A Review: Analysis of Metal and Mineral Content in the Complexity of Sidoarjo Hot Mud as a Source of Renewable Energy in Indonesia

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Abstract: The Sidoarjo Hot Mud is a phenomenon of mudflow caused by exploration activities of PT. Lapindo Brantas since 2006. The purpose of this article is to provide information related to the empowerment of the Sidoarjo Hot Mud which has the potential as alternative source of renewable energy: source of electrical energy and biodiesel catalyst. Based on XRF results on samples at two locations: the center of the eruption and Lusi Island, it showed that there were various metallic elements and oxide minerals. Based on the results, the Sidoarjo Hot Mud from the center of the eruption resulted in potential difference of 8.8 V and electric power of 7.07135 watts/hour (8 circuits). The hot mud samples of Lusi Island produced potential difference of 4.38 V and electric power of 3.5196 watts/hour (3 circuits); 5.84 V and 4.6928 watts/hour (4 circuits). The silica mineral in the center of the eruption was 45.0% (radius 500 m), 45.3% (radius 1000 m), and 43.3% (radius 2000 m), while on Lusi Island it was 43.8%. Based on these results, the Sidoarjo mud has the potential to be used as a source of renewable energy in Indonesia, as a source of electrical energy and for synthesis for biodiesel catalyst.

Keywords: Sidoarjo Hot Mud, Lusi Island, Renewable Energy, Electrical Energy, Catalysts, Silica

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INTRODUCTION

Sidoarjo Hot Mud is an ecological phenomenon of mudflow caused by the exploration activities of PT. Lapindo Brantas in Balongnongo, Renokenongo, Porong, Sidoarjo, East Java, which has occurred since November 2006. This phenomenon has included about 250 hectares of land i.e: 7 villages, rice fields, sugar cane plantations, irrigation canals, and transportation routes. The average volume of mudflow per day is around 50,000 – 120,000 m^3. The mudflow comes from a hole with a diameter of approximately 50 m (1). ±60,000 m^3 of ±80,000 m^3 volume of released mud is flowed into the sea through the Porong River (2). The overflow of mud into the Porong river causes the river to become shallow and the water flows slowly at high tide. The contained Sediment in river flow forms sedimentary deposits. Over time, these deposits formed a new island or better known as "Lusi Island" (3).

The Sidoarjo mudflow has had a tremendous impact in various fields, both for the life of the people around the center of the eruption and in East Java. In the economic field, it causes disruption of transportation facilities, namely the interruption of the main traffic routes of Surabaya-Malang and Surabaya-Banyuwangi. Disruption of aspects of education, where several formal and non-formal schools are flooded. Public health was also disrupted due to the toxic gas released from the hot mudflow. In addition, residents' houses were submerged in mud, causing economic losses. Therefore, the empowerment of the Sidoarjo mud is considered very important to minimize the impact (4).

Based on research by Utomo (2009), the results of the elemental content in Sidoarjo mud consisted of Si 25.67%, Na 1.17%, Mg 1.75%, Al 13.27%, Cl 0.91%, K 1.93%, Ca 1.54%, Fe 7.89%, Cd 0.3 %, Cu 0.4%, and Pb 0.73% (5). From these contents there are several metal elements that have the potential to be used as sources of electrical energy such as Na, Mg, Al, Fe, and Cd. This makes the Lapindo mud potential as a new renewable energy source to generate electricity by applying the study of chemistry "Voltaic Cell/Galvanic Cell". A voltaic cell or galvanic cell is an electrochemical cell that can generate electrical energy caused by a spontaneous oxidation-reduction reaction (6) (7).

Electrical energy is one of the essential basic needs in human life. Almost all human activities are related to electrical energy. In line with the increasing economic growth in Indonesia, the demand for electrical energy is also increasing. In the period 2013-2023 or the next 10 years, the Java-Bali electricity system is estimated to increase from 144 terra watts/hour (TWh) in 2013 to 375 TWh in 2022, which means a growth of 7.6%/year (8).

In addition to its elemental content, Sidoarjo hot mud also contained oxide minerals, including Al_2O_3 16%, SiO_2 49.9%, K_2O 2.51%, CaO 6.14%, TiO_2 1.74%, and Fe_2O_3 21.7% (9). Based on these data, silica content is one of the main mineral components in the Sidoarjo mud. Therefore, Sidoarjo hot mud has the potential to be used as a source of silica. One of the uses of silica is as a raw material for making synthetic zeolite to be used as a biodiesel/biofuel catalyst (10). The use of silica as a raw material for the manufacture of synthetic zeolite is carried out because the price of silica in the market isrelatively expensive (11).

