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MUNICIPAL SOLID WASTE MANAGEMENT IN BANDUNG, INDONESIA: IS INCINERATION THE RIGHT WAY TO TREAT YOUR WASTE?

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Abstract. Globally, the most used waste treatment method is landfilling, although (improper) landfilling, which is typical for developing countries, has no material or energy recovery possibility compared with other treatment methods. In Indonesia, open dumping on final disposal sites covers most of the treated waste, which is an even worse method than landfilling in terms of environmental issues. The main objective of this article is to evaluate the feasibility of the waste-to-energy solution/waste incineration approach for proper and sustainable waste management in Bandung. A big issue of municipal solid waste is the organic portion of waste, as most emissions and pollution come from organic waste and improper handling. A specific objective is to conduct the risk analysis of an incineration plant model and to compare the environmental impact of incineration vs landfilling. The input data for the assessment will be obtained from the laboratory analyses of solid waste samples collected from the Sarimukti disposal site. The lab analyses will comprise the determination of fractional composition (biodegradable and non-biodegradable compounds like food waste, paper, textiles, plastics) and physico-chemical properties (such as moisture content, calorific values, trace elements). The research will also include general calculations of energy balance and economic costs of the incineration plant. Thus, the selected criteria will assess the following aspects of the incineration plant model: technical, environmental, social, energy, and economic.

Key words: Municipal wastes; Solid wastes; Waste management; Open dumping; Incineration; Waste handling; Energy recovery.

Реферат. По всему миру, наиболее распространённым способом обращения с мусором является его размещение на свалках. Однако по сравнению с другими способами, создание свалок ненадлежащим способом, типичное для развивающихся стран, не представляет возможности переработки отходов или выработки энергии. В Индонезии большая часть всего собранного мусора оказывается на открытых необорудованных свалках окончательно, что с точки зрения экологии является худшим способом, чем расположение мусора на оборудованных свалках. Основной целью статьи является оценка возможности переработки отходов в энергию с помощью мусоросжигания как вариант надлежащего и устойчивого обращения с мусором в Бандунге. Серьёзной проблемой твёрдых бытовых отходов является их органическая часть, т.к. большая часть выбросов и загрязнений связана именно с органическими отходами и неправильным обращением с ними. Одна из целей исследования - это проведение анализа рисков модели мусоросжигательного завода и сравнение воздействия на окружающую среду мусоросжигания и расположения мусора на свалках. Чтобы получить исходные данные для комплексной оценки, методология исследования будет включать лабораторный анализ образцов твердых отходов с полигона Саримукти, а именно определение фракционного состава (биоразлагаемые и бионеразлагаемые компоненты, такие как пищевые отходы, бумага, текстиль, пластмассы) и физико-химические свойства (таких как влажность, теплотворная способность, микроэлементы). В исследование также будут включены общие расчеты энергетического баланса и экономических затрат на установку мусоросжигательного завода. Таким образом, модель мусоросжигательного завода будет оценена с точки зрения технических, экологических, социальных, энергетических и экономических аспектов при помощи выбранных критериев.

Ключевые слова: Муниципальные отходы**;** Твердые отходы; Управление отходами; Открытая свалка; Сжигание; Выработка энергии.

INTRODUCTION

Developing countries are facing a huge population growth along with fast economic growth and, apart from it, a generally weak infrastructure existing in these societies. One of the underdeveloped areas is waste management, mainly in the big cities with large urban agglomerations, where there is a lack of or poor waste management services. The situation is accompanied by increased waste production, primarily in urban areas (Makarichi, L. et al. 2018). Bandung city from Indonesia is a good example of economic growth impacted by population increase, higher waste production, weak infrastructure, etc. (Tarigan, A.K. et al. 2016).

Landfilling and open dumping (Figure 1) represent typical treatment methods in these areas. A cru-

cial problem in Indonesia is the lack of space due to the island state and high population density. Other environmental and economic issues to be mentioned are groundwater pollution, waste transfer to nature because of improper handling, methane leaking and explosions, leachate leaking, underutilisation of sources (new materials, waste as a fuel, methane production) (Cointreau, S.).

