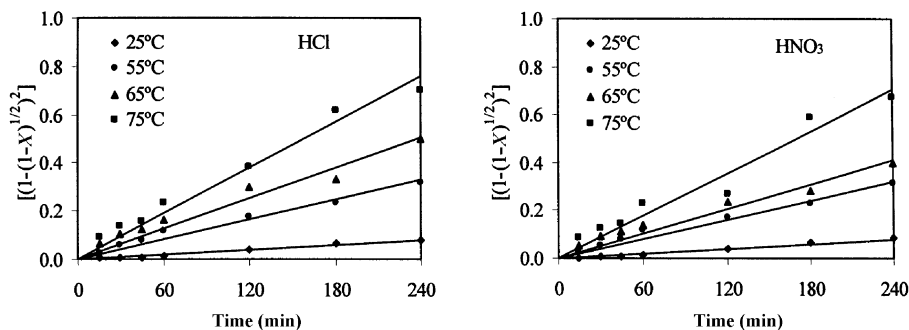


Figure 1. Effect of reaction temperature on the dissolution process (acid concentration = 1 mol/L; average particle size = 0.00755 cm; solid-to-liquid ratio = 2.5 g of solid/100 mL of acid).

The rate equation of product-layer diffusion control for disc-shaped particles is established as follows (Wadsworth and Miller, 1979; Gonzalez-Hernandez *et al.*, 1986):

$$[1 - (1 - X)^{1/2}]^2 = kt \quad (7)$$

The apparent rate constant in equation 7 is $k = 2MD_eC/\sigma\rho r^2$

The apparent rate constant k varies with experimental conditions and is a function of temperature, acid concentration, particle radius, solid-to-liquid ratio, number of active sites on the solid, and the diffusion constant. When sepiolite samples with the same properties are used in all the experiments, the rate constant, considered a function of reaction temperature, acid concentration, particle radius and solid-to-liquid ratio can be expressed by the following equation:

$$k\alpha e^{-E_a/RT} C^n r^m (s/l)^p \quad (8)$$

where E_a is the apparent activation energy (kJ mol^{-1}); R , the ideal gas constant, 8.314×10^{-3} (kJ/mol K); T , the reaction temperature (K); C , the acid concentration (mol/1000 mL); r , the initial particle radius (cm); s/l , the solid-to-liquid ratio (g of solid/100 mL of acid) and n , m and p are the constants.

If acid concentration, particle size and solid-to-liquid ratio are kept constant, the rate constant becomes proportional to reaction temperature and is given as

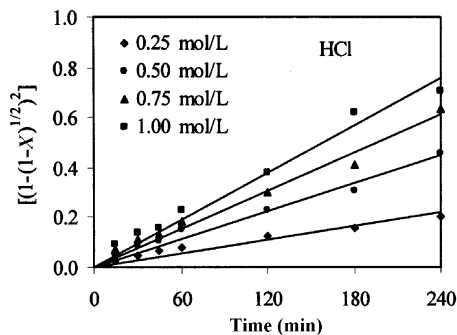


Figure 2. Effect of acid concentration on the dissolution process (reaction temperature = 75°C; average particle size = 0.00755 cm; solid-to-liquid ratio = 2.5 g of solid/100 mL of acid).

follows, considering the validity of the Arrhenius equation:

$$k = k_1' e^{-E_a/RT} \quad (9)$$

when only acid concentration or particle size or solid-to-liquid ratio are varied. Rate constants can be given by the following equations:

$$k = k_2' C^n \quad (10)$$

$$k = k_3' r^m \quad (11)$$

$$k = k_4' (s/l)^p \quad (12)$$

where k_1' , k_2' , k_3' and k_4' are the second-order rate constants. The kinetics of the reactions between sepiolite and hydrochloric and nitric acids were studied statistically and graphically using heterogeneous reaction models. The kinetic analysis shows that the process does not fit the film-diffusion control and the surface-chemical reaction control models. According to these models, plots of $[1 - (1 - X)^{1/3}]$ vs. t should be a straight line when the dissolution reactions follow these. As can be seen in Tables 3 and 4, the R^2 values of these models are <0.89 . Further analysis shows that the dissolution process is expressed with product layer diffusion control. The plots of $[1 - (1 - X)^{1/2}]^2$ and $[1 - \frac{2}{3}X - (1 - X)^{2/3}]$ vs. t give straight lines with correlation coefficients between 0.98 and 0.91, and 0.98 and 0.89, respectively, for both acids as can be seen in Tables 3 and 4. However, the straight lines shown in Figures 1, 2, 3 and 4 show that

