Designing Heap Leaching for Nickel Production that Environmentally and Economically Sustain

Sri Listyarini

***Abstract*—Some of laterite mineral from Southeast Sulawesi, Indonesia, has low grade nickel contain. This research was done in 3 steps to analyze the possibility of extracting nickel from low grade laterite for industry. In the first step of this research heap leaching method is used in laboratory scale for extracting the nickel from laterite mineral using sulfuric acid and hydrochloric acid. The result of the first step research is the higher the acid concentration used will be the more concentration of nickel produced in the Pregnant Leach Solution (PLS), and with the same concentration of sulfuric acid to produce more nickel than hydrochloric acid. The second step of this research was done in micro industry scale using sulfuric acid to leach nickel from laterite with the variety of laterite height and sulfuric acid concentration. The result from the second step research is stated that 2 M of sulfuric acid is the optimum concentration and 1.5 m laterite sample height. The third step of this research is to design the pilot industry scale for nickel heap leaching reactor with bamboo as a part of reactor and to analyze the feasibility cost. The reactors designed in this study do not produce waste, so that it is expected to meet environmental sustainability rules. The results of the calculation show that the heap leaching reactors designed in this reseach will economically sustain, and will give benefit for 126.13 US $ for each nickel production.**

***Index Terms*—Heap leaching, hydrochloric acid, laterite, nickel, pregnant leach solution (PLS), sulfuric acid.**

I. Introduction

Indonesia is the world's fourth largest nickel producing country, as Indonesia is one of the countries with large amounts of nickel deposits in the form of laterite minerals [1]. During this time, the processing of nickel ore from laterite minerals in Indonesia is limited to laterite with high nickel content through pyrometallurgical technology, high heating. On the other side, the laterite ore with nickel content is less than 2% and widely found in Southeast Sulawesi, has not been utilized properly [2]. The pyrometallurgical technique creates environmental costs due to the high levels of pollution from metal processing through high heating. The pyrometallurgical technique is very expensive because of the high energy and the required capital input, therefore for laterite minerals with low nickel content is uneconomical when processed using pyrometallurgy techniques. In pyrometallurgycal process the metal losses to discard slags, energy requirements and sulfur disposition are important considerations in process and equipment selection due to environmental consideration [3].

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Sri Listyarini is with the Faculty of Mathematics and Natural Sciences, Indonesia Open University (Universitas Terbuka), Indonesia (e-mail: listyarini@ecampus.ut.ac.id).

Beside the pyrometallurgy techniques to process nickel from laterite, there is hydrometalurgy called heap leaching. Processing of laterite ore with low nickel concentration through heap leaching technique is expected to increase added value, improve nickel optimization and conservation, and preserve the environment. Heap leaching is the process of extraction of metal ions by spraying minerals with chemical reagents so that metal ions are released from the minerals and dissolve. The heap leaching method is done by flushing laterite using acid solution with a certain concentration so that the ion nickel (II) dissolved in acid that has been contacted and flows to the bottom of laterite due to gravity [4]. The result of heap leaching is PLS (Pregnant Leach Solution) in the form of a solution containing metal ions will be separated.

Eventhough patents regarding the process of nickel heap leaching stated that the process of nickel heap leaching is particularly effective for ores that have nickel-containing greater than about 10%, by weight [5], these series of research can prove that heap laeching for laterite ore with low content of nickel can be done and will sustain from the environment and economic point of view.

II. Materials and Methods

Before heap leaching was done, the laterite sample from North Konawe, Southeast Sulawesi was characterized using XRD (x-Ray Diffraction) spectroscopy to know the content of laterite. The nickel contains in laterite sample will be used to know how many the nickel concentration in the laterite sample.

This research was conducted in three steps: first step is the laboratory scale research, where nickel ions (Ni^{2+}) are extracted from low nickel laterite with heap leaching method using sulfuric acid (H_2SO_4) and hydrochloric acid (HCl) with acid concentration variation. The second step of this research is using the heap leaching method of nickel ions from laterite on a micro scale of the industry with the variation of laterite height and sulfuric acid concentration. The third step of this research is to design the heap leaching reactor in the pilot industrial scale and analyze the cost-effectiveness.