Figure 1. Sarimukti landfill and open dumping in Bandung, Indonesia

According to I. Madon (2019), the low-income developing countries lack financial resources in order to find adequate sanitary landfill systems. Furthermore, there are low-cost approaches to safe municipal solid waste disposal, but international funding organisations rarely support them. A low-cost sanitary landfill is designed to exclude a composite liner system. Consequently, these facilities are not considered environmentally safe.

Waste-to-energy system is very beneficial for such a case: Bandung depends on electricity production mainly generated from fossil fuels (oil, gas, coal). Due to economic growth, electricity use is increasing rapidly, and Bandung faces many blackouts because of an overload of an electrical network (Tarigan, A.K.M. et al. 2016). Estimations of electricity production from waste, with the production of around 1,800 tons of waste per day in Bandung, could cover up to 10% of electricity demand in the city. Moreover, incineration significantly decreases waste amount, up to 90% in volume and 0% in mass reduction (Dastjerdi, B. et al. 2019).

As a result of this research, there should be an optimal proposal for adequate waste-to-energy solutions for Bandung city, and namely waste incineration technology with energy recovery. Bandung represents a city in a developing country with great potential for economic growth like many other cities in Southeast Asia, therefore this research could be applicable in many other different areas.

MATERIALS AND METHODS

Firstly, the literature review is needed for mapping incineration technologies in developed and developing countries, mainly, the cases from Southeast Asia are crucial for describing current situation. Several studies (Brunner, P.H. et al. 2015; Lombardi, L. et al. 2015; Ouda, O.K. et al. 2016; Kumar, A. et al., 2017; Malinauskaite, J. et al. 2017; Beyene, H.D. et al. 2018) identified incineration of municipal solid waste as a promising source of energy as well as the most appropriate method to decrease waste volume. But, incineration plants occupy smaller areas in comparison with disposal sites. When appropriately managed, incineration ensures superior waste handling with lower environmental impacts, less greenhouse gas emissions, and uses waste as a resource. Similar studies (Tan, S.T. et al. 2015; Lin, X. et al. 2015; Ouda, O.K. et al. 2016) were also conducted in developing countries with positive results.

Data collection

Research is targeted at Indonesia, focusing on the case study in Bandung city, West Java region. Data collection will include observation and documentation of waste generation and treatment facilities

such as disposal sites. Waste samples will be collected for further laboratory measurements. Interviews will be conducted among workers of the disposal sites, waste banks, and government offices. Field data collection will be assisted by colleagues from Padjadjaran University, Bandung. Interviews will be focused on the current situation in municipal solid waste management, possibilities of sorting and recycling of municipal solid waste, conditions of waste disposal sites and their operation, disposal sites' leachate collection, recirculation and treatment, and the potential of energy production from disposal sites.

Waste production and prospects (sensitivity analysis)

Sensitivity analysis should help to predict the future situation of waste production in Bandung, a good example of a city in a developing country. Three scenarios should occur: linear increase, exponential increase and deterioration of waste production.

Comparison of current Waste management vs. Incineration technologies:

Environmental, economic, social and energy aspects of disposal sites - Sanitary landfill criteria

- According to S. Cointreau (2004), a landfill must meet sanitary landfill standards such as:
- Minimising Leachate Generation
- Leachate Management
- Gas Management
- Stability
- Construction Phasing
- Siting
- World Bank Environmental Requirements
- Private Sector Involvement

Criteria are set to meet the basic environmental needs of proper waste handling on disposal sites. Any violation and simplification could endanger the environment locally via waste spreading and leachate leaking and in global terms via greenhouse gas emission. In the research, the main conditions of the local disposal site will be investigated by observations, interviews, measurements, and a review of official governmental documents.

Economic and energy aspects

Landfill gas has renewable energy potential due to the high percentage of methane gas production (50-70 %). On the other hand, implementing waste-to-energy technology in an old but operating disposal facility may not have such potential as a new one with the waste-to-energy system. Additionally, landfill gas production represents the most significant anthropogenic emissions of methane gas in the world, accounting for roughly 30% of the total emissions (Purmessur, B. et al. 2019). Also, methane has the global warming potential 21-23 times higher than CO_2 (Johari, A. et al. 2012).