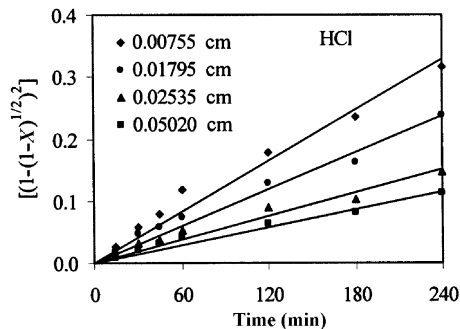


Figure 3. Effect of average particle size on the dissolution process (reaction temperature = 55°C; acid concentration = 1 mol/L; solid-to-liquid ratio = 2.5 g of solid/100 mL of acid).

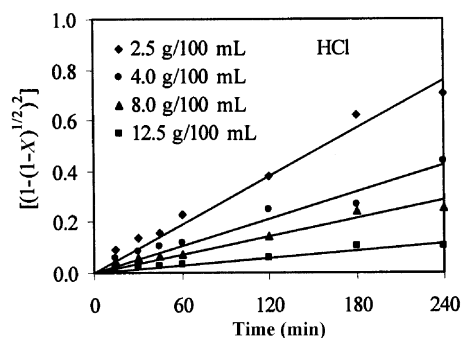


Figure 4. Effect of solid-to-liquid ratio on the dissolution process (reaction temperature = 75°C; acid concentration = 1 mol/L; average particle size = 0.00755 cm).

equation 7 can represent the dissolution process more adequately. In accordance with these results, the equation representing the kinetics of this process can be expressed as $[1 - (1 - X)^{1/2}]^2 = kt$. This situation is in agreement with previous studies. Gonzalez-Hernandez *et al.* (1986) carried out the reactions in the ranges 25–80°C, 1.5–3 mol/L H_2SO_4 acid concentration, 0.005–1.750 mm average particle size and 15 g of solid/100 mL of acid solid-to-liquid ratio. Corma *et al.* (1986) carried out similar reactions in the ranges 25–80°C, 0.05–3 mol/L HCl acid concentration, <0.074 mm of particle size and 25 g of solid/100 mL of acid solid-to-liquid ratio and reported that the dissolution rate was controlled by the product-layer diffusion process. Çetişli and Gedikbey (1990) obtained the same kinetic model in the ranges of 23–54°C reaction temperature, 0.25–2 mol/L HCl and HNO_3 concentrations, 0.1795–0.5020 mm average particle size and 0.5 g of solid/100 mL of acid solid-to-liquid ratio.

Linear regression was used to calculate slopes that are k values. Considering equations 9–12, the $\ln k$ values calculated from these k values were plotted against $1/T$, $\ln C$, $\ln r$ and $\ln s/l$ (Figures 5–8). The apparent activation energies n , m and p were calculated from the slopes of the lines. The second-order rate constants were found from their intercepts. The values obtained are given in Table 5.

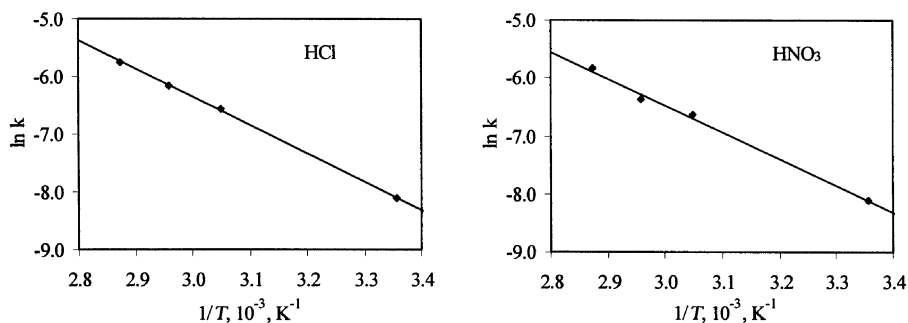


Figure 5. Effect of reaction temperature on the rate constant (acid concentration = 1 mol/L; average particle size = 0.00755 cm; solid-to-liquid ratio = 2.5 g of solid/100 mL of acid).

Effects of parameters

The effects of the parameters on the dissolution process were investigated using the values given in Table 2 for each parameter.

