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MINERAL CONTENT ANALYSIS OF MERAPI VOLCANIC SAND AND ITS POTENTIAL APPLICATION

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Abstract

Research on mineral content analysis of Merapi volcanic sand at Yogyakarta-Indonesia has been done to determine the mineral content of the Mount Merapi volcanic sand and to identify its potential application. Samples were taken from three locations i.e. Kuning River, Opak River, and Gendol River. Before analysis process, the samples were firstly washed with aquades until neutral pH, dried at 120 °C, and then pulverized with ball mill to obtain the size of 60 mesh. The characterization of the minerals were conducted using XRD and XRF. XRF analysis results showed the highest mineral content of the all samples were silica, followed by aluminum and iron. The metal elements such as Ti, Zn, Zr, Cr, Sr, Sn existed with very small percentage that was less than 1%. While the results of XRD analysis showed that mineral content on three samples were quartz, albite, anorthite, muscovite, illlite, hematite, and magnetite.

Key words: Merapi Volcanic sand, mineral content, XRD, XRF

INTRODUCTION

Indonesia is the country that has the largest number of volcanoes, as many as 127 mountains (Pikiran Rakyat, 2015). A large number of volcanoes in Indonesia as a result of the geographical location of Indonesia are formed due to subduction zones between the Eurasian plate and the Indo-Australian plate. Volcanoes in Indonesia are part of the Pacific Ring of Fire, which is across Sumatra, the Sunda Strait and Java, the Lesser Sunda Islands (Bali, Lombok, Sumbawa, Flores, Sumba), Banda Islands (Maluku and small islands in the vicinity), Sulawesi and Sangihe Islands, and Halmahera (Tom Simkin and Lee Siebert, 1994). Such geographical conditions, which will directly impact on the surrounding material content because every time there was an eruption will issue a wide range of material to the surface of the earth. Mount Merapi is one of the most active volcano located in central Java, partly into the region of Yogyakarta Province and other part into Central Java Province. Throughout the history of the Mount Merapi eruption frequent, small eruptions occur every 2-3 years and a major eruption occurs 10-15 years where the last major eruption occurred in November 2010.

Each eruption is accompanied scattering material from deep within the earth, in the form of lava, ash and hot clouds. When exposed to air usually lava forming large and small boulders which then undergoes gradation produces gravels and sands. The material existence is very much up to envelop the mountain area and partly carried by the flow of the river. At the atomic scale, volcanic material containing a variety of metals and non-metallic minerals which further beneficial to humans. It is underlying the reason for the natural wealth of Indonesia.

Most material resulting from the eruption of Mount Merapi is sand. In addition, the sand contains elements such as silica, iron, aluminum, titanium. However, the fact mentioned that although Indonesia is rich in natural resources, but until now has not been optimal utilization and mostly only sold as raw materials that have a lower sale value. While the raw materials largely for fulfill the needs of production relies on imports so the cost of production is very high and the competitiveness is low. The cumulative value of total imports during the year 2013 reached 186.63 billion US dollars to the value of oil imports 45.27 billion US dollars and non-oil imports 141.36 billion US dollars (Antara News, 2014). Therefore, this article intends to expose the results of the research "identifying mineral deposits contained in the sands of Mount Merapi" simultaneously reviewing the potential that could be developed to support national development. It is based on the presence of sand in Indonesia is very abundant, especially those originating from volcanic eruptions. In the hope, volcanic sand can be processed to be raw material or semi-finished raw material for purposes to substitute import and to meet the needs of the domestic industry.

RESEARCH METHOD

The tools were used: glass tools, ball mill, pH meters, magnetic, magnetic stirrer, heating ovens, X-ray diffractometer (XRD), X-Ray Fluorescence (XRF). The sample used in the study: Mount Merapi volcanic sand taken from the three rivers, the Kuning River, the Opak River and the Gendol River.

Treatment of samples: the sample is washed to neutral pH, filtered, dried at 110 ° C for 3 hours, the process of grinding up to a size of 60 mesh, followed by analysis using XRD and XRF. Interpretation of XRD signal using the MATCH! program. While review the mineral potential is done through a literature review.

RESULT AND DISCUSSION

Volcanic sand samples derived from the three largest rivers in Yogyakarta, i.e. the Yellow River, the Opak River, and the Gendol River. Samples were taken from three locations to compare mineral content of the sand from different river even though the source material is the same, i.e the eruption of Mount Merapi. Differences in the concentration of mineral is possible because of the condition and the length of each river flow is different and allows for absorption and deposition of minerals throughout the area traversed.