Currently, the majority of energy needs in Indonesia are met by fossil fuels as non-renewable energy sources. Meanwhile, its availability in nature is increasingly depleting, this can be proven by the decline in the average oil reserves in Indonesia in the last five years, which is 22 billion barrels/year (12), (13). The continuous use of non-renewable energy sources causes a decrease in the quantity of petroleum resources. Based on data from the Minister of Energy and Mineral Resources (ESDM) in 2020, Arifin Tasrif in the Indonesian Energy Portrait Webiner on Tempo Energy Day (Wednesday 21/10/2020) said that without the discovery of alternative energy sources, oil in Indonesia will run out. in the next 9 years (2029), natural gas will run out in the next 22 years (2042), and coal will last for the next 65 years (14). These data indicated that Indonesia has limited energy and is in danger of experiencing an energy crisis in the future. Therefore, it is necessary to empower alternative energy sources to solve this problem. One alternative is empowering Sidoarjo hot mud which can be used as a potential source of electrical energy and biodiesel/biofuel.

Based on the above explanation, this article is expected to provide information to the public regarding the empowerment of Sidoarjo hot mud to be used as a renewable energy source (electric energy source and biodiesel catalyst source) in Indonesia. This idea can be a solution to the complex problem of the Sidoarjo hot mud, as well as a solution to the threat of the energy crisis in Indonesia.

MATERIAL AND METHODS

The used research method was the Systematic Literature Review (SLR) method. Using the SLR method, a systematic review and identification of journals can be carried out which followed the organized steps (31).

Research Question

Research questions were made based on the needs of the topic chosen by the author. The following were the research questions in this study, namely:

1. What are the metals and minerals contained in the Sidoarjo hot mud sample?
2. How the differences in the metal and mineral content contained in the Sidoarjo hot mud samples obtained from 2 different locations (eruption center and Lusi island)?
3. How the potential sources of renewable energy that can be utilized from the Sidoarjo hot mud phenomenon?

Search Process

The search process was used to obtain relevant sources to answer Research Questions/research questions and other related references. The search process used the Google Scholar database. In this study, the authors conducted a search with several keywords. Each keyword and its search results are shown in Table 1.

Table 1: Search Results for Each Keyword in Indonesian Language.

Num.	Keyword	Search Result
1	"Potensi Energi Baru dan Terbarukan"	13.700 articles
2	"Menjadi energi listrik"	147.000 articles
3	"Lumpur Sidoarjo menjadi sumber energi"	1.530 articles
4	"Lumpur Sidoarjo menjadi sumber energi listrik"	792 articles

Inclusion and Exclusion Criteria

This stage is to determine the found data for use in Systematic Literature Review method. A study was eligible to be selected according to the following criteria:

Data used in the last 15 years.

1. Data obtained through Google Scholar.
2. The used data was only focused on problems regarding the analysis of Sidoarjo hot mud content as a potential source of renewable energy.

Data Collection and Data Analysis

Data collection is the stage where the research data was collected. The data collected in this study was secondary data. Secondary data obtain in journals and research articles. From all the articles obtained, the authors filter the results of the appropriate articles and journals to obtain accurate data for use in this study.

In this study, the researcher used 23 samples with details of 19 articles and 4 academic final reports. Researchers took data by reviewing existing information and facts, then re-paraphrasing and providing a thorough analysis.

RESULTS AND DISCUSSION

Analysis of Compound Content

Analysis of compound content in Sidoarjo hot mud samples consisted of elemental content analysis and analysis of oxide mineral compounds using XRF test. The principle of the XRF test is based on the interaction of the material with X-rays (15). This test is often used in mineral analysis, because of fast, accurate, non-destructive, and usually requires only minimal sample preparation (16).

XRF Test Results

In the study of this article, the samples studied were sourced from 2 locations, the mud sample at the center of the Sidoarjo hot mudflow (radius 500 m, 1000 m, and 2000 m) and the mud on Lusi Island.

Sidoarjo Hot Mudflow Center

The results of elemental content in the Sidoarjo hot mud at a radius of 500 m, 1000 m, and 2000 m from the center of the eruption are shown in Table 2.

Table 2: Results of Elemental Content Analysis in Sidoarjo Hot Mud Using XRF.

