Eduvest – Journal of Universal Studies
Volume 4 Number 10, October, 2024
p- ISSN 2775-3735- e-ISSN 2775-3727

GAS LEAKAGE RISK MANAGEMENT OF BIOGAS POWERPLANT USING ALOHA GAS DISPERSION MODELLING AND BOWTIE ANALYSIS

Abdul Rasyid[1], Tatan Sukwika[2], Soehatman Ramli[3], Sugiarto S Citroatmojo[4]
[1,2,3,4]Universitas Sahid Jakarta, Indonesia
Email: abdulrasyid8793@gmail.com

ABSTRACT

Biogas, a fuel derived from organic waste, has gained popularity as a sustainable energy source. The adaptability of biogas allows its utilization for electricity and heating. This study aims to evaluate the risk of biogas leakage using ALOHA gas dispersion modeling and Bowtie analysis to identify hazard zones and evaluate the effectiveness of preventive and mitigation measures. The research method using Gas dispersion modeling in ALOHA software can simulate the spread of leaked biogas, identify potential hazard zones, and inform emergency response planning. The results show that gas dispersion reaches up to 296 meters from the leak source in a worst-case scenario without ignition, with significant implications for safety. The ignition scenario produces high thermal radiation, further exacerbating the risk. In conclusion, these findings highlight the intolerable risk of biogas leakage, requiring comprehensive risk mitigation measures. This study recommends the implementation of a robust control system, routine maintenance, and emergency response plan to ensure the safety and sustainability of biogas facility operations.

KEYWORDS *Biogas, Risk Analysis, Powerplant, Gas Dispersion, Leakage.*

INTRODUCTION

Biogas is a complex mixture of methane and carbon dioxide, with trace amounts of other gases like hydrogen sulfide. its composition and production process can vary depending on the feedstock and digestion conditions (del Rosario Rodero et al., 2020). biogas produce by anaerobic digestion of organic waste has a relatively higher hydrogen/carbon ratio, making it more flammable than natural gas (Gholizadeh et al., 2019). Biogas is also produced in large quantities as a byproduct of wastewater treatment and landfill operations (Hassaneen et al., 2020); (Johnstone et al., 2015).

How to cite:	Abdul Rasyid, et.al. (2024). Gas Leakage Risk Management Of Biogas Powerplant Using Aloha Gas Dispersion Modelling And Bowtie Analysis. *Journal Eduvest. 4*(10), 9160-9172
E-ISSN:	2775-3727
Published by:	https://greenpublisher.id/

Biogas can be use directly as fuel for electricity and thermal energy generation, or it can be further purified and upgraded to biomethane for injection into natural gas grids or use as vehicle fuel. For electricity generation, biogas was processed from raw material until transfered to gas engine generator (Yudiartono et al., 2018).

Biogas supply chain are susceptible to leaks and fugitive emissions, which can lead to safety hazards, environmental pollution, and economic losses. the high methane content of biogas makes it a potent greenhouse gas, and uncontrolled releases can contribute significantly to climate change. the flammability and explosivity of biogas also pose serious fire and explosion risks that can threaten worker safety and nearby communities (Johnstone et al., 2015) ; (Gholizadeh et al., 2019).

Risk management is crucial to ensure the safe and sustainable utilization of biogas. comprehensive hazard identification, risk assessment and mitigation strategies are essential to address the unique challenges posed by biogas systems (Nyifi et al., 2018); (del Rosario Rodero et al., 2020); (Hassaneen et al., 2020);. Emergency management are also critical to respond effectively to potential incidents by divided into prevention, preparedness, response, and recovery stages.

The biogas power plant operation involving gas storage, compression, transport, and combustion have inherent risks that must be carefully managed. gas leakage is a primary concern, as it can lead to fire, explosion, an environmental and health hazards. the dispersion of leaked gas and the potential impact on people and the environment must be understood to develop appropriate mitigation measures.

Biogas leakage may occur due to a variety equipment failures, operational errors, or external events such as natural disasters. dispersion modeling can estimate the extent of the hazardous zones around the leak site, allowing for the design of appropriate safety systems and emergency response plans.