To observe the effect of reaction temperature on the dissolution rate, experiments were carried out using four different reaction temperatures (25, 55, 65 and 75°C) at an acid concentration of 1 mol/L, an average particle size of 0.00755 cm and a solid-to-liquid ratio of 2.5 g of solid/100 mL of acid. The dissolution rate increases with increasing reaction temperature, as seen in Figure 1. This can be attributed to the increasing solubility of Mg^{2+} ions in sepiolite with increasing reaction temperature. The rate constants conform to the Arrhenius equation (Figure 5). The E_a values (Table 5) calculated from this equation are 40.8 and 38.3 kJ mol⁻¹ for hydrochloric and nitric acids, respectively. The fact that the activation energies are low means that the dissolution rate of sepiolite in acid solutions is controlled by product-layer diffusion. Similar results were given by Çetişli and Gedikbey (1990). In other studies, activation energies were given as 64.8 and 63.6 kJ mol⁻¹ in 1.5 mol/L and 3 mol/L sulfuric acid, respectively (Gonzalez-Hernandez *et al.*, 1986). The activation energy in 1 mol/L hydrochloric acid was found to be 90.0 kJ mol⁻¹ by Corma *et al.* (1986). This larger value than in the present study can be explained by structural differences between the sepiolite samples which came from two different sources. Since the silica ratio in the Vallecas sepiolite is greater than that in the sepiolite used in this study, the tetrahedral silica sheets are thicker in the Vallecas sepiolite and this results in the occurrence of a greater diffusion barrier to the removal of Mg^{2+} ions formed.

The effect of the acid concentration on the dissolution rate was studied using four different acid concentrations (0.25, 0.50, 0.75 and 1.00 mol/L) at a reaction temperature of 75°C, an average particle size of 0.00755 cm and solid-to-liquid ratio of 2.5 g of solid/100 mL of acid. The dissolution of sepiolite was studied at acid concentrations given above because the best results related to surface area development were

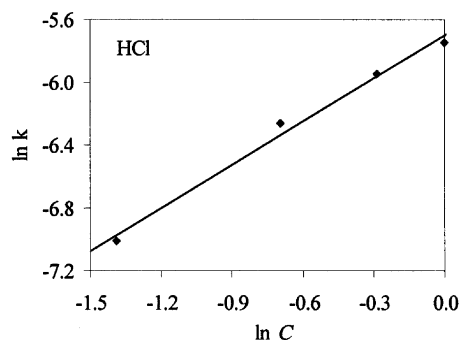


Figure 6. Effect of acid concentration on the rate constant (reaction temperature = 75°C; average particle size = 0.00755 cm; solid-to-liquid ratio = 2.5 g of solid/100 mL of acid).

obtained with acid concentrations of ≤ 1 mol/L (Rodriguez-Reinoso *et al.*, 1981; Corma *et al.*, 1986). The behavior of the dissolution rate for various acid concentrations is shown in Figure 2. These show that the increasing acid concentration increases the dissolution rate. This can be explained by the fact that the diffusion rates of Mg^{2+} ions from the solid to the solution increase since diffusion rates of hydronium ions from the solution to the active sites on the solid increase as the acid concentration increases. Furthermore, when the acid concentration increases, the porosity, pore volume and total surface area increase and new micro- and mesopores that are more resistant to experimental effects form. In acid concentrations >1 mol/L, the number of micro- and meso-pores decreases and the ratio of the external surface area increases (Rodriguez-Reinoso *et al.*, 1981; Corma *et al.*, 1986; Gonzalez-Hernandez *et al.*, 1986). Yebra-Rodriguez *et al.* (2003) suggested that after acid treatment (0.5 N HCl for 24 h) dissolution on both octahedral and tetrahedral sheets started at the center of chains, creating 5.20×6.29 Å tunnels along the *a* axis. The rate constants are proportional to the concentrations of both of the acids (Figure 6 and Table 5). The dissolution reaction of Mg from sepiolite is first order in terms of the acid concentration. Similar

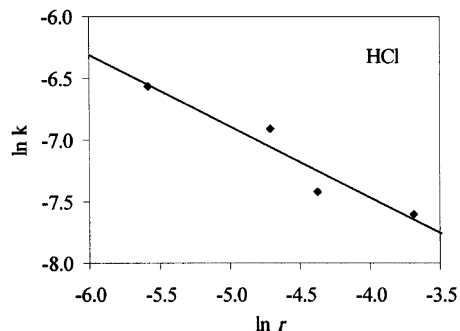


Figure 7. Effect of initial particle radius on the rate constant (reaction temperature = 55°C; acid concentration = 1 mol/L; solid-to-liquid ratio = 2.5 g of solid/100 mL of acid).

behavior was also observed in other studies (Abdul-Latif and Weaver, 1969; Çetişli and Gedikbey, 1990). Corma *et al.* (1986) reported that the rate constants of the product-layer diffusion-control model are proportional to $C^{0.72}$ and $C^{0.73}$ for flat plate and cylinder-shaped particles, respectively.