Element	% Radius 500 m	% Radius 1000 m	% Radius 2000 m
Al	11	11	9.9
Si	32.7	33.0	31.1
K	4.03	3.88	3.81
Ca	7.78	8.19	7.99
Ti	2.13	2.11	2.20
V	0.081	0.087	0.087
Cr	0.100	0.099	0.11
Mn	0.45	0.47	0.53
Fe	34.2	33.9	36.4
Ni	0.03	-	-

Element	% Radius 500 m	% Radius 1000 m	% Radius 2000 m
Cu	0.15	0.14	0.16
Zn	0.08	0.07	0.07
Br	0.39	0.31	-
Sr	1.1	1.1	0.86
Mo	5.1	5.1	5.4
Eu	0.59	0.58	0.67
Yb	0.1	-	-
Re	0.2	0.2	0.3
P	-	-	0.44

Based on Table 2, the main elemental contents in Sidoarjo hot mud were Iron (Fe) 34.2% (radius 500 m), 33.9% (radius 1000 m), and 36.4% (radius 2000 m). The second main contents were silicon (Si) of 32.7% (radius 500 m), 33.0% (radius 1000 m), and 31.1% (radius 2000 m). The other elements were Al, K, Ca, Ti, V, Cr, Mn, Ni, Cu, Zn, Br, Sr, Mo, Eu, Yb, Re, and P. The content of silicon in this study was slightly higher. Larger than the results of the initial analysis conducted by Assolah (2015) which obtained an elemental Si content of 19.70%. In addition to analyzing the elemental content in the Sidoarjo mud, this XRF analysis also analyzes the oxide content which is shown in Table 3.

Based on Table 3, the main oxide content in Sidoarjo mud was silica of 45.0% (radius 500 m), 45.3% (radius 1000 m), and 43.3% (radius 2000 m). The second main content was iron oxide, namely 24.1% (radius 500 m), 23.7% (radius 1000 m), and 25.9% (radius 2000 m), the presence of iron content was correlated to the blackish gray color of the Sidoarjo hot mud. Other oxides contained in it were Al_2O_3, K_2O, CaO, TiO_2, VO_5, Cr_2O_3, MnO, NiO, CuO, ZnO, SrO, MoO_3, Eu_2O_3, Yb_2O_3, and Re_2O_7. Thus, this Sidoarjo hot mud has the potential to be used as a source of silica in the future and further exploration can also be carried out due to the presence of soil minerals that were rarely identified.

Table 3: Results of Oxide Content Analysis in Sidoarjo Mud Using XRF.

Oxide	% Radius 500 m	% Radius 1000 m	% Radius 2000 m
Al_2O_3	14	14	13
SiO_2	45.0	45.3	43.3
K_2O	2.76	2.64	2.64
CaO	6.05	6.34	6.30
TiO_2	1.91	1.88	2.01
V_2O_5	0.076	0.081	0.083
Cr_2O_3	0.077	0.076	0.085
MnO	0.29	0.30	0.35
Fe_2O_3	24.1	23.7	25.9

Oxide	% Radius 500 m	% Radius 1000 m	% Radius 2000 m
NiO	0.02	-	-
CuO	0.084	0.079	0.092
ZnO	0.04	0.04	0.04
SrO	0.60	0.56	0.46
MoO_3	4.6	4.5	4.8
Eu_2O_3	0.35	0.35	0.40
Yb_2O_3	0.05	-	-
Re_2O_7	0.1	0.1	0.2
P_2O_5	-	-	0.62

As for obtaining silica with a high level of purity, a synthesis method is needed that can significantly reduce the level of impurities in the sample. Research by Silvia & Zainuri has succeeded in synthesizing silica from Bancar beach natural sand which has the highest purity reaching 100% from an initial content of 81.7% using the coprecipitation method with NaOH solvent (17). This shows that the coprecipitation method or others can be applied to samples containing silica such as Sidoarjo hot mud to obtain high purity. Therefore, this Sidoarjo hot mud has the potential as a source of high purity silica.

Lusi Island

The results of the analysis of elemental content in Lusi Island are shown in Table 4.

Table 4: Results of Elemental Analysis on Lusi Island Using XRF.