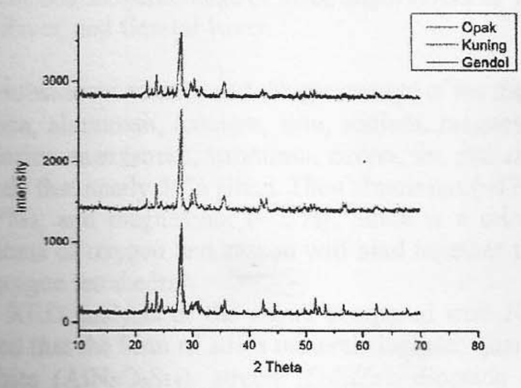


Figure 1. XRD analysis results signal of Mount Merapi sand samples from three streams, namely Opak River, Yellow River, and the Gendol River.

Table 1. XRD Data of Mount Merapi Sand Samples

Substituent	Percentage (%)		
	Kuning River	Opak River	Gendol River
Si	48.13	48.15	49.61
Al	16.87	17.39	17.83
Ca	11.54	10.55	9.54
Fe	14.28	11.19	9.07
Na	-	4.69	5.95
Mg	3.55	2.73	2.69
K	2.17	2.28	2.41
Ti	1.32	1.06	0.8
P	0.75	0.67	0.76
S	0.27	0.30	0.52
Cl	0.34	0.34	0.33
Mn	0.36	0.30	0.26
Sr	0.10	0.10	0.11
Nd	0.05	0.04	0.03
Zr	0.07	0.11	0.02
Sn	0.02	0.01	0.02
Zn	0.02	0.02	0.01

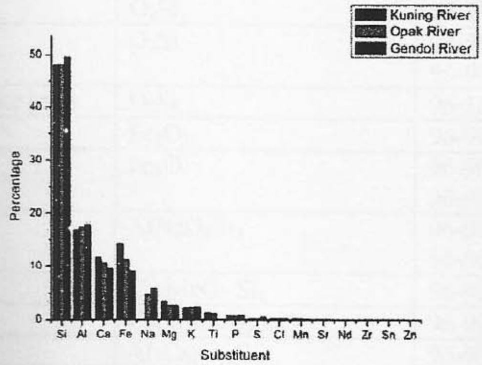


Figure 2. Mineral content and the percentage of three major rivers in Yogyakarta, namely Yellow River, Opak River, and Gendol River.

In general, the substituent content and the percentage of the third river is almost the same minerals, including silica, aluminum, calcium, iron, sodium, magnesium, potassium, titanium, phosphorus, sulfur, chlorine, manganese, strontium, zircon, tin, and zinc (Figure 2). The highest concentration of minerals that nearly 50% silica. Then aluminum (~17%), iron (~ 14%), calcium (~ 11%), sodium (~ 7%), and magnesium (~ 3%). Silica is a mineral which is the highest percentage since the atoms of oxygen and silicon will bind together the first time when magma cools to form silicon-oxygen tetrahedral.

The results of XRD analysis of the signal compared with JCPDS using the MATCH! Program, it can be stated that the form of silica minerals include: quartz (O_2Si), tridimite (O_2Si), cristobalite (O_2Si), albite ($AlNaO_8Si_3$), zircon (O_4SiZr), diopside ($CaMgO_6Si_2$), akermanite ($Ca_2MgO_7Si_2$), grossular ($Al_2Ca_3O_{12}Si_3$), illite ($Al_2H_2KO_{12}Si_4$), anorthite ($Al_2CaO_8Si_2$), muscovite (Al[illegible]H_2K[illegible]$O_{12}Si_{3.86}$), andradite ($Ca_3Fe_2O_{12}Si_3$). Silicate rock fragments also produce non-silicate minerals such as magnetite (Fe_3O_4), maghemite (Fe_2O_3), goethite (FeO_2), ilmenite (FeO_3Ti), and iron oxide dititanium (FeO_5Ti_2). Table 2, Table 3, and Table 4 show the compounds contained in volcanic sand samples from the three rivers as a result of XRD signal interpretation based on JCPDS.

