Vol. 11 No. 2 (2020) 43-50

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri

Journal homepage : http://www.jrtppi.id

Kementerian Perindustrian
REPUBLIK INDONESIA

Processing of Granite Quarry Solid Waste into Industrial High Silica Materials using Leaching Process with HCl Concentration Variation

Muhammad Amin[1], Slamet Sumardi[1], Roniyus Marjunus[2], Frista Clarasati[2], David Candra B[1], Muhammad Al Muttaqi[1], Kusno Isnugroho[1], Yusup Hendronursito[1]

[1]Research Unit for Mineral Technology, Indonesian Institute of Sciences (BPTM-LIPI)

[2]Department of Physics, Faculty of Mathematics and Natural Sciences, University of Lampung

ARTICLE INFO

Article history:
Received 17 September 2020
Received 27 October 2020
Accepted 27 October 2020
Available online 19 November 2020

Keywords :
Granite
Silica
Leaching
HCl

ABSTRACT

This study was aimed to increase granite's silica content using the leaching process with HCl concentration variation. The granite used in this study came from Lematang, South Lampung. This study aims to determine the effect of variations in HCl concentration, particle size, and rotational speed on the crystalline phase and chemical elements formed in the silica product produced from granite. The HCl concentration variations were 6.0 M, 7.2 M, 8.4 M, and 9.6 M, the variation in particle size used was 270 and 400 mesh. Variations in rotational speed during leaching were 500 and 750 rpm. Granite powder was calcined at 1000 ºC for 2 hours. Characterization was performed using X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD), and Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP- OES). The results showed that the silica content increased with increasing HCl concentration, the finer the particle size, and the higher the rotational speed. XRF analysis showed that the silica with the highest purity was leached with 9.6 HCl with a particle size of 400 mesh and a rotational speed of of 750 rpm, which was 73.49%. Based on the results above, by leaching using HCl, the Si content can increase from before. The XRD diffractogram showed that the granite powder formed the Quartz phase.

1. INTRODUCTION

Lampung Province, with an area of ± 3,528,835 ha, has a very diverse natural resource potential, especially mineral resources. The diversity of mineral resources in Lampung Province includes metal minerals, industrial minerals, energy minerals, and construction minerals. Lampung Province produces industrial excavation of 117,184 m^3 andesites, 234,375 m^3 feldspars, and 62,232,727 m^3 granite (ESDM, 2019). These data show that industrial granite excavation has the potential to be developed. One of the potential granite rocks in Lampung Province is in the Lematang Village area, Tanjung Bintang, South Lampung Regency.

Granite is a deep igneous rock (intrusive). The mineral is coarse-grained to medium light, has many colors, generally white, gray, pink, or red. This color is caused by the color variation of the mineral feldspar. Granite is formed from magma (Judson, Deffeyes & Hargraves, 1978). So far, in Lematang Village, granite is only used as a foundation stone. Silica is refined from granite to increase granite value, which can be used as an advanced material application. So far, small granite quarries measuring 50 mm and below have been discarded, so they are not used because they are used as foundation stones which are larger than 100 mm in size. Therefore mineral silica can be obtained from pumice stone

*Correspondence author.
E-mail : yusuph_ugm07@yahoo.com (Yusup Hendronursito)

doi : https://10.21771/jrtppi.2020.v11.no.2.p43-50

Accreditation number : (LIPI) 756/Akred/P2MI-LIPI/08/2016

(Mourhly, Khachani, Hamidi, Kacimi Halim & Arsalane, 2015), diatomite (Puntharo, Sankram, Chantaramee & Pokmanee, 2013), and quartz sand (Saleh, Ibrahim & Salman, 2015). Apart from quartz sand, granite is a mineral with a high silica content of up to 72.04% (Harvey & Tracy, 1997). Some researchers using several methods to synthesize silica, including combustion (Rozainee Ngo, Salema, Tan, Ariffin & Zainura, 2008), sol-gel (Le, Thuc & Thuc, 2013), leaching acid (Umeda & Kondoh, 2010), the precipitation (Yuvakkumar, Elango, Rajendran & Kannan, 2012). The method leaching and deposition have the advantage that the resulting silica is higher than the silica synthesized by other methods from some of the above methods. The leaching and deposition method is a simple and economical method for silica purification (Ha, Akhtar & Malik, 2014).