Element	% Content	Element	% Content	Element	% Content
Al	12	Mn	0.75	Sr	-
Si	32.1	Fe	38.5	Mo	3.9
K	2.10	Ni	0.03	Eu	0.55
Ca	6.86	Cu	0.18	Yb	0.1
Ti	2.05	Zn	0.09	Re	0.2
V	0.088	Mn	0.75	P	-
Cr	0.083	Br	-	-	-

Based on Table 4 , the largest element content in Lusi Island was Iron (Fe) 38.5%. The second largest content was silicon (Si) 32.1%. Other elements contained in it were Al, K, Ca, Ti, V, Cr, Mn, Ni, Cu, Zn, Mo, Eu, Yb, and Re. The metal content of Fe in Lusi Island was slightly higher than the content of Fe in the Sidoarjo Mud which was 36.4% (radius 2000 m). Meanwhile, the silicon (Si) content in Lusi Island was slightly lower than that in Sidoarjo hot mud of 33.0% (radius 1000 m). In addition to analyzing the elemental content in Lusi Island, this XRF analysis also analyzed the oxide content as shown in Table 5.

Table 5: Results of Oxide Content Analysis in Lusi Island Using XRF.

Oxide	% Content	Oxide	% Content	Oxide	% Content
Al_2O_3	16	V_2O_5	0.083	CuO	0.10
SiO_2	43.8	Cr_2O_3	0.064	ZnO	0.05
K_2O	1.44	MnO	0.49	SrO	-
CaO	5.39	Fe_2O_3	26.9		
Al_2O_3	16	NiO	0.01		

Based on Table 5, the most dominant oxide content in Lusi Island was silica of 43.8%. The second dominant content was iron oxide, which was 26.9%. Other oxides contained in it were Al_2O_3, K_2O, CaO, TiO_2, VO_5, Cr_2O_3, MnO, NiO, CuO, ZnO, SrO, and MoO_3. The silica content in Lusi Island was slightly lower than that in Sidoarjo Mud, which is 45.3%.

Based on the results of the XRF test, it was found that the content of metallic elements and oxide minerals in the Sidoarjo hot Mudflow Center and Lusi Island had almost the same percentage. With this content, this mud has the potential to be used as a new renewable energy source (source of electrical energy and a source of silica as a biodiesel catalyst).

The Effectiveness of Utilizing Sidoarjo Mud as a Source of Electrical Energy

Based on the XRF test data, the Sidoarjo Hot Mud and Lusi Island have high metal content. Through the application of the principle of the voltaic cell, Sidoarjo Mud can be used as a source of environmental friendly electrical energy. By making a circuit, copper and magnesium as electrodes connected to a digital multimeter can be produced relatively large electric currents. Based on the research results of Rokhim the Sidoarjo mudflow at the center of the eruption can be produced a potential difference of 8.8 volts and an electric power of 7.07135 watts/hour (8 sets of cells). Meanwhile, in Lusi Island, 3 sets of cells produced a potential difference of 4.38 volts and an electrical power of 3.5196 watts/hour. In 4 series of cells it produced a potential difference of 5.84 volts and an electric power of 4.6928 watts/hour (8).

Utilization of Sidoarjo hot mud as a source of electri cal energy has a high effectiveness. This referred to the results of research by (18), (19), and (19) concluding that Sidoarjo Hot Mud can be used as bioelectricity by using microbial fuel cells (MFC). Another study conducted by (20) concluded that Sidoarjo Hot Mud can be used as a potential source of new renewable energy based on SCL (Soil Cell) with hydrothermal technology.

Potential electrical energy that can be generated from Sidoarjo hot mud processing is an electric voltage of 163.83 Volt/m^2 and an electric current of 0.01 A/m^2 (18), while the results of the research by Saragih & Melaca produced an electric voltage of 210.25 volts/m^2,and an electric current of 51.75 A/m^2 (18).

Another effectiveness of the utilization of the Sidoarjo hot mud is that it can be used as a lithium battery with a large output and it can be used repeatedly until its lifetime runs out (21), (22), and (22). The results of this study were reinforced by the results of research by Noerochim, Satriawangsa, and Widodo that in the Sidoarjo Hot Mud geothermal fluid there was a lithium content of 5.81 mg/liter which can be used as the most potential source of lithium. By doing a rough calculation and assuming that the amount of sludge discharge and the content of Lithium is constant, Lusi can be produced at least 18 tons of Lithium every year (23). Extraction and Processing of Lithium from Sidoardjo Hot Mud can be used as a Lithium Battery Cathode Manufacturing.