In detail the first step of this research, heap leaching in laboratory scale is done with the sample of 25 grams laterite for each variation in the reactor as can be seen in Fig. 1. Variation of sulfuric acid concentrations used 0.01 M; 0.1 M; 1 M; and 2.5 M. Variation of chloride acid concentrations used 1 M; 2M; 3M; 4M; and 5 M [6],[7]. The concentration of nickel ion (Ni^{2+}) from each heap leaching process in the laboratory scale (PLS fraction) is analyzed by Flame Atomic Absorption Spectroscopy (FAAS).

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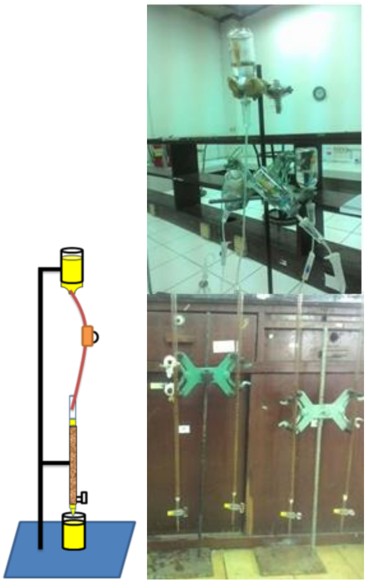


Fig. 1 a). Design of the heap leaching reactor in laboratory scale. b). The heap leaching reactor in laboratory scale.

The second step of this research is doing the nickel heap leaching in the micro industry scale by a variety of laterite sample height (0.5 m, 1 m, and 1.5 m) and sulfuric acid concentration (2 M, 2.5 M, and 3M). In this step of the research the reactor of heap leaching consist of a series of 4 inch diameter PVC pipes as can be seen in Fig. 2. The concentration of nickel ion (Ni^{2+}) of the PLS fraction from each heap leaching process in a micro industry scale is analyzed by FAAS.

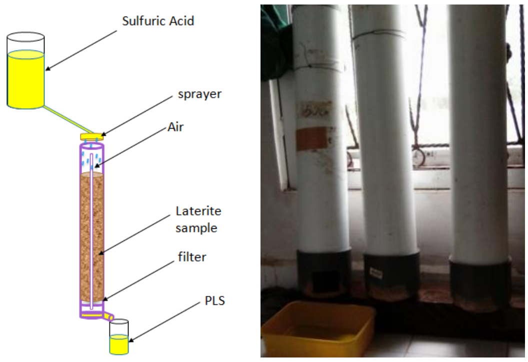


Fig. 2 a). Design of the heap leaching reactor in micro industry scale. b). The heap leaching reactor in micro industry scale.

The third step of this research is designing the nickel heap leaching reactor in the pilot industry scale that environmentally sustained and calculating the feasibility cost.

III. Results and Discussion

The first result of this research is the output from XRD spectroscopy that show the laterite samples is composed by chlorite, pyroxene and talc as the main mineral, as can be seen in Fig. 3. Other minor minerals present in laterite samples are quartz, olivine and amphibole. The Ni^{2+} ions inside the laterite are present as an olivine mineral containing iron oxide and silica. Olivine is solid-solution of iron-silicates and magnesium-silicates containing relatively small amounts of nickel and chromium, and is the precursor of weathered laterite ore [8]. The XRD spectra calculation shows that the nickel content in the laterite sample is only 1.2%. Cao *et al.*[9] stated the laterite content of nickel less than 1.2% was called the low grade laterite ore.

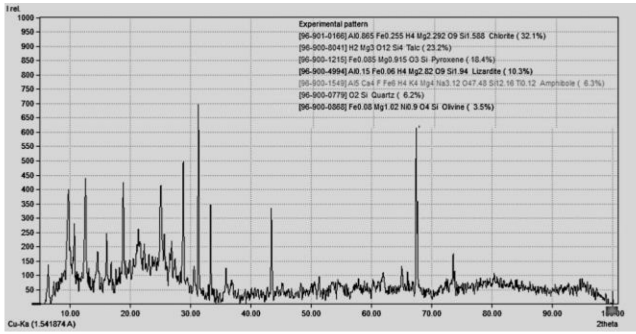


Fig. 3. XRD characterization of laterite sample.