In the study of A. Johari et al. (2012), it was described the situation of Malaysia landfill gas potential. It was found that both economic and environmental aspects could be improved through implementing methane capture and its positive usage. According to Intergovernmental Panel on Climate Change methodology, the average amount of methane emissions from disposal sites in Bandung could be estimated, consequently showing the economic and energetic potential of landfill gas usage as a renewable source with its advantages.

Social aspects

Social aspects as a perception of waste disposal technology, current situation of waste management in the city, sanitation, and health risks will be described by the literature review and quantitative questionnaire survey completed by Bandung city inhabitants.

Environmental, economic, social and energy aspects of waste incineration technologies - Environmental life cycle assessment

Environmental life cycle assessment is a tool to predict the overall environmental impact of a process over its entire life cycle; it is applied to assess the environmental sustainability of waste management systems (Mendes, M.R. et al. 2004). This article is intended to introduce a comparison of landfilling and incineration of municipal solid waste in Bandung, Indonesia.

- The Life cycle assessment methodology will be used according to M.R. Mendes et al. (2004) and it consists of four stages:

- Goals and scope definition;
- Life cycle inventory analysis;
- Life cycle impact analysis;
- Interpretation analysis or improvement analysis.

The most important factors are physical and chemical composition of waste, theoretical economic prosperity, greenhouse gas emission and global warming potential.

Economic and energy aspects

A study accomplished in Malaysia (Tan, S. et al. 2014) showed that potential thermal energy production from incineration technology far exceeds improved landfills with a gas recovery system. Both economic and environmental aspects were improved thanks to the implementation of the incineration technology. The payback period (PBP) calculation will be based on investments, operational costs and benefits from the thermal energy production, and it will be calculated as follows:

$$PBP = \frac{I}{P_r - N_{pr}}$$

where:

PBP – payback period, years; I – initial investments, USD; P_r – benefits from thermal energy production, USD/year; N_{pr} – operational costs, USD/year.

Energy payback period (EPP) calculation is one of the crucial factors that should also be included:

$$EPP = \frac{E_i}{E_o}$$

where:

EPP – energy payback period, years; E_i – energy investments, MJ; E_o – annual energy output, MJ.

Social aspects

Such social aspects as the perception of waste incineration technology, improvement of the situation due to better waste management in the city, life quality improvement, and better job opportunity due to new technology will be described in the literature review and quantitative questionnaire completed by Bandung inhabitants.

Material properties (as input for environmental, technological and energy assessment)

The elemental composition of municipal solid waste can significantly vary among countries and cities as a result of differences in the waste's physical composition (Komilis, D. et al. 2012). It is necessary to determine municipal solid waste's composition, calorific value and other energy characteristics in order to design municipal solid waste incinerator for waste treatment and electricity production.

In this research, the following main parameters and values will be measured:

Elemental waste content (C, N, H, S, O) and flue gas analysis

Calorific value and ash content of waste samples

Average organic matter content in waste

RESULTS AND DISCUSSIONS

According to many authors (Tan, S. et al. 2015; Lin, X. et al. 2015; Ouda, O.K.M. et al. 2016; Madon, I. et al. 2019), waste incineration technology is suitable for developing countries despite different weather conditions, higher moisture, and different waste composition than in developed countries. For Indonesia, the Bandung case study, it is necessary to compare current local conditions and waste composition with adequate and appropriate conditions for waste incineration technology, which could highlight the enormous potential of unused material.

According to Papargyropoulou, E. et al. (2015) and Sudibyo, H. et al. (2017), waste production increase is caused not just by population growth but also by urbanisation and improvement of the economic situation in countries. In the long term, developed countries have higher waste production than developing ones. Establishing a responsible program with sufficient infrastructure to cover all waste management needs and minimise waste disposal is imperative. Other important recommendations include:

- implementing a waste treatment hierarchy and ensuring public awareness about waste handling;

- providing adequate services and infrastructure in order to recycle as much waste as it is possible;
- proposing and implementing a modern and well-equipped incineration plant with energy production and top-quality emissions control (Ogunjuyigbe, A.S.O. et al. 2017).