Leaching is the extraction of certain materials to remove material impurities by dissolving it (Matori, Haslinawati, Wahab, Sidek, Ban & Ghani, 2009). Inorganic impurities can be removed through a process leaching using an acid solution to obtain high purity silica before the combustion process. Researchers have carried out the process leaching before conducting the thermal process using HCl, H_2SO_4, HNO_3 (Matori, Haslinawati, Wahab, Sidek, Ban & Ghani, 2009), citric acid (Umeda & Kondoh, 2010), and oxalic acid (Kalapathy, Proctor & Shultz, 2002). The use of HCl because HCl is a strong acid and is more reactive than other acids.

Several studies have been conducted to obtain large amounts of silica using the method leaching. For example, Darwis et al. (2017) purified silica from quartz sand using the method leaching with HCl. From XRF results showed that 99.90% of silica obtained from 5 hours-milled sample [14]. Abdellaoui et al. (2013), synthesizing silica with diatomite by method leaching using HNO_3 (Abdellaoui, Islam, Sakurai, Hamzaoui & Akimoto, 2018). Lahsen et al. (2016) also synthesized silica from granite using the method leaching with the solvent HCl. From this experiment, Lahsen et al. (2016) showed the maximum leaching efficiency was 92.4% and about 93.8% the leached can be separated (Lahsen, Mohamed, Cheira, Zaki & Allam, 2016). Therefore this study was aimed to purification of silica from granite quarry solid waste with different HCl concentration into industrial high silica.

Table 1. Variations in HCl concentration, particle size and rotational speed.

Sample	HCl (M)	Size (mesh)	Rotation speed (rpm)
1	6	270	500
2	7.2	270	500
3	8.4	270	500
4	9.6	270	500
5	6	270	750
6	7.2	270	750
7	8.4	270	750
8	9.6	270	750
9	6	400	500
10	7.2	400	500
11	8.4	400	500
12	9.6	400	500
13	6	400	750
14	7.2	400	750
15	8.4	400	750
16	9.6	400	750

Table 2. Result of Granit Stone before leaching

Compounds	Percentage (wt%)
SiO_2	62.806
Al_2O_3	18.365
P_2O_5	0.764
K_2O	10.112
TiO_2	0.623
Fe_2O_3	6.951

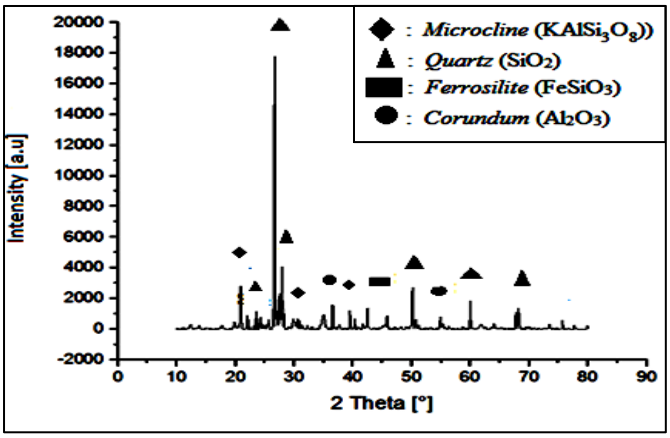

Figure 1. XRD analysis for granite

Table 3. The results of XRF Analysis *Leaching* Granite Stone with Particle Size 270 Mesh and Rotation Speed 750 rpm.

Compounds	% Leaching			
	6.0 M	7.2 M	8.4 M	9.6M
SiO_2	69.31	71.55	72.229	72.29
Al_2O_3	16.38	15.30	15.068	14.95
Fe_2O_3	-	2.373	2.361	2.413
TiO_2	0.528	0.515	0.500	0,491
K_2O	8.166	9.180	8.95	-
P_2O_5	0.661	0.073	0.711	0.716

2. METHODS

2.1. Material

Material used in this study included granite from Lematang-Tanjung South Lampung, 12.06 M HCl, and aquades.

2.2. Method

The powder preparation process refers to the research conducted by Lahsen et al. (2016), which started with washing granite stones using aquades until they were cleaned, then drying them for 2 hours at 120°C using an oven. Furthermore, the granites was refined using ball milling for 5 hours to produce granite powder, which was still in a rough state. Then the granite powder was dried using an oven for 2 hour at temperature of calcination. After drying, the granite powder is sieved with a 270 mesh and 400 mesh sieves to obtain a fine granite powder. Furthermore, granite's fine powder is weighed as much as 5 grams as a sample to be tested using XRD and XRF.