Safety professional need to conduct thorough risk assessments to identify potential failure modes, hazards, and consequences associated with biogas systems. advanced modelling and simulation tools like ALOHA (areal locations of hazardous atmospheres) can be leveraged to assess gas leak scenarios and inform risk mitigation strategies.

Previous studies have demonstrated the use of ALOHA gas dispersion modeling to assess the risks associated with natural gas and other industrial gases. aloha is a publicly available software developed by the US Environmental Protection Agency and the National Oceanic and Atmospheric Administration to model the movement and dispersion of hazardous gas clouds following accidental releases (Nyifi et al., 2018); (del Rosario Rodero et al., 2020); (Hassaneen et al., 2020);. To estimate rate of gas leakage, dispersion, and potential consequences, aloha requires inputs such as release rate, gas composition, meteorological conditions, and terrain information. by simulating different leak scenarios, aloha can identify areas at risk of gas exposure and the potential for fire or explotion.

In addition to dispersion modelling, a bowtie analysis can provide a structured approach to identifying the causes and consequences of a biogas leak, as well as the safety barriers and control measures to prevent or mitigate such incidents.

Bowtie analysis can help biogas plant operators systematically analyze the potential threats and hazards, develop risk controls, and establish emergency response plans. the bowtie diagram visually represents the relationships between threat, consequences, an the various preventive and mitigative barriers to manage risks.

The combination of ALOHA gas dispersion modeling and bowtie analysis can provide a comprehensive framework for assessing and managing gas leakage risks in biogas powerplants. by simulating leak scenarios, identifying hazardous zones and modeling the effectiveness of control measures, operators can develop robust safety systems and emergency response plans to ensure the safe and sustainable operation of biogas facilities. (Pacsi et al., 2019); (Afebu et al., 2015); (Gholizadeh et al., 2019);.

Process safety indicator shows the effectiveness of the implemented controls and barriers, allowing for continuous improvement and optimization of the risk management system. overall, this integrated approach can enhance the safety and reliability of biogas utilization, supporting its wider adoption as a renewable energy source.

This study aims to analyze and assess the risk of biogas leakage in biogas power plants using ALOHA gas dispersion modeling and Bowtie analysis. Through this study, it is expected to identify the danger zone of gas leakage and evaluate the effectiveness of mitigation and prevention measures that can be applied to minimize the impact on worker safety and the environment.

The benefits of this study are to provide important guidance for biogas power plant operators in identifying and managing the risk of gas leakage, which is a serious threat to the safety and sustainability of operations. Implementation of the recommended mitigation measures will improve operational safety and reduce the potential for accidents.

RESEARCH METHOD

This research was carried out at a biogas power plant located in the Riau Province, Indonesia. The plant uses anaerobic digestion of wastewater to produce biogas, which is used to generate electricity. Researchers retrieve data on the plant's equipment, operating parameters, weather condition and historical incident records. this information was used to develop an ALOHA gas dispersion model of the biogas system, including storage, compression, and combustion equipment.

The model simulated various leak scenarios, considering factors such as leak size, gas composition, weather conditions, and terrain. the results were used to identify hazardous zones around the plant and assess the potential consequences of gas releases in terms of flammability, toxicity, and dispersion. Operational and environmental data used in this research can be seen in table 1.

Table 1. Biogas Power Plant Operational and Environmental Data

Parameter	**Value**
Digester (Bioreactor)	
Shape	Hemispherical Cylinder Tank
Diameter	23 m
Height	16 m
Operational Pressure	99.689 atm.
Temperature	29ºC
Gas Composition	
Methane	483.6 m^3/h

Carbon dioxide	245.52 m^3/h
Hydrogen Sulphide	5.952 m^3/h
Environmental Data	
Wind direction	Northwest (Barat Daya)
Average wind speed	6.333 m/s
Maximum wind speed	16 m/s
Relative humidity	75%
Air temperature	29ºC

This study using gaussian dispersion model to estimate the extent of gas cloud and defined the hazardous zones around the plant. The results were then integrated into a bowtie analysis framework to identify threats, consequences, and the effectiveness of preventive and mitigative controls. Biogas leak will be simulated in the Digester Tank (Bioreactor) with circular holes with a diameter of 1.5 cm, 2.5 cm, 3.5 and 4.5 cm.