In the first step of this research the measurements of Ni^{2+} in every PLS fraction with sulfuric acid concentration variation (0.01 M; 0.1 M; 1 M; and 2.5 M.) were done using FAAS with a wavelength of 341.5 nm, the result can be seen in Fig. 4. Ni^{2+} which is at PLS accumulated. The higher sulfuric acid concentration was used, the more Ni^{2+} can be extracted (3.8%; 14.4%; 47.3%; 50.0%). This result is supported by the research was done by Agacayak and Veysel [10] that stated the nickel percentation obtained at the concentration of 0.1 and 2.0 M sulfuric acid obtained 23.8% and 65.27%.

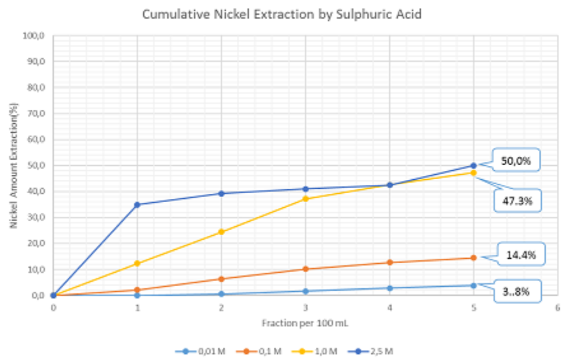


Fig. 4. Cumulative nickel heap leaching using Sulfuric acid in laboratory scale.

In the first step of this research the extraction of nickel from the laterite using hydrochloric acid with a variety of hydrocloric acid concentration (1 M; 2M; 3M; 4M; and 5 M) is also done, the result can be seen in Fig. 5. The higher hydrochloric acid concentration was used, the more Ni^{2+} ion can be extracted (17.6%; 30.3%; 58.0%; 71.6%; 97.8%).

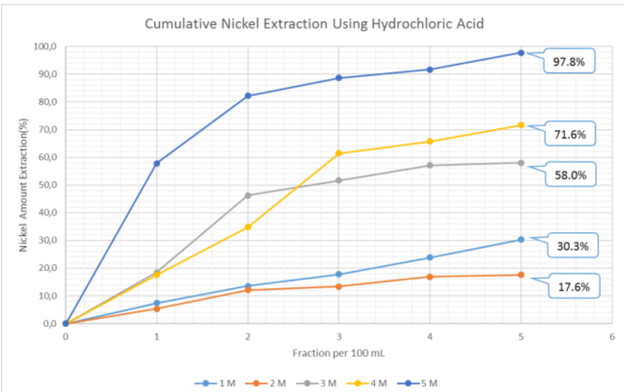


Fig. 5. Cumulative nickel heap leaching using Hydrochloric acid in laboratory scale.

Comparison of heap leaching results between sulfuric acid and hydrochloric acid with the same concentration (1 M) can be seen in Fig. 6. The same concentration of the acid used in heap leaching produces a different PLS, where sulfuric acid produces PLS with a higher nickel ion concentration than hydrochloric acid.

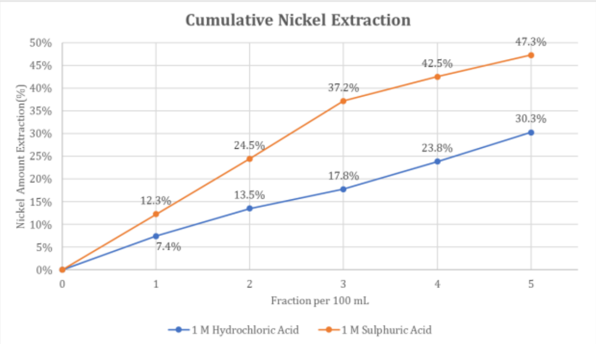
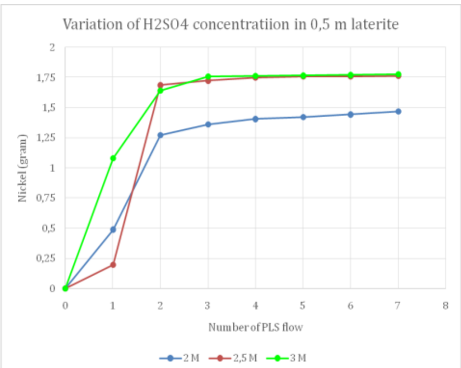
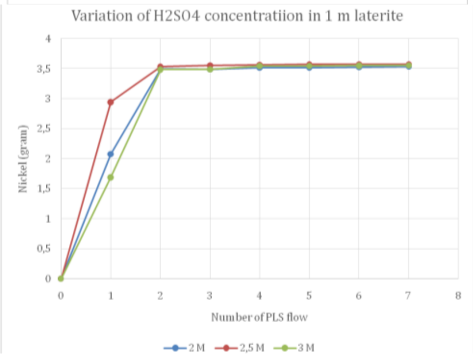


Fig. 6. Comparison of nickel heap leaching using sulfuric acid and hydrochloric acid in laboratory scale.