Table 2. Compounds Contained in Volcanic Sand of The Yellow River by Interpretation XRD Signal with JCPDS

Compound Name	Chemical Formula	JCPDS
Albite	$AlNaO_8Si_3$	96-900-3701
		96-900-2204
Magnetite	Fe_3O_4	96-901-3530
Maghemite	Fe_2O_3	96-901-2693
Goethite	FeO_2	96-901-1413
Zircon	O_4SiZr	96-500-0120
		96-900-2557
Diopside	$CaMgO_6Si_2$	96-900-5334
Ilmenite	FeO_3Ti	96-900-5334
Iron dititanium oxide	FeO_5Ti_2	96-200-2319

Table 3. Compounds Contained in Volcanic Sand of The Opak River by Interpretation XRD Signal with JCPDS

Compound Name	Chemical Formula	JCPDS
Quartz	O_2Si	96-901-2606
Quartz low	O_2Si	96-101-1160
Cristobalite	O_2Si	96-900-9687
		96-900-9688
Silicone oxide (Cristobalite low)	O_2Si	96-101-0939
Maghemite	Fe_2O_3	96-900-6318
Magnetite	Fe_3O_4	96-900-5838
		96-900-5840
Albite	$AlNaO_8Si_3$	96-900-2204
		96-900-0526
Akermanite	$Ca_2MgO_7 Si_2$	96-901-3637
Dolomite	$C_2Ca_{1.07}Mg_{0.93}O_6$	96-900-4931
Grossular	$Al_2Ca_3O_{12}Si_3$	96-900-2686

Table 4. Compounds Contained in Volcanic Sand of The Gendol River by Interpretation XRD Signal with JCPDS

Compound Name	Chemical Formula	JCPDS
Quartz	O_2Si	96-901-2604
		96-901-3322
Albite	$AlNaO_8Si_3$	96-900-0703
Cristobalite	O_2Si	96-900-9687
Trydimite	O_2Si	96-901-3492
Quartz low	O_2Si	96-101-1173
Magnetite	Fe_3O_4	96-901-0940
Hematite	Fe_2O_3	96-900-9783
Illite	$Al_2H_2KO_{12}Si_4$	96-901-3722
		96-901-3733
Anorthite	$Al_2CaO_8Si_2$	96-100-0035
Muscovite	$Al_{1.94}H_2K_{0.86}O_{12}Si_{3.86}$	96-900-4410
Akermanite	$Ca_2MgO_7Si_2$	96-900-6942
Andradite	$Ca_3Fe_2O_{12}Si_3$	96-900-7694

Based on the results of the XRD signal interpretation, silica in the silica sand contained in the form of silicon dioxide and silicate minerals. Silicon dioxide is found in several forms, namely quartz, kristabalit, and tridymite. Besides as silicon dioxide, most of the silica in volcanic sand are in the form of silicate minerals. Characterization by XRD results showed that silicon dioxide and minerals have an amorphous structure. The results of XRD signal interpretation indicates the type of silica minerals in volcanic sand, among others, albite ($AlNaO_8Si_3$), zircon (O_4SiZr), diopside ($CaMgO_6Si_2$), akermanite ($Ca_2MgO_7Si_2$), grossular ($Al_2Ca_3O_{12}Si_3$), illite ($Al_2H_2KO_{12}Si_4$), anorthite ($Al_2CaO_8Si_2$), muscovite ($Al_{1.94}H_2K_{0.86}O_{12}Si_{3.86}$), andradite ($Ca_3Fe_2O_{12}Si_3$). Mineral variations in the volcanic sand due to minerals that make up the magma is not formed at the same time or in the same conditions. Certain minerals will crystallize at higher temperatures than other minerals.

Albite ($AlNaO_8Si_3$) and anorthite ($Al_2CaO_8Si_2$) minerals including feldspar group. Feldspar has a structure of SiO_2 with tectosilicate structure formed by SiO_4 groups. Angle variation allows the formation of a crystalline structure variation on silicon dioxide and can be easily form an amorphous structure.

Diopside and akemanite minerals belonged piroxin group. Minerals are a source of Ca and Mg in the volcanic sand. While mineral grossular ($Al_2Ca_3O_{12}Si_3$) and andradite ($Ca_3Fe_2O_{12}Si_3$) including garnet group, i.e. a group of minerals commonly used as a gem. Both types of minerals is a metamorphic minerals of igneous rocks as a result of temperature and pressure. This group is appreciated because of hardness and brilliance, and consists of a variety of colors that show luxury. Garnet is not a single mineral, but rather a set of isomorphous minerals are closely related to the main composition of Ca, Fe, Al.