The dispersion modeling considers the plant layout, meteorological data, and gas properties to determine the area and population at risk. the bowtie analysis help identify the potential causes and consequences as well as the critical safety barriers (Prisilia & Purnomo, 2022). To assess the impact of gas leaks, the ALOHA model was run for different leak scenarios, including discharge of all gas without ignition and the gas immediately ignites and forms a jet-fire. The results were analyzed to determine the extend of toxic areas, flammable areas, blast areas and thermal radiation zones.

Data Collection Techniques

Field Observation

Researchers conducted direct observations at the biogas power plant operating in Riau Province, Indonesia. The data obtained included information related to facility operations, equipment conditions, and meteorological parameters such as wind speed, air temperature, and wind direction.

Direct Measurement

Researchers measured the operational conditions of equipment at the biogas facility, such as operational pressure in the bioreactor tank, operating temperature, and the composition of the gas produced, including methane and carbon dioxide levels. In addition, data on previous gas leak incidents were also obtained.

Documentation

This study also utilized secondary data in the form of operational reports, history of leak incidents, and documentation of the risk management system implemented at the facility.

Reference Sources

Other secondary data were obtained from literature reviews, scientific journals, and publications related to gas leak risk management and gas dispersion modeling using ALOHA software and Bowtie analysis.

Data Analysi

Gas Dispersion Modeling (ALOHA)

The operational data collected was used to conduct simulations using ALOHA (Areal Locations of Hazardous Atmospheres) software. This model calculates gas dispersion based on various leak scenarios by considering conditions such as leak hole size, gas composition, pressure, and weather conditions. The result of this modeling is an estimate of the distance of the danger zone from the leak point.

Bowtie Analysis

After gas dispersion modeling, Bowtie analysis is performed to map the potential causes and impacts of biogas leaks. This analysis is used to identify preventive and mitigation measures that can be applied at various critical points in the operating system. The Bowtie diagram helps identify the relationship between threats, the central event (gas leak), and existing controls to prevent or reduce its impact.

Risk Analysis

The results of the two techniques above are combined to produce a risk map that shows the level of danger of each gas leak scenario. The risk matrix is used to assess the severity and probability of a gas leak, and determine the mitigation measures needed to minimize the risk to workers, the surrounding community, and the environment.

RESULT AND DISCUSSION

When the biogas leakage happens, the amount of gas release, the wind speed and direction will affect the dispersion pattern, and the area impacted (Gholizadeh et al., 2019). The amount of gas will be related to the size of the leak orifice and the pressure in the gas system. the wind speed and directions will determine how the gas cloud move.

The leakage simulation process in digester tank was carried out using several leak point sizes, namely 1.5 cm, 2.5 cm, 3.5 cm, and 4.5 cm. The leak orifice was located on the roof of the reactor tank at a height of 16-meter and the release time is 60 minutes. In the release of gas without ignition, the results were obtained for a leak orrifice size of 1.5 cm, dispersed gas with a concentration of more than 5000 ppm reached 97-meters from the source of the leak. The dispersion distance of gas cloud increased as the leak orrifice increases as shown in table 2.

Table 2. Gas release distance from digester tank for without ignition scenario

Leakage hole size (cm)	Gas release distance (m)		
	5000 ppm	30000 ppm	50000 ppm
1.5	97	39	31
2.5	163	66	51
3.5	230	92	72
4.5	296	119	92

The process of releasing the gas accompanied by ignition of flammable gas cloud resulted in fire or explosion will emits intense heat radiation and shock waves, which can cause severe injuries or fatalities to nearby workers and damage to equipment. This process is simulated by ALOHA to displays the exposure of heat radiation to the area around the leak point as shown in figure 1.