Utilization of Sidoarjo Mud into alternative energy as Renewable Energy is a form of saving the environment, especially in the area around the Sidoarjo hot mud (2), (8). In addition, it is also an effort to overcome the use of non-renewable natural resources, especially in the problem of electrical energy in Indonesia.

Effectiveness of Utilizing Sidoarjo Mud as a Silica Source

The mineral composition of the Sidoarjo hot mud in the eruption Center and Lusi Island has almost the same percentage. Based on the data, the XRF test results showed that the highest and most dominant oxide percentage in both places were silica (SiO_2). The silica content in the Sidoarjo Hot Mud and Lusi Island, respectively, was 45.3% (radius 1000 m) and 43.8%. Therefore, these minerals have the most potential for exploitation. To obtain silica, several methods of silica extraction are necessary. Commonly, the used silica extraction methods on samples of the Sidoarjo hot mud type included continuous methods, sol gel, leaching, and coprecipitation as shown in Table 6.

Based on the literature review on the Table 6 , the majority of researchers used the continuous method in extracting silica contained in the Sıdoarjo hot mud. One of the potential silica can be used as a raw material in the manufacture of catalysts. For example, the catalyst is a synthetic zeolite which was the hydrated porous alumino-silicate crystals (28). The use of silica from natural materials as raw material for the manufacture of synthetic zeolite was carried out because the price of silica in the market is relatively expensive (28). Zeolite made from silica is useful as a catalyst for biodiesel and biofuel (10).

Biodiesel is a long chain methyl ester compound that can be produced through the esterification-transesterification process of vegetable oils or animal fats. The process usually use a homogeneous base or acid catalyst, so the process can reacts at low temperature and selective products (29).

The synthesis of biodiesel can use homogeneous catalysts, such as acids and bases. The use of this homogeneous catalyst causes problems in the resulting product, one of which still contained a catalyst that must be separated again. On the other hand, the use of base catalysts can also overcome side reactions, namely the saponification reaction, which affected the process of biodiesel synhtesis. So, the use of heterogeneous catalysts, such as activated synthetic zeolite, will facilitate the separation of the catalyst from the product (30). Biodiesel is an alternative fuel from renewable resources that has many advantages, including: environmentally friendly, relatively low emissions of air pollution, can be decomposed naturally (biodegradable), and can be used without the need for engine modification processes. Therefore, the use of silica as a raw material for the manufacture of zeolite (biodiesel catalyst) is a form of solution for using alternative energy as a new renewable energy source in Indonesia.

Table 6: Silica Extraction Method on the Sample.

Method	Starting material	Procedure Sequence	Product	Reference
Continuous	Dried mud solids	• Mud washed with distilled water • Soaked with 2 M HCl • Dry at 110 ℃ • Flowing with alkaline solution (KOH) • Conditioned under acidic conditions (pH =4)	Precipitated amorphous silica	(24)
Sol Gel	Dried mud solids	• Soaked with 2 M HCl (4 hours) • Filtration (took the sediment) • Washed with distilled water • Reacted with 7 M NaOH (5 hours, 80 ℃) • Filtration • The filtrate was heated T= 100 ℃, 10 minutes • Add 3 M HCl until the pH was close to 7	Silica white precipitate	(25)
Leaching	Dried mud solids	• Reacted with 6 M NaOH, T= 90 ℃, 5 hours • Titration with HCl (pH up to 8) • Washed and dried, T= 120 ℃, 10 hours	Xerogel Silica	(26)
Coprecipitation	Dried mud solids	• Reacted with NaOH • Heated and stirred • Filtration • The filtrate was dripped with HCl (pH up to 7)	Precipitated amorphous silica	(27)

CONCLUSION

Based on the XRF test results, it can be concluded that the metal and mineral oxide content of the Sidoarjo Hot Mud in two locations namely the center of the Sidoarjo Hot mudflow and the Lusi island have relatively the same content. The oxide contents in the Sidoarjo Hot Mud were SiO_2, Fe_2O_3, Al_2O_3, K_2O, CaO, TiO_2, VO_5, Cr_2O_3, MnO, NiO, CuO, ZnO, SrO, and MoO_3. The high metal content in the mud has the potential to be used as a source of environmentally friendly electrical energy. While the content of silica minerals can be used as the basic material for zeolites synthesis (biodiesel catalysts). So, the empowerment of the Sidoarjo Hot Mud can be used as an alternative solution for renewable energy.

CONFLICT OF INTEREST

All authors declare no conflict of interest.

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