Due to the lack of financial services in developing countries such as Indonesia, waste management is a neglected sector. Generally, most disposal sites in Indonesia do not meet the standards of sanitary landfills. Figure 2 shows the unsecured closed Leuwigajah landfill, which could be a future threat due to methane leaking, leachate leaking and others. The main environmental issues are disregarded (Madon, I. et al. 2019). Incineration of municipal solid waste as a solution was already mentioned, but there was no adjustment of local conditions (calorific value of waste, moisture content, ash content, ratio of organic and nonorganic waste) to the specific requirements. Furthermore, no comparison of theoretical environmental and economic issues of municipal solid waste incineration with the current situation in municipal solid waste treatment was made.

Figure 2. Leuwigajah unsecured closed landfill in Bandung, Indonesia

Incineration as a waste-to-energy treatment method has better environmental and economic effects than waste disposal methods. Generally, in the context of waste handling, incineration, along with recycling and reusing waste have more positive impacts than landfilling. Furthermore, incineration ensures the recovery of waste as a new source. Despite technological evolution, there are still concerns about contamination/pollution of the environment (Nabavi-Pelesaraei, A. et al. 2017).

As a result, we foresee that any activity related to waste management in Bandung should help to improve the city's situation with all consequences on both infrastructure and even directly on inhabitants. Waste incineration could cause an immediate waste reduction and partially subsidise the production of so much demanded energy. On the other hand, a change in the municipal solid waste management approach in more cities such as Bandung could positively impact the global environment.

CONCLUSIONS

The research findings aim to contribute to the waste management issues in developing countries. Changes in municipal solid waste management in Bandung city are expected to improve the situation. Incineration is a waste treatment technology that leads to the exploitation of waste as an energy source. The environmental impact assessment of waste incineration in Bandung can contribute to reach higher standards of municipal solid waste management compared with current situation, including non-sanitary disposal sites. Research has to provide reliable information to policymakers about this issue to be considered in future waste management planning in Bandung city. In addition, the environmental impact assessment of incineration in comparison with the current state in Indonesia could be used as an example

for countries with similar environment, economy and waste management conditions. In order to achieve this success in the waste management progress in Bandung, Indonesia, a series of actions should be implemented: to conduct studies, to make laboratory tests and to carry out many awareness campaigns among the local population. It is also important to connect the public with experts, governmental authorities and the private sector dealing with waste management issues.