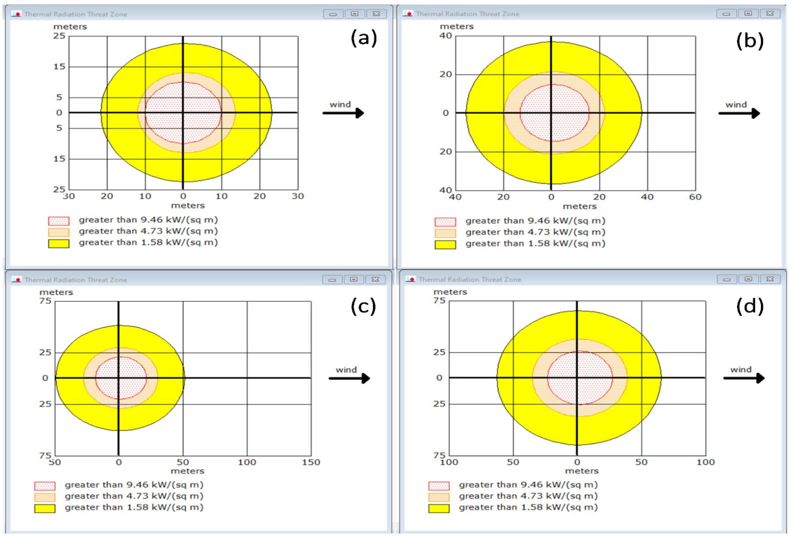

Figure 1. Heat radiation model from reactor tank with ignition for leak hole size (a) 1.5 cm (b) 2.5 cm (c) 3.5 cm and (d) 4.5 cm

The heat radiation distance was increasing with larger hole size, this happen because the amount of gas released is also increasing. The simulation results data can be seen in table 3.

Table 3. Heat Radiation Distance From Reactor Tank For Ignition Scenario

Leakage hole size (cm)	Heat radiation distance (m)		
	1.58 kW/m^2	4.73 kW/m^2	9.46 kW/m^2
1.5	23	14	10
2.5	38	22	16
3.5	52	31	22
4.5	65	38	28

The risk assessment for a gas leak will be assessed based on the likelihood of the leak occurring and the potential consequence on facility, workers, and nearby communities. the aim of risk assessment is to identify the critical equipment, operating conditions, and external factors that could lead to a gas leakage. The bowtie analysis identified the potential threats and contributing factors that could lead to a biogas leak, such as equipment failure, operational errors, external events like lightning strikes. The diagram also mapped out the preventive and mitigative control measures. The risk assessment was assessed using estimated exposed human population, failure rate and probability of ignition.

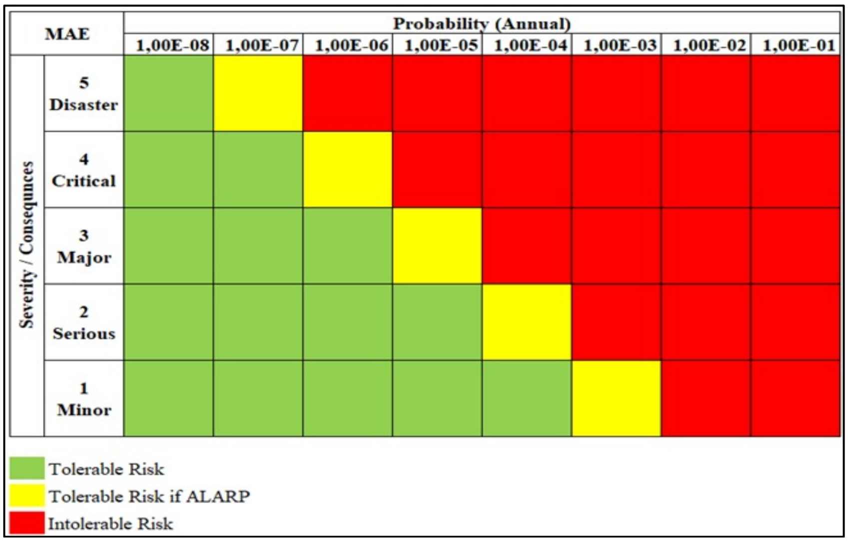

Figure 2. Risk Matrix Of Major Accident Event

The risk and consequences matrix use to determine the overall risk and to prioritize the risk mitigation measures. The risk matrix will consider both the likelihood and severity of the potential consequences. Higher risk items will require more robust controls and emergency response plans.