This refining process is a process carried out to obtain pure silica from granite with various treatments, as shown in Table 1.

This granite process leaching referred to research that has been conducted by Lahsen et al. (2016). First, the preparation of 100 mL of HCl, with concentration variations of 6.0 M, 7.2 M, 8.4 M, 9, 6 M. After the solution has been prepared, 10 grams of granite powder was dissolved into each of the HCl solutions that have been prepared. Each solution was then stirred for 7 hours while stirring at a rotational speed as in Table 1 and heated to purify the silica contained in granite powder. The next stage was the result stirrer used filtered with filter paper Whatman No. 41. The filtered residue was then oven-dried for 2 hours at a temperature of calcination. Then it was calcined with furnace at for 2 hours, then characterized by XRD and XRF.

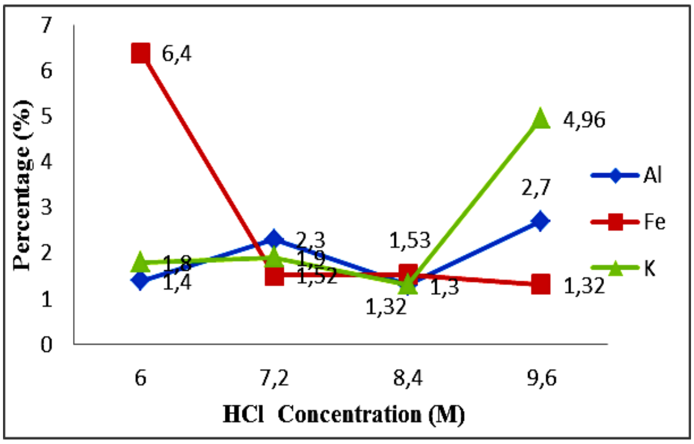

Figure 2. The graph of the relationship between HCl concentration and the solubility of Al, Fe, and K, the graph of a particle size of 270 mesh and a rotating speed of 750 rpm.

3. RESULT AND DISCUSSION

Granite structures were analyzed using XRF Analysis. Leaching process were conducted using HCl 6.0 M; 7.2 M; 8.4 M and 9.6 M for 7 hours at 110 °C. After that it was filtered with Whatmann filter paper no. 2, then calcined for 2 hours at a temperature of 1000 °C. Last tested with XRD and XRF. The results of the XRF analysis of granite are as in Table 2.

The results of XRD analysis for granite as shown in Figure 1. The phases formed are Quartz (SiO_2), Microcline ($KAlSiO_2$), Corundum (Al_2O_3), and Ferrosilite ($FeSiO_3$). The highest peak is at 2θ = 26.6251° Quartz (SiO_2).

The analysis results of XRF leaching granite with 270 mesh particle size and 750 rpm rotation speed are as in Table 3.

Based on Table 3, XRF analysis results showed that the percentage of SiO_2 compound after leaching was higher than before leaching. The SiO_2 highest produced was found in samples leached with a concentration of 9.6 M. In this study, the silica obtained continued to increase the concentration of HCl was used. The concentration of HCl affects the hydrolysis's speed and condensation reactions of the material, which affects the silica gain and the crystallinity of the material (Hilmy, 2007).

Leaching using HCl can dissolve other metals, including Fe, Al, and K, so that after leaching, the levels of other metals such as Fe, Al, and K decreased, and the silica content in the sample increased, as the concentration of HCl is used (Hasbi, Sigit, Indah, Septian & Efendi Bintang, 2016). Analysis the solution sample was leaching analyzed using ICP-

OES to detect chemical elements dissolved during the process leaching. Graph of analysis results from ICP-OES leaching granite with a particle size of 270 mesh, and a rotating speed of 750 rpm is presented as in Figure 2. Dissolving with HCl on elements Al, Fe, and K does not have trend the same due to HCl's ability, which is not completely dissociated so that it cannot dissolve the metal completely (Fitri, 2013).

The XRD analysis results for leaching granite stone with a particle size of 270 mesh and a rotating speed of 750 rpm are as shown in Figure 3.

Table 4. The results of XRF Analysis for Leaching Granite with Particle Size 400 Mesh and Spin Speed 750 rpm.