Based on the comparison of the PLS nickel ion concentration from the first step of the research and residual of hydrochloric acid in post-heap leaching laterite soil is harmful to plants [11], the second step of this research was done using only sulfuric acid. The second step of this research is done on a larger scale, called micro industry scale. At this step the heap leaching is done with a variation of laterite soil sample height and sulfuric acid concentration. The result of the second step of this research can be seen in Fig. 7.

From Fig. 7a it can be seen that the concentration of 2 M sulfuric acid is the optimum concentration for doing nickel heap leaching from the laterite sample. This is consistent with research conducted by Agacayak and Veysel [10], whose research results show that the percentage of nickel from the nickel laterite ore extracting process increases with the increase of sulfuric acid concentration.





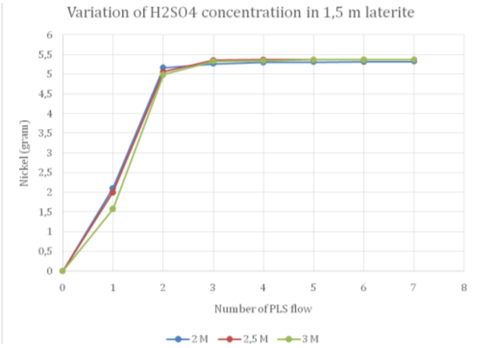
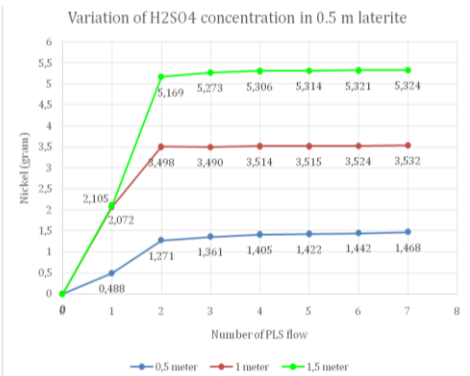


Fig. 7a. Heap leaching with a variation of sulfuric acid concentration in micro industry scale.

Fig. 7b shows the higher the laterite samples the more the amount of nickel dissolved in the PLS and the nickel concentration in the PLS will be relatively stable at the second PLS flow. The higher the laterite sample represents the greater number of laterite samples, of course, the greater the yield of nickel concentration in the resulting PLS. The observation results show the physical properties of laterite samples, such as grain size, density and porosity, greatly determine the metal concentration in the resulting PLS. This is in accordance with the research doing by Steemson *et al.* [12], which states the physical properties of the laterite ore, including: particle size distribution; clay contents and clay mineral type; density and porosity; degree of saturation; and segregation affects the heap leaching results. Based on this second step of research result the third step is designed to use the laterite in 1.5 m height and 2 M sulfuric acid.

The third step of this research is designing the heap leaching reactor in the pilot industrial scale. The reactor designed can be seen in Fig. 8. The heap leaching reactor is designed to be 10 m x 10 m in size and uses bamboo as part of this reactor, that are easily found in Southeast Sulawesi. In this reactor bamboo-chamber functions as a part that separates the laterite and PLS on the process of heap leaching. Bamboo stakes are used to prevent laterite from aglomerating due to sulfuric acid leach. Bamboo can be planted around the industrial area and can be used as a phytoremediation plant [13]. In general heap leaching using PVC plastic instead of bamboo that is difficult to degrade.

The result of heap leaching is a PLS containing nickel and other metals contained in laterite and dissolved in sulfuric acid. This PLS can be processed through electrolysis technique to produce a pure nickel and other metals. The rest of the PLS fluid after electrolysis is a dilute sulfuric acid that can be reused for the next heap leaching process, of course with the addition of more concentrated sulfuric acid.