To investigate the effect of the particle size on the dissolution rate, experiments were carried out using four different average particle sizes (0.05020, 0.02535, 0.01795 and 0.00755 cm) at a reaction temperature of 55°C, an acid concentration of 1 mol/L and a solid-to-liquid ratio of 2.5 g of solid/100 mL of acid. When the particle size increases, the dissolution rate decreases due to the increasing thickness of the layer acting as a diffusion barrier (Figure 3). The rate constants for hydrochloric and nitric acids are inversely proportional to $r^{0.6}$ and $r^{0.5}$, respectively (Figure 7 and Table 5). In previous investigations, the rate constants were assumed to be inversely proportional to the square of the initial particle radius (Wadsworth and Miller, 1979; Gonzalez-Hernandez *et al.*, 1986). Recently, Çetişli and Gedikbey (1990) indicated that the rate constants are inversely proportional to the square root of the initial radius. Similar results were also obtained from our study.

The effect of the solid-to-liquid ratio on the dissolution rate was studied using four different solid-to-liquid ratios (2.5/100, 4.0/100, 8.0/100 and 12.5 g of solid/100 mL of acid) at a reaction temperature of 75°C, an acid concentration of 1 mol/L and an average particle size of 0.00755 cm. As the solid-to-liquid ratio increases, the dissolution rate decreases (Figure 4). This can be explained by the increase in the amount of solid per amount of reagent in the solution. For both acids, the rate constants are inversely proportional to *s/l* (Figure 8 and Table 5).

According to Table 5, the apparent rate constants of the dissolution process are given as $k\alpha e^{-4910(1/T)}Cr^{-0.6}$ (s/l)⁻¹ and $k\alpha e^{-4606(1/T)}Cr^{-0.5}$ (s/l)⁻¹ for hydrochloric and nitric acids, respectively. Thus, reaction temperature is the most important parameter affecting the Mg dissolution process, followed by acid concentration, solid-to-liquid ratio and particle size, respectively.

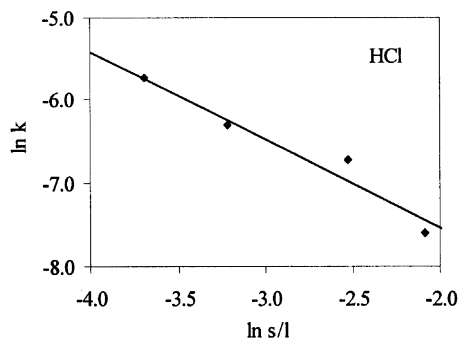


Figure 8. Effect of solid-to-liquid ratio on the rate constant (reaction temperature = 75°C; acid concentration = 1 mol/L; average particle size = 0.00755 cm).

Table 5. Estimated kinetic parameters.

Acid type	E_a (kJ mol ⁻¹)	k_1' (min ⁻¹)	n	$k_2', 10^{-3}$ ((min ⁻¹ (L/mol) ^{0.92(0.93)})	m	$k_3', 10^{-4}$ (min ⁻¹ cm ^{0.57(0.54)})	p	$k_4', 10^{-5}$ (min ⁻¹ g of solid/100 mL of acid)
HCl	40.82	4316	0.92	3.35	-0.57	2.17	-1.0	6.64
HNO ₃	38.30	1548	0.93	3.00	-0.54	2.33	-1.0	7.09

CONCLUSIONS

In this study in which the dissolution kinetics of sepiolite in hydrochloric acid and nitric acid were investigated in a batch reactor, it was determined graphically and statistically that the heterogeneous model with product-layer diffusion control for disc-shaped particles fits the experimental data. Dissolution rate increased with increasing reaction temperature, acid concentration and decreasing solid-to-liquid ratio and particle size. The most effective parameter was reaction temperature followed by acid concentration, solid-to-liquid ratio and particle size. The activation energies of the dissolution process were 40.8 and 38.3 kJ mol⁻¹ for hydrochloric and nitric acids, respectively. The apparent rate constants were expressed as a function of reaction temperature, acid concentration, particle radius and solid-to-liquid ratio: $k\alpha e^{-4910(1/T)}Cr^{-0.6}$ (s/l)⁻¹ and $k\alpha e^{-4606(1/T)}Cr^{-0.5}$ (s/l)⁻¹ for hydrochloric and nitric acids, respectively.

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