Compounds	% Leaching			
	6.0 M	7.2 M	8.4 M	9.6M
SiO_2	71.25	71.49	72.81	73.49
Al_2O_3	15.1	14.38	14.29	13.1
Fe_2O_3	2.89	2.64	2.53	267
TiO_2	0.50	0.44	0.42	0.48
K_2O	9.29	9.08	8.90	9.22
P_2O_5	0.73	0.73	0.74	0.78

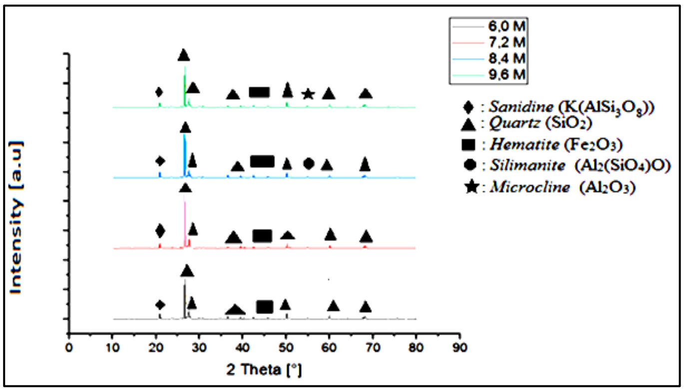

Figure 3. The XRD analysis results for granite with a particle size of 270 mesh and a rotational speed when leaching 750 rpm.

Based on Figure 3, it can be seen that the results of XRD characterization on variations samples leaching of granite with variations in HCl concentrations of 6.0 M, 7.2 M, 8.4 M, and 9.6 M indicate that the phase that dominates the diffraction peaks is Quartz (SiO_2), Sanidine ($K(AlSi_3O_8)$), Hematite (Fe_2O_3), Sillimanite ($Al_2(SiO_4)O$) and Microcline (Al_2O_3) consecutively. Phase Quartz (SiO_2) is the phase that dominates the diffraction peaks because SiO_2 is calcined at temperatures of 800 and 1000 °C (Wibawa, Eko & Anggoro, 2015). The XRF analysis results for leaching granite with a particle size of 400 mesh and a rotation speed of 750 rpm are as in Table 4.

Based on Table 3. and Table 4. it can be seen that the resulting silica content in leaching granite with a particle size of 400 mesh is higher than the silica produced in leaching granite with particle size 270 mesh. This result agreed with the theory of particle size, namely the smaller the particle size, the larger its surface area. Hence, reaction will be faster, and the resulting product will be more and more (Bentz, Garboezi, Haecker & Jensen, 1999).

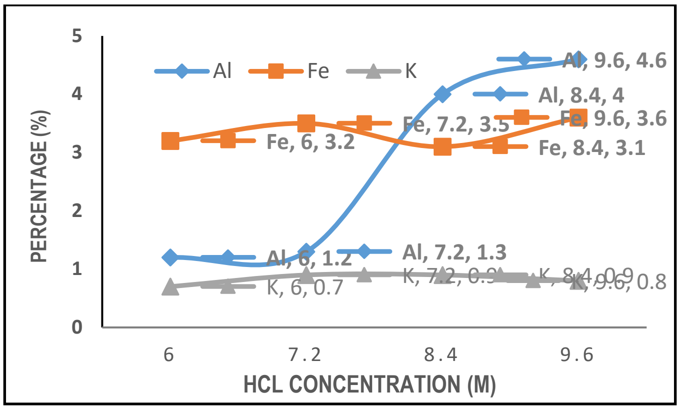

Figure 4. The relationship between HCl concentration and the solubility of Al, Fe, and K, at a particle size of 400 mesh and a rotational speed of 750 rpm.

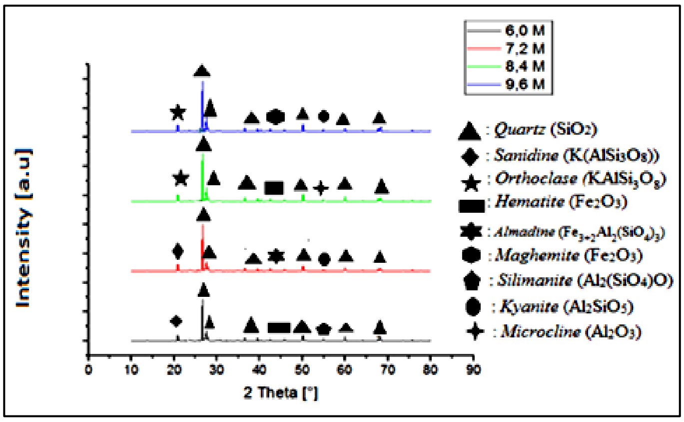

Figure 5. The XRD analysis of granite with a particle size of 400 mesh and rotational speed *leaching* of 750 rpm.