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REFERENCES

1. BEYENE, H.D., WERKNEH, A.A., AMBAYE, T.G. (2018). Current updates on waste to energy (WtE) technologies: a review. In: Renewable Energy Focus, vol. 24, pp. 1-11. ISSN 1755-0084. Available: https://doi.org/10.1016/j.ref.2017.11.001
2. BRUNNER, P.H., RECHBERGER, H. (2015). Waste to energy - key element for sustainable waste management. In: Waste Management, vol. 37, pp. 3–12. ISSN 0956-053X. Available: https://doi.org/10.1016/j.wasman.2014.02.003
3. COINTREAU, S. (2004). Sanitary landfill design and siting criteria. World Bank. Available: https://sswm.info/sites/default/files/reference_attachments/COINTREAU%202004%20Sanitary%20Landfill%20Design%20and%20Siting%20Criteria.pdf
4. DASTJERDI, B., STREZOV, V., KUMAR, R., BEHNIA, M. (2019). An evaluation of the potential of waste to energy technologies for residual solid waste in New South Wales, Australia. In: Renewable and Sustainable Energy Reviews, vol. 115(C). ISSN 1364-0321. Available: DOI: 10.1016/j.rser.2019.109398
5. JOHARI, A., AHMED, S.I., HASHIM, H., ALKALI, H., RAMLI, M. (2012). Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. In: Renewable and Sustainable Energy Reviews, vol. 16(5), pp. 2907-2912. ISSN 1364-0321.
6. KOMILIS, D., EVANGELOU, A., GIANNAKIS, G., LYMPERIS, C. (2012). Revisiting the elemental composition and the calorific value of the organic fraction of municipal solid wastes. In: Waste Management, vol. 32(3), pp. 372–381. ISSN 0956-053X.
7. KUMAR, A., SAMADDER, S.R. (2017). A review on technological options of waste to energy for effective management of municipal solid waste. In: Waste Management, vol. 69, pp. 407-422. ISSN 0956-053X.
8. LIN, X., WANG, F., CHI, Y., HUANG, Q., YAN, J. (2015). A simple method for predicting the lower heating value of municipal solid waste in China based on wet physical composition. In: Waste Management, vol. 36, pp. 24–32. ISSN 0956-053X.
9. LOMBARDI, L., CARNEVALE, E., CORTI, A. (2015). A review of technologies and performances of thermal treatment systems for energy recovery from waste. In: Waste Management, vol. 37, pp. 26-44. ISSN 0956-053X.
10. MADON, I.., DREV, D., LIKAR, J. (2019). Long-term risk assessments comparing environmental performance of different types of sanitary landfills. In: Waste Management, vol. 96, pp. 96–107. ISSN 0956-053X.
11. MAKARICHI, L., JUTIDAMRONGPHAN, W., TECHATO, K. (2018). The evolution of waste-to-energy incineration: A review. In: Renewable and Sustainable Energy Reviews, vol. 91(C), pp. 812-821. ISSN 1364-0321.
12. MALINAUSKAITE, J. et al. (2017) Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. In: Energy, vol. 141(C), pp. 2013-2044. ISSN 0360-5442.
13. MENDES, M.R., ARAMAKI, T., HANAKI, K. (2004). Comparison of the environmental impact of incineration and landfilling in São Paulo City as determined by LCA. In: Resources, Conservation and Recycling, nr. 41(1), pp. 47–63. ISSN 0921-3449.
14. NABAVI-PELESARAEI, A., BAYAT, R., HOSSEINZADEH-BANDBAFHA, H., AFRASYABI, H., CHAU, K. (2017). Modelling of energy consumption and environmental life cycle assessment for incineration and landfill systems of municipal solid waste management - A case study in Tehran Metropolis of Iran. In: Journal of Cleaner Production, nr. 148(C), pp. 427–440. ISSN 0959-6526.
15. OGUNJUYIGBE, A.S.O., AYODELE, T.R., ALAO, M.A. (2017). Electricity generation from municipal solid waste in some selected cities of Nigeria: An assessment of feasibility, potential and technologies. In: Renewable and Sustainable Energy Reviews, vol. 80, pp. 149-162. ISSN 1364-0321.
16. OUDA, O.K.M., RAZA, S.A., NIZAMI, A.S., REHAN, M., AL-WAKED, R., KORRES, N.E. (2016). Waste to energy potential: A case study of Saudi Arabia. In: Renewable and Sustainable Energy Reviews, vol. 61, pp. 328-340. ISSN 1364-0321.

17. PAPARGYROPOULOU, E., COLENBRANDER, S., SUDMANT, A.H., GOULDSON, A., TIN, L.C. (2015). The economic case for low carbon waste management in rapidly growing cities in the developing world: The case of Palembang, Indonesia. In: Journal of Environmental Management, vol. 163, pp. 11–19. ISSN 0301-4797.
18. PURMESSUR, B., SURROOP, D. (2019). Power generation using landfill gas generated from new cell at the existing landfill site. In: Journal of Environmental Chemical Engineering, nr. 7(3). ISSN 2213-2929.
19. SUDIBYO, H., PRADANA, Y.S., BUDIMAN, A., BUDHIJANTO, W. (2017). Municipal Solid Waste Management in Indonesia - A Study about Selection of Proper Solid Waste Reduction Method in D.I. Yogyakarta Province. In: Energy Procedia, vol. 143, pp. 494-499. ISSN 1876-6102.
20. TAN, S., HASHIM, H., LEE, C., TAIB, M.R., YAN, J. (2014). Economical and environmental impact of waste-T o-energy (WTE) alternatives for waste incineration, landfill and anaerobic digestion. In: Energy Procedia, vol. 61, pp. 704–708. ISSN 1876-6102.
21. TAN, S.T., HO, W.S., HASHIM, H., LEE, C.T., TAIB, M.R., HO, C.S. (2015). Energy, economic and environmental (3E) analysis of waste-to-energy (WTE) strategies for municipal solid waste (MSW) management in Malaysia. In: Energy Conversion and Management, vol. 102, pp. 111-120. ISSN 0196-8904.
22. TARIGAN, A.K.M., SAGALA, S., SAMSURA, D.A.A., FIISABIILILLAH, D.F., SIMARMATA, H.A., NABABAN, M. (2016). Bandung City, Indonesia. In: Cities, nr. 50, pp. 100-110. ISSN 0264-2751.

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