The risk and consequences matrix are proposed for reference, the actual risk assessment should be based on the specific plant conditions, gas properties, and local regulations. Proposed risk matrix can be seen in Figure 2 and the consequences matrix is shown in Table 4.

The risk level is determined by considering two scenarios: one where gas is released without ignition at a concentration of 50,000 ppm (LEL), and another involving gas release with ignition at an energy rate of 9.46 kW/m². The risk level is expressed as the potential loss of life (PLL), calculated by multiplying the individual risk (IR) by the estimated exposed population (EEP).

$$PLL = IR \; x \; EEP \tag{2}$$

Table 4. Consequences Matrix

Category	Consequence		
	People	Environment	Community
5 Disaster	Multiple worker fatalities at the site	Outside remediation response required. Long-term impact and clean-up required (>5 years)	Multiple public fatalities
4 Critical	Multiple worker fatalities within the area	Outside remediation response required. Midterm impact and clean-up required. (2~5 years)	One community fatality

3 Major	Single worker fatality	Company remediation response required. Localised and short-term impact and clean-up required (<2 years)	One or more injuries/illness to communities
2 Serious	Permanent injury of multiple workers	Reportable event	No impact on the community
1 Minor	Permanent injury of worker	Non-reportable event	No impact on the community

In scenarios where biogas is released without ignition, the Individual Risk (IR) is determined by the failure rate. However, in cases involving ignition, the IRi value is calculated by multiplying the failure rate by the ignition probability (IP_r).

$$IR_i = Failure\ rate\ x\ IP_r \quad (3)$$

PLL is the primary factor in assessing the hazard risk level. Table 5 presents the data from the PLL calculations for each scenario.

Table 5. Potential Loss Of Life Calculation Data

Scenario	Hole size (cm)	Estimated Exposed Population (EEP)	Failure Rate[a]	IP_r[b]	IR	PLL
Digester	1.5	6	1,00E-05	-	1,00E-05	6,00E-05
	2.5	6	1,00E-05	-	1,00E-05	6,00E-05
	3.5	9	1,00E-05	-	1,00E-05	9,00E-05
	4.5	36	1,00E-05	-	1,00E-05	3,60E-04
Gas Holder	4	6	1,00E-08	1,61E-02	1,61E-10	9,64E-10
	6	6	1,00E-08	2,49E-02	2,49E-10	1,49E-09
	8	6	1,00E-08	3,95E-02	3,95E-10	2,37E-09
	10	6	1,00E-08	5,08E-02	5,08E-10	3,05E-09

Source: an International Association of Oil and Gas Producers (2019), b National Fire Protection Association (2019).

The results of the analysis show that the risk level is intolerable for both scenarios and require further control. Both scenario resulting into disaster category, where both scenarios can cause more than one fatality involving the company's internal as well as from the community around the company.

To conduct risk mitigation, the biogas plant operator should implement a comprehensive set of control measures and safety systems. these may include (Turgut et al., 2013) ; (Chaiklieng, 2021b); (Chaiklieng, 2021a). Bowtie analysis is a visual risk management technique that examines the causal pathways and barriers that prevent or mitigate unwanted central events, such as gas leaks (Shan et al., 2017). This approach provides a systematic way to identify potential threats, consequences, and the various preventive and mitigative barriers to manage risks. Identified mitigative barriers for biogas powerplant shown in Figure 3.

In the bowtie analysis diagram, the central event is a biogas leak, which could lead to a range of consequences, from worker injuries and equipment damage to offsite community impacts (Pettitt & Pennicott, 2016); . The identified barriers can be divided into physical barriers, such as leak detection systems, automated shut-off valves, and gas detectors, and non-physical barriers, such as operator training, maintenance procedures, and emergency response planning.