The analysis sample of the solution was leaching analyzed using ICP-OES to detect chemical elements dissolved during the process leaching. Graph of analysis results from ICP-OES leaching granite with a particle size of 400 mesh and a rotating speed of 750 rpm is presented as in Figure 4.

The XRD analysis results leaching stone granite with a particle size of 400 mesh and rotation speed 750 rpm are shown in Figure 5.

Based on Figure 5, it can be seen that the phase that dominates the diffraction peaks is Quartz (SiO_2), Sanidine ($K(AlSi_3O_8)$), Orthoclase ($KAlSi_3O_8$), Hematite and Maghemite (Fe_2O_3), Almandine ($Fe_{3+2}Al_2(SiO_4)_3$), Kyanite (Al_2SiO_5), Mullite ($Al_{2.35}Si_{.64}O_{4.82}$), Sillimanite ($Al_2(SiO_4)O$) and Microcline ($Al_2O_3$). Phase Quartz ($SiO_2$) is the phase that dominates the diffraction peaks.

The resuls of XRF of leaching granite with 270 mesh particle pize and 500 rpm rotation speed are as in Table 5.

Table 5. The results of XRF Analysis for Leaching Granite with 270 Mesh Particle Size and 500 rpm Rotation Speed.

Compounds	% Leaching			
	6.0 M	7.2 M	8.4 M	9.6M
SiO_2	68.33	69.05	69.05	69.14
Al_2O_3	16.76	16.57	16.59	16.36
Fe_2O_3	3.08	2.66	2.77	2.73
TiO_2	0.71	0.70	0.70	0.72
K_2O	10.06	9.96	9.84	9.99
P_2O_5	0.79	0.8	0.78	0.8

Table 6. Results of XRF analysis for Leaching Granite with Particle Size 400 Mesh and Rotation Speed 500 rpm.

Compounds	% Leaching			
	6.0 M	7.2 M	8.4 M	9.6M
SiO_2	68.57	68.92	70.17	70.24
Al_2O_3	17.55	17.73	16.6	16.20
Fe_2O_3	2.44	2.23	2.22	2.35
TiO_2	0.65	0.62	0.65	0.66
K_2O	9.87	9.60	9.44	9.37
P_2O_5	0.71	0.7	0.71	0.77

Based on Table 2 and Table 5, it can be seen that the silica produced in leaching granite with a particle size of 270 mesh with a rotating speed of 750 and 500 rpm, the greater the silica made at speed turn 750 rpm. This is following the stirring speed's effect, the faster the stirring of a particle. When the faster stirred, the contact between the granite powder and the HCl will occur, and the more product is produced at the highest stirring speed (Fitri, 2013).The solution's analysis sample was leaching analyzed using ICP-OES to detect chemical elements dissolved during leaching. Graph of analysis results ICP-OES leaching granite with a particle size of 270 mesh, and a rotating speed of 500 rpm is presented as in Figure 5.

The results of XRD analysis leaching stone granite with a particle size of 400 mesh and rotation speed 750 rpm are shown in Figure 6.

Based on Figure 6, it found that the phase dominates the diffraction peaks such as Quartz (SiO_2), Sanidine ($K(AlSi_3O_8)$), Hematite (Fe_2O_3), Ferrosilite and Clinoferrosilite (Fe_2SiO_3), Kyanite (Al_2SiO_5), Mullite ($Al_{4.75}Si_{1.25}O_{9.63}$), Corundum ($Al_2O_3$) and microcline ($Al_2O_3.K_2O.6SiO_2$). Phase Quartz ($SiO_2$) is the phase that dominates the diffraction peaks.

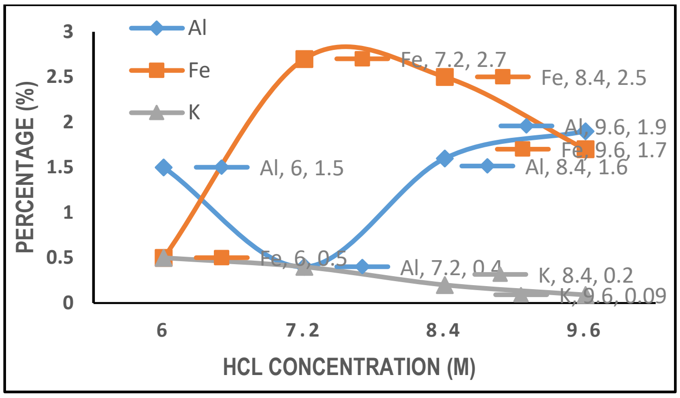

Figure 5. The graph of the relationship between HCl concentration and the solubility of Al, Fe and K, a particle size of 400 mesh and a rotational speed of 750 rpm.