Hydroxyl group containing minerals (-OH) belonged to the mica is muscovite ($Al_{1.94}H_2K_{0.86}O_{12}Si_{3.86}$) and illite ($Al_2H_2KO_{12}Si_4$) so called aluminum silicate hydrate. The mica group is a source of aluminum in the volcanic sand. This mineral is a calcium-aluminum species of gems, although in certain parts, it allows Al^{3+} ions occupied by Fe^{3+} ions. The minerals found in igneous rocks rich in silica. Muscovite are also in sedimentary rocks and metamorphic.

Interpretation of XRD signal also indicates that Mount Merapi volcanic silicate sands containing zircon, though only a little amount of about 0.03%. Zirconium is one element in nature which has a high temperature-resistant properties. Zirconium is not present in free form in nature, but in the form of zirconium silicate ($ZrSiO_4$). These minerals include nesosilicate group. This group has the simplest structure which $(SiO_4)^{4-}$ tetrahedral separate (Akhtar-Waseem, 2003).

Almost 90% of the Earth's crust consists of silicate minerals and almost 100% of the Earth's mantle. Silicate minerals is a combination of the main elements contained in the earth which is O, Si, Al, Fe, Ca, Na, K, Mg. So, silicates are the main parts that make up the rocks, sediments, igneous rocks and metamorphic rocks (Deer, et.al., 1992).

Potential Application of Mount Merapi Mineral

Based on the analysis XRD and XRF, sands of Merapi Mount has a lot of mineral content, here are some potential that could be developed.

1. Potential Applications of Feldspar

Ceramics - Ceramic and glass industries are two industries that use large amounts of feldspar. The raw material of sand can be processed into various types of ceramics, there is impact resistant ceramic, burning ceramic, and dielectric function ceramic. Content of impact resistant ceramic is a mixture of fine aluminum powder (Al_2O_3), calcined silica (SiO_2), titanium oxide (TiO_2) and zirconium oxide (ZrO_2) (Nurul T.R., et.al. 2013). Feldspar is used for the purposes ceramic contains K and Na is greater than 10% in order to use the lower combustion temperature. A glaze may contain 30-50% feldspar. On the size of the fine, 200 mesh, potash and soda spars are used in glazes as a source of alumina and water insoluble alkali. Usages levels range from less than 10% in certain wall tiles to as much as 60% in some floor tiles (Peter A. Ciullo, 1996).

Glass - Feldspar is used primarily in container glass, followed by flat glass and glass fiber. In glassworking, the principal starting material is silica (SiO_2); Glass-grade products are typically coarsely ground, 20-40 mesh, and contain 4-6% K_2O, 5-7% Na_2O, about 19% Al_2O_3, and less than 0.1% Fe_2O_3. Feldspar is used mainly as a source of alumina, which improves both the workability of the glass melt and the chemical and physical stability of the finished product. It also provides the alkaline oxides (Na_2O, K_2O) that provide fluxing in partial substitution for calcium oxide, which improves chemical resistance. In areas where inexpensive feldspathic sands are abundant, they may be used in preference to processed feldspar. Feldspar beneficiated free of all impurities except quartz is sold for glassmaking as well.

Other uses - Feldspar is used as a flux in welding electrodes, and beneficiated 325 mesh soda spar finds limited use as a filler in plastics, rubber, adhesives, and coatings. In filler applications it offers low vehicle demand, high dry brightness with low tint strength, and resistance to abrasion and chemical degradation. In coatings it also provides good film durability and high resistance to chalking and frosting (Peter A. Ciullo, 1996).

2. Potential Applications of Mica

Joint cements - Fine dry-ground (fluid energy-milled) muscovite is used in drywall joint compounds, where it contributes to consistency and workability, smooth surface finish, and resistance to shrinkage and cracking. The uses of cement are as a grout, cement mortar, render and concrete. Cement mortar used to bed bricks or as render, is produced by mixing cement with builder's sand and lime and sometimes an air entraining agent (for example a platiciser), which improves frost resistance and worksbility. The strength of mortar depends on the proportion of cement to sand and lime, and the grade of sand used in the mix. Concrete is formed by mixing cement with aggregate, gravel or crushed stone. The strength of concrete is dependent on the type of cement, mix proportions, the water/cement ratio and the properties of the aggregate (CIRIA, 1996)