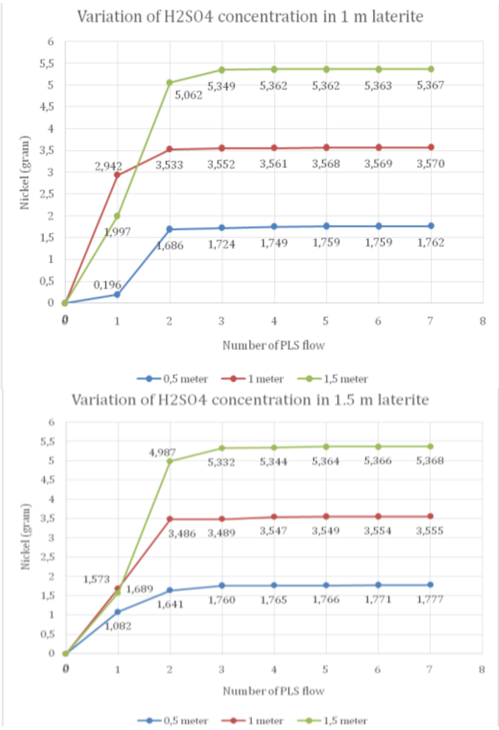


Fig. 7b. Heap leaching with a variation of laterite height in micro industry scale.

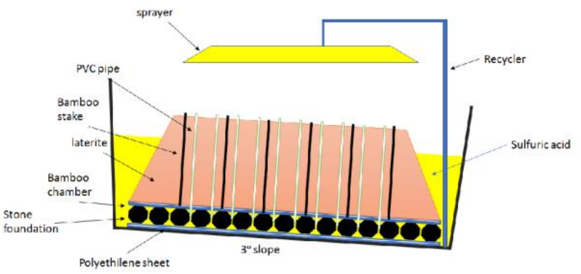


Fig. 8. The design of heap leaching reactor in pilot industry scale.

TABLE I: BREAKDOWN OF NICKEL PRODUCTION COST

Material	Quantity	Unit	Unit Price (US $)	Price (US $)
Laterite Volume	150	m^3	-	-
Laterite Mass	130	ton	-	-
Wage	5	man	76.92	384.62
Soil remediation	-	-	76.92	76.92
Sulfuric Acid	611	kL	3.70	2263.37
Bamboo chamber	200	m^2	2.96	592.59
Acid pipe	60	m	7.41	444.44
Acid hoose	120	m	1.48	177.78
Polyetilen plastic	144	1.5 m^2	2.37	23.70
Bamboo stake	150	m	5.93	888.89
Spayer	16	piece	5.93	94.81
Water tank	6	piece	92.59	555.56
Water pump	1	piece	222.22	222.22
Acid resistant pump	1	piece	148.15	148.15
Total Cost				5873.06

The laterite soil that has been processed through the heap leaching has reduced nickel and other metal contained and is acidic because it contains residual of sulfuric acid. After mixed with alkaline lime, this acid soil can be returned to the environment. This limed laterite soil can be used to grow bamboo or other plants around the nickel processing industry. The reactors designed in this study do not produce waste, so that it is expected to meet environmental sustainability rules.

The sustainability of this reactor is economically analyzed through feasibility cost of nickel production from low grade laterite that can be seen in Table I. The cost breakdown in Table 1 shows the total cost required to process 130 tons of laterite is 5873.06 US $. The concentration of sulfuric acid used 2 M (according to research results of step 1 and 2) with heap leaching 7 times or a week, is expected to produce at least 0.5% nickel or 0.65 tons. This is pessimistic expectation.

The price of nickel metal on August 4, 2017 was 10,255.02 US $ per ton [14]. Assuming 10% of the price of nickel is needed for the electrolysis and purification process, the profit earned from each heap leaching process is 126.13 US $. The results of this calculation show that the heap leaching reactors designed in this reseach will economically sustain.

IV. Conclusions

The first conclusion of this research is nickel concentration in laterite ore sample only 1.2%. Heap leaching using sulfuric acid produces PLS with higher nickel content than using hydrochloric acid. Variance of sulfuric acid concentration in the second step of research showed that 2 M concentration was the optimum concentration of nickel heap leaching process from 1.5 m of height laterite soil. Design of heap leaching reactor for small scale industry made from bamboo with size 10 m x 10 m and use the 1.5 m laterite heights with a cost equal to 5873.06 US $ which will yield profit 126.13 US $ every time heap leaching process done. The heap leaching reactor designed proves that its method with sulfuric acid as an extracting agent and the use of bamboo as part of the reactor can meet environmental sustainability rules and economically sustained.