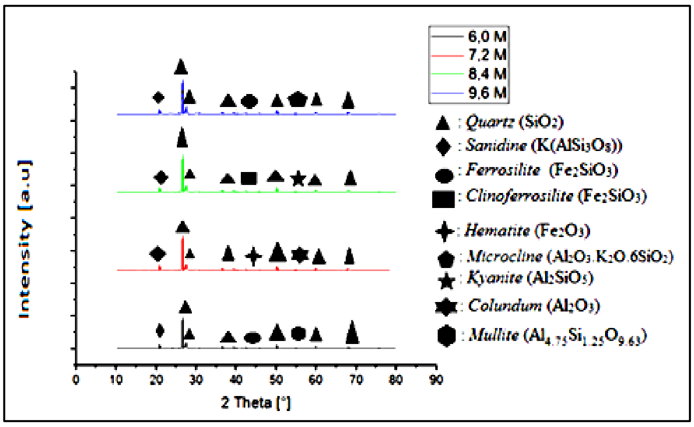

Figure 6. The results of XRD analysis of granite with a particle size of 400 mesh and rotational speed leaching of 750 rpm.

The XRF analysis results of Leaching Granitewith a Particle Size of 400 Mesh and Rotation Speed of 500 rpm are as in Table 6.

Based on Table 5 and Table 6, it can be seen that the silica produced in leaching granite with a particle size of 270 mesh with particle size of 400 is greater than the resulting silica when the particle size is 400 mesh. The silica produced when the particle size is 270 mesh with a rotating speed of 750 rpm as in Table 3 bigger than the silica when particle size is 270 mesh with a rotating speed of 500 rpm as shown in Table 6. So that, the highest silica results at the particle size 400 mesh and leaching at 750 rpm rotational speed.The solution sample was leaching analyzed using ICP-OES to detect chemical elements dissolved during the process leaching. Graph of analysis results ICP-OES leaching granite with a particle size of 400 mesh, and a rotating speed of 500 rpm is presented as in Figure 7.

The results of XRD analysis leaching stone granite with a particle size of 400 mesh and rotation speed 750 rpm are shown in Figure 8.

Based on Figures 9, it can be seen that the silica produced in leaching linear granite rises upward along with the large concentration of HCl used and the fine particle size. Silica with a particle size of 400 mesh is larger than the silica produced in leaching granite with a particle size of 270 mesh. Based on rotation speed, it can be seen that the silica produced in leaching linear granite rises upward along with the amount of HCl concentration used and the rotational speed used. The silica produced in leaching at a rotational speed of 750 rpm is greater than the silica produced in leaching granite at a rotational speed of 500 rpm.

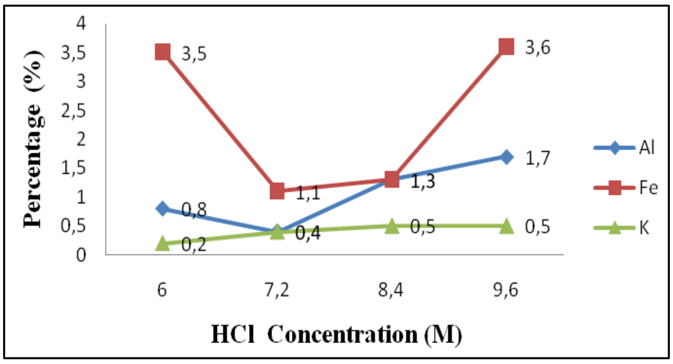

Figure 7. The Graph of the relationship between HCl concentration and the solubility of Al, Fe and K, at a particle size of 400 mesh and a rotational speed of 500 rpm.

Table 7. Phases and types of minerals formed.