Coatings - Fine-ground (325) mesh and micronized mica grades are used in paint as a pigment extender and for dry film reinforcement. The inert, platy mica improves suspension stability, controls film checking, chalking, shrinkage, and blistering, improves resistance to weathering, chemicals, and water penetration, and improves adhesion to most surfaces. Coarser grinds are used in textured paints, and wet-ground mica is used in high quality exterior house paints. High aspect ratio grades are preferred for porous surface sealers to seal pores, control penetration, and reduce sagging and film cracking. Automotive paints use high aspect ratio mica to achieve a metallic effect either as is, or after conversion to pearlescent pigments by surface coating with metal oxides (Peter A. Ciullo, 1996).

Plastics - Finely ground, -325 mesh and micronized micas are used in plastics to improve electrical, thermal, and insulating properties. Mica is considered the most effective mineral for reducing warpage and increasing stiffness and heat deflection temperature in plastics. In general, mica reinforces crystalline better than amorphous polymers. Best results are obtained with nonpolar polymers when mica is pretreated with a coupling agent to improve wetting. Mica is used in both thermoplastics and thermosets. Its largest single use is in polyolefins, even though it requires stabilizers to prevent degradation of polypropylene. Both muscovite and phlogopite micas are used in plastics, with high aspect ratio grades preferred for their superior reinforcement properties (Peter A. Ciullo, 1996).

Drilling fluids - Coarse, hammermilled (±10 mesh) mica is used in waterbased oilwell drilling fluids to prevent fluid loss into porous rock formations. The coarse mica flakes bridge openings and seal porous sections of the drill hole against loss of circulation. Mica's platy nature also aids in the suspension of drilling fluid solids and cuttings (Peter A. Ciullo, 1996).

Other uses - Ground mica is used as an asbestos substitute in certain thermal boards, brake linings, gaskets, and cement pipes, as a filler and nonstick surface coating for roll roofing and asphalt shingles, as a mold lubricant and release agent in the manufacture of tires and other molded rubber goods, as a flux coating on welding rods, and as a pearlescent pigment in wallpapers (Peter A. Ciullo, 1996).

3. Potential Applications of Iron Oxide

Industri Besi/Baja – Most of the ore contains iron oxides (magnetite, Fe_3O_4 and hematite, Fe_2O_3) along with gangue minerals such as oxides of calcium, silicon, phosphorus, and sulful. The primary purpose of smelting in a blast furnace is to reduce the iron oxide to iron which, in the process, becomes saturated with carbon from the coke. Before iron or steel product formed, iron minerals in the process are made sponge first. Sponge iron, also called Direct-reduced iron (DRI), is formed, when naturally available iron ore which is an oxidised form of Iron (magnetite or hematite) is reduced to its metallic form. In the form of lumps, pellets or fines, sponge iron is produced by a reducing gas produced from natural gas or coal. The reducing gas is a mixture majority of hydrogen (H_2) and carbon monoxide (CO) which acts as reducing agent. This reduction process occurs below the melting temperature of both metallic iron and its oxidised form (Tapash Ranjan Majhi, 2012). Sponge can be formed by iron sand pellets blended 3% hematite and 15% carbon, then calcined at 1300 ° C for 3 hours. Sponge further processed into iron ingots. If iron is reacted with carbon at high temperatures will produce iron carbide. It is usually done in the steel industry (Nurul TR, et al, 2013). The iron tapped from the furnace may be cast in solid pieces known as "pig iron" may be left in the molten state when it is known in the industry simply as "hot metal".

Steel is an alloy of iron, carbon (less than 2%) and manganese (less than 1%), athough other alloy metals are used to produce specific properties. Mechanical properties can be varied by changes in composition. Either the hot metal from blast furnaces or iron / steel scrap or a mixture of both is the main raw material for any steel furnace (CIRIA, 1995).

Pigment - Pigment-based iron oxide has been developed with pulverized iron sand. Iron oxide pigments has the advantage that no toxic properties, chemical stability and the number of color variations resulting, i.e. yellow ($Fe_2O_3.H_2O$), red (Fe_2O_3), and black (Fe_3O_4) (Nurul T.R., 2013).

4. Potential Applications of Silica

In Glass and Ceramic - A pure crystalline silica is used. The iron content must be less than 0.03%, and there are strict limits on the amounts of other impurities. Even the grain size of the crystals is specified. In the finished glass, the silica content must be at least 98.5%. Ceramics and porcelain are made from finely ground crystalline silica, silica flour called.