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References

[1] A. H. P. Permadhi, Pramusanto, and S. Widayati. (2016). *Technical and Economical Analysis of Planning Sponge Ferronickel Production from Nickel Lateritic Ore*. [Online]. Available: http://karyailmiah.unisba.ac.id/index.php/pertambangan/article/view/5106

[2] Kementerian Energi dan Sumber Daya Mineral. (2015). *Dampak Pembangunan Smelter di Kawasan Ekonomi Khusus (Studi Kasus Provinsi Sulawesi Tenggara)*. [Online]. Available:

https://www.esdm.go.id/assets/media/content/KEI-Dampak_Pembangunan_Smelter_di_Kawasan_Ekonomi_Khusus_(Studi_Kasus_Provinsi_Sulawesi_Tenggara).pdf

[3] C. M. Diaz *et al*., "A review of pyrometallurgical operations," *The Journal of The Minerals, Metals & Materials Society (TMS)*, vol. 40, issue 9, pp 28–33, 1988.

[4] A. Oxley *et al*., "Why heap leach nickel laterites?" *Minerals Engineering*, vol. 88, pp. 53-60, 2015.

[5] *Patent of Heap Leaching of Nickel Containing Ore Number US 6312500 B1*. [Online]. Available: https://www.google.com/patents/US6312500

[6] H. Purwanto *et al*., "Recovery of nickel from selectively reduced laterite ore by sulphuric acid leaching," *ISIJ International.*, vol. 43, no. 2, pp. 181-186, 2003.

[7] O. S. Ayanda *et al*., "Comparative study of the kinetics of dissolution of laterite in some acidic media," *Journal of Minerals & Materials Characterization & Engineering*, vol. 10, no. 15, pp, 1457-1472, 2011.

[8] R. M. Santos *et al*., "Nickel extraction from olivine: Effect of carbonation pre-treatment," *Metals*, 2015.

[9] C. Cao *et al*., "Making ferronickel from laterite nickel ore by coal-based self-reduction and high temperature melting process," *International Journal of Nonferrous Metallurgy*, vol. 5, no. 2, pp, 9-15, 2016.

[10] T. Agacayak and Veysel, "Dissolution kinetics of a lateritic nickel Ore in sulphuric acid medium," *Acta Montanistica Slovaca*, vol. 17, issue 1, pp. 33-41, 2012.

[11] R. Sipayung. (2003). *Stres Garam dan Mekanisme Toleransi Tanaman*. [Online]. Available: https://s3.amazonaws.com/academia.edu.documents/43085124/bdp-rosita2.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1502429632&Signature=QfC%2B%2BGDG%2FHZGayg%2Br2QR435IZow%3D&response-content-disposition=inline%3B%20filename%3DBdp-rosita.pdf

[12] M. L. Steemson and M. E.,Smith. (2009). *The Development of Nickel Laterite Heap Leach Projects*. [Online]. Available: http://www.ausenco.com/uploads/papers/64024_The_Development_of_Nickel_Laterite_Heap_Leach_Projects.pdf

[13] A. Kushwaha *et al*., "Heavy metal detoxification and tolerance mechanisms in plants: implications for phytoremediation," *Environmental Reviews*, vol. 24, pp. 39-51, 2016.

[14] Mining Market & Investment. *Infomine*. (2017). [Online]. Available: http://www.infomine.com/investment/metal-prices/nickel/

Sri Listyarini was born on April 7, 1961 in Jakarta, Indonesia. She received the bachelor in chemistry from the Faculty of Mathematics and Natural Sciences, University of Indonesia in 1985 and the master in management of distance education from the Faculty of Education, Simon Fraser University, Vancouver, Canada in 1990. She received her doctor in management of environmental and natural resources, from Bogor Agriculture University, Indonesia in 2009. She has served for 30 years in Indonesia Open University (Universitas Terbuka) as a lecturer in the Faculty of Mathematics and Natural Sciences. Her fields of specialization include environmental and ecological system modeling and simulations, especially air pollution modeling and simulations. She has journal publication in Journal of Environmental Science and Development, Der Pharma Chemica, The Sustainable City, and Jurnal Matematika, Sains, dan Teknologi.