Type of mineral	Phase	Percentage (%)
Quartz	SiO_2	67
Sanidine	$K(AlSi_3O_8)$	8
Orthoclase	$KAlSi_3O_8$	1.13
Hematite	Fe_2O_3	8
Maghemite	Fe_2O_3	1.13
Almadine	$Fe_{3+2}Al_2(SiO_4)_3$	1.13
Ferrosilite	Fe_2SiO_3	3.4
Clinoferrosilite	Fe_2SiO_3	1.13
Silimanite	$Al_2(SiO_4)O$	1.7
Microcline	Al_2O_3	1.13
Kyanite	Al_2SiO_5	1.7
Mullite	$Al_{2.35}Si_{.64}O_{4.82}$	0.56
Colundum	Al_2O_3	0.56
Mullite	$Al_{4.75}Si_{1.25}O_{9.63}$	0.56
Microcline	$Al_2O_3.K_2O.6SiO_2$	0.56
Andalusite	$Al_2(SiO_4)O$	0.56

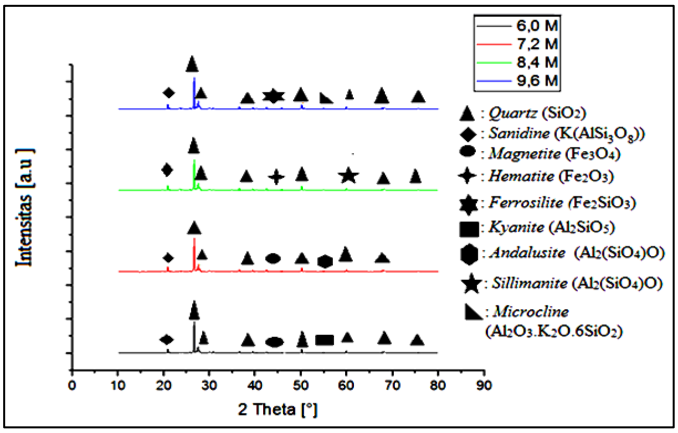

Figure 8. The results of XRD analysis of granite leaching with a particle size of 400 mesh and rotational speed of 500 rpm.

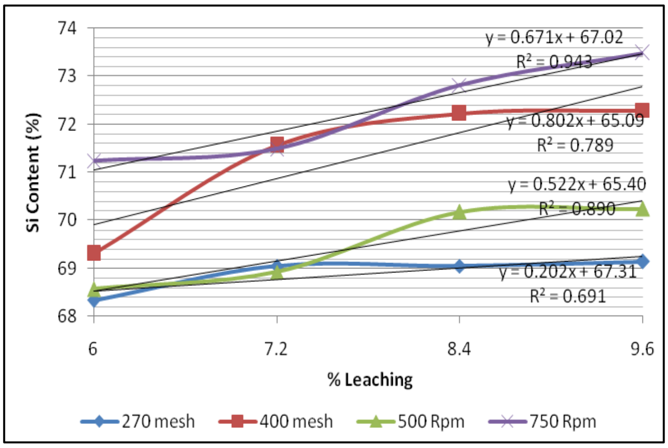

Figure 9. The relationship between silica concentration and various parameters

Several phases and minerals formed in the diffractogram pattern in the XRD analysis are presented in Table 7.

4. CONCLUSION

The highest silica obtained at a concentration of 9.6 M. Thus, the higher the concentration of HCl is used, then the higher the SiO_2 obtained. So that the concentration of the HCl solution affects the solubility of impurity oxides other than SiO_2. The silica obtained at a particle size of 400 mesh is higher than that of 270 mesh. This shows that the finer the particle size, the higher the silica is obtained. This is due to the wider the surface area of the particles, the faster the HCl solution will reduce impurity oxides other than SiO_2. Silica obtained during leaching at a rotational speed of 750 rpm is higher than at 500 rpm. This shows that the higher the rotational speed when leaching, the higher the silica will be obtained. This is because the rotational speed affects the friction that occurs, so the higher the rotational speed or, the faster the stirring, the faster the HCl solution will dissolve other impurity particles besides SiO_2.

ACKNOWLEDGMENT

Thanks are conveyed to BPTM-LIPI and PPII, who has provided the facilities and infrastructure for this research, and the Physics of the Faculty of Mathematics and Natural Sciences, the University of Lampung, who has guided until this research is complete. Contributors statement: In this paper, all authors are main contributors.

REFERENCE

ESDM. Ketersediaan Batu Granit di Lampung; 2019 [cited 15 march 2020]. Available from: *http://psdg.bgl.esdm.go.id/index.php?option=com_content&view=article&id=1301&Itemid=742.*

Judson S, Deffeyes K S, Hargraves R B. *Physical Geology*. New Delhi. Prentice-Hall of India Privat Limited.1978.

Mourhly A, Khachani M, Hamidi A E, Kacimi M, Halim M, Arsalane S. The Synthesis and Characterization of Low-Cost Mesoporous Silica SiO_2 from Local Pumice Rock. *Nanomaterials and Nanotechnology.* 2015;5:1-7.