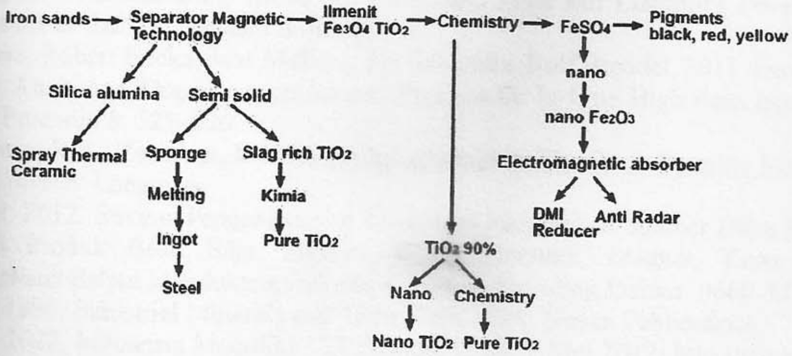
In Construction - Building materials, Reviews such as concrete and dimension stone (sandstone, granite, and limestone are examples) contain crystalline silica in the form of quartz. Quartz is a component of cement, another technological development dating from ancient times. In the past, sandpaper and grinding wheels were made from quartz, and it was the primary abrasives used in sandblasting operations. Quartz is also used as functional filler in plastics, rubber, and paint (Branch of Industrial Minerals, 1992).

In Heavy Industry - Foundry molds and cores for the production of metal castings are made from quartz sand. The manufacture of high-temperature silica brick for use in the linings of Glass- and steel-melting furnaces represents another common use of crystalline silica in the industry. The oil and gas industry uses crystalline silica to break up the rock in wells. The operator pumps a water-sand mixture, under pressure, into the rock formations to fracture them so that oil and gas may be brought to the surface Easily. Quartz sand is also used for filtering sediment and bacteria from water supplies and in sewage treatment.

Cement Raw Materials - Silica is one of the important components of the cement constituent. Raw materials used in the manufacture of portland cement, among others: (60-67%) of lime, (19-25%) of silica, (3-8%) alumina, with varying small amounts of iron oxide, sulfur trioxide, magnesia, titanium oxide and manganese oxide. Good silica sand for the manufacture of cement is SiO_2 levels $\pm$ 90%. The cement content can be modified according to the product to generate. Cements sulphate resistant contain less than 3% tricalcium aluminate. Ultra high strengh early cements, extra gypsum is added to the mix. Air entrained cements, a plasticiser is added to improve the frost resistance and workability. The iron content in the cement may serve as a conductor of heat in the manufacturing process of slag cement. There are also high alumina cement, lime containing 35-40%, 40-50% alumina, up to 25% iron oxide, and no more than 5% silica (CIRIA, 1996).

High-Tech Applications - Semiconducting silicon made from polycrystalline silicon is the base material for electronic and electrotechnical industry, the which produce millions of discrete and integral devices, microprocessors. More than 80% of computing, radio, video, robotics, telecommunications, controlling automatisation and PV and other equipment are manufactured with the use of monocrystalline silicon. Silica is used in various industries. The most important application is its use for silicon production with reviews their different grades: metallurgical grade (MG-Si) solar grade (SG-Si) and electronic grade (EG-Si). Super-pure silicon can be doped with boron, aluminum, phosphorus and aluminum, for the manufacture of silicon used for transistors, solar cells, refining, and tools other solid-state, which is used in electronics and aerospace industries. Pure silicon structure as diamond (tetrahedral) so it is very hard and relatively difficult to conduct electricity. Together with other elements, such as aluminum (Al) or boron (B), silicon is a semiconductor (a little electricity) (Christoph Madera et.al., 2011; Xiaodong Pi., 2012). Doped silicon has been developed for the purposes of the solar cell.

Recently, Nurul T.R., et al. (2013) has made iron sand processing integrated into a wide range of products, among others, iron, pigments, ceramics, magnets, cosmetics and photocatalyst. Figure 3 shows the processing flow in an integrated iron sand.



Source: Nurul T.R., et.al., 2013.

Figure 3. Plot of iron sand processing into various products.