Puntharod R, Sankram C, Chantaramee N, Pookmanee P. Synthesis and Characterization of Wollastonite from Egg Shell and Diatomite by Hydrothermal Method. *Journal Ceramics Process Research.* 2013;14:198-201.

Saleh NJ, Ibrahim RI, SalmanAD.Characterization of Nano-Silica Prepared From Local Silica Sand and Its Application in Cement Mortar Using Optimization Technique. *Advanced Powder Technology.* 2015;26:1123-1133.

Harvey B, Tracy RJ.*PetrologiEdisiKedua.* New York: Freeman;1997:66. ISBN0-7167-2438-3.

Rozainee M, NgoSP, Salema AA, Tan KG, AriffinM, Zainura ZN. Effect of Fluidising Velocity on the Combustion of Rice Husk in a Bench-scale Fluidised Bed Combustor for the Production of Amorphous Rice Husk Ash. *Bioresource Technology.* 2008;99:703-713.

Le VH, ThucCNH,Thuc HH. Synthesis of Silica Nanoparticles from Vietnamese Rice Husk by Sol-gel Method. *Nanoscale Research Letters.* 2013;8:1-10.

UmedaJ,KondohK. High-Purification of Amorphous Silica Originated from Rice Husk by Combination of Polysaccharide Hydrolysis and Metallic Impurities Removal. *Industrial Crops and Products.* 2010;32:539-544.

YuvakkumarR, ElangoV, Rajendran V, Kannan N. High-purity Nano Silica Powder from Rice Husk Using a Simple Chemical Method. *Journal of Experimental Nanoscience.* 2012;9:272-281.

Haq IU, Akhtar A, Malik A. Effect of Experimental Variables on the Extraction of Silica from the Rice Husk Ash. *Journal of Chemical Society of Pakistan* 2014; 36:382-387.

MatoriKA, Haslinawati MM, Wahab ZA, SidekHAA, Ban TK, Ghani WAWAK. Producing Amorphous White Silica from Rice Husk. *MASAUM Journal of Basic and Applied Sciences.* 2009.;1:512-515.

Kalapathy U, Proctor A, Shultz J. An Improved Method for Production of Silica from Rice Hull Ash. *Bioresource Technology.* 2002; 85:285-289.

Darwis D, Khaeroni R, Iqbal. Purification and Characterization of Silica Using Purification (Leaching) Method with Variations of Milling Time from Quartz Sand on Pasir Putih Village South Pamona Sub-district of Poso District. Natural

Science: Journal of Science and Technology. 2017;6(2):187-193

Abdellaoui I, Islam MM, Sakurai T, Hamzaoui S, Akimoto K. Impurities removal process for high-purity silica production from diatomite. Hydrometallurgy. 2018;179:207-214.

Lahsen TA, Mohamed SA, Cheira MF, Zaki DI, Allam EM. Leaching and Recovery of Rare Earth Elements from Altered Alkaline Granite Rock from Nusab El-Balgum Area, South Western Desert, Egypt. Research Article. 2016; 4:787-801.

Hilmy MA. *Pengaruh Konsentrasi HCl dan Temperatur Perlakuan Hidrotermal Terhadap Kristalinitas Material Mesopori Silika SBA-15.* Jakarta: Universitas Indonesia; 2007.

Hasbi MY, Sigit DY, Indah NC, Septian AC, Efendi Bintang A. Penggunaan Aqua Regia dan HCl Sebagai Larutan Pelindian pada Proses Pemurnian Silikon Tingkat Metalurgi dengan Variasi pH.*Seminar Nasional Sains dan Teknologi.* 2016:1-7.

Fitri NTD. *Ekstraksi dan Penentuan Kadar Ion Aluminium Hasil Ekstraksi dari Fly Ash Batubara.* Skripsi. Jurusan Kimia Universitas Negeri Jember; 2013.

Wibawa A, Eko TS, Anggoro TM. Pengaruh Variasi Temperatur pada Proses Kalsinasi Silika Amorf dari PLTP Dieng. *Pemaparan Hasil Penelitian Geoteknologi.* 2015:2-6.

Bentz DP, Garboezi EJ, Haecker CJ, Jensen OM. Effects of Cement Particle Size Distribution on Performance Properties of Portland Cement-Based Materials. *Cement and Concrete Research.* 1999;29:1663-1671.