Mechanisms are iron sand washing and separation of inorganic impurities, Al_2O_3 and SiO_2, physically using a magnetic separator, in order to obtain iron oxide concentrate containing ilmenite up to 50-55%. $Al_2O_3.SiO_2$ obtained is used to make specialty ceramics and saucer for burning. The iron concentrate in-milling up to 325 mesh and partially in-pellets with a mixture of coal, clay and lime before it is reduced in a furnace at a temperature of 900-1300 °C to be a sponge iron with a capacity of 100 kg / day are ready to be melted to produce ingot iron and TiO_2-rich slag. Iron ingots with induction furnace reprocessed into products of cast iron or steel. Most iron concentrate with size 300 mesh in-leaching by using either HCl or H_2SO_4 results TiO_2 with levels of about 90% and an iron salt solution which will be deposited with an alkaline solution to obtain Fe_2O_3. TiO_2 concentrate purified back and made into a solution of $TiCl_4$ as raw material TiO_2 nanoparticles for cosmetic applications, pigments, ceramic coating and photocatalystic.

CONCLUSION AND SUGGESTION

The following conclusions were obtained from the research and review of the literature:

1. Three highest minerals contained in the sand of Merapi Mount are silica (~ 50%), aluminum (~ 17%), and iron (14%) and some other minerals (concentration <10%). Most of the elements as mineral such as quartz, albite, anorthite, Muscovite, illite, hematite, magnetite, etc.
2. Minerals contained in the sands of Merapi Mount has a great potential to be processed into industrial raw materials which have high economic value, including for the ceramic industry, glass industry, cement industry, iron / steel industry, industrial pigments, industrial production of silicon, etc. Purification and development of elements with high purity has the potential to be developed into a high-tech products such as solar cells.

REFERENCES

Akhtar, M.J., Waseem, S. 2013. Computational Study of Scheelite ($ZrSiO_4$) by Employing Static Simulation Techniques. Solid State Sciences 5. p. 541–548.

Antara News. 2014. BPS: Ekspor Naik, Impor Masih Sulit Ditekan. February 3rd 2014. http://www.antaranews.com/berita/417155/bps-ekspor-naik-impor-masih-sulit-ditekan.

Branch of Industrial Minerals. 1992. Crystalline Silica Primer. United States: Bureau Of Mines.

CIRIA (Construction Industry Reasearch and Information Association). 1995. Metal Manufacturing, Refining, and Finishing Works: Iron and Steelworks. Contaminated Land and Liabilities Division. UK: Department of the Environment Industry.

CIRIA (Construction Industry Reasearch and Information Association). 1996. Ceramics, Cement, and Asphalt Manufacturing Works. Contaminated Land and Liabilities Division. UK: Department of the Environment Industry.

Christoph Madera, Robert Bocka, Jens Müllera, Jan Schmidta, Rolf Brendel. 2011. Formation of Locally Aluminum-Doped *p*-type Silicon Regions by In-Line High-Rate Evaporation. Energy Procedia 8: 521–526.

Deer, W.A.; Howie, R.A.; Zussman, J. 1992. An Introduction to The Rock-Forming Minerals. 2nd ed. London: Longman.

Nurul T.R., et.al. 2012. Review Pengembangan Teknologi Pengolahan Sumber Daya Pasir Besi Menjadi Produk Besi/ Baja, Pigmen, Bahan Keramik, Magnet, Kosmetik, dan Fotokatalistik dalam Mendukung Industri Nasional. Prosiding Insinas. 0660. MT: 84-91.

Peter A. Ciullo, 1996. Industrial Minerals and Their Uses. USA: Noyes Publications.

Pikiran Rakyat. 2012. Indonesia Memiliki 127 Gunung Aktif. 2 Mei 2012. http://www.pikiran-rakyat.com/node/186891.

Tapash Ranjan Majhi. 2012. Modeling of Rotary Kiln for Sponge Iron Processing Using CFD Package (ANSYS 13.0). *A Thesis in Chemical Engineering.* Rourkela, India: Department of Chemical Engineering National Institute of Technology.

Tom Simkin and Lee Siebert (1994). *Volcanoes of the World: A Regional Directory, Gazetteer, and Chronology of Volcanism During the Last 10,000 Years* (ed. 2nd). Geoscience Press.

Xiaodong Pi. 2012. Doping Silicon Nanocrystals with Boron and Phosphorus. Journal of Nanomaterials. Volume 2012. http://dx.doi.org/10.1155/2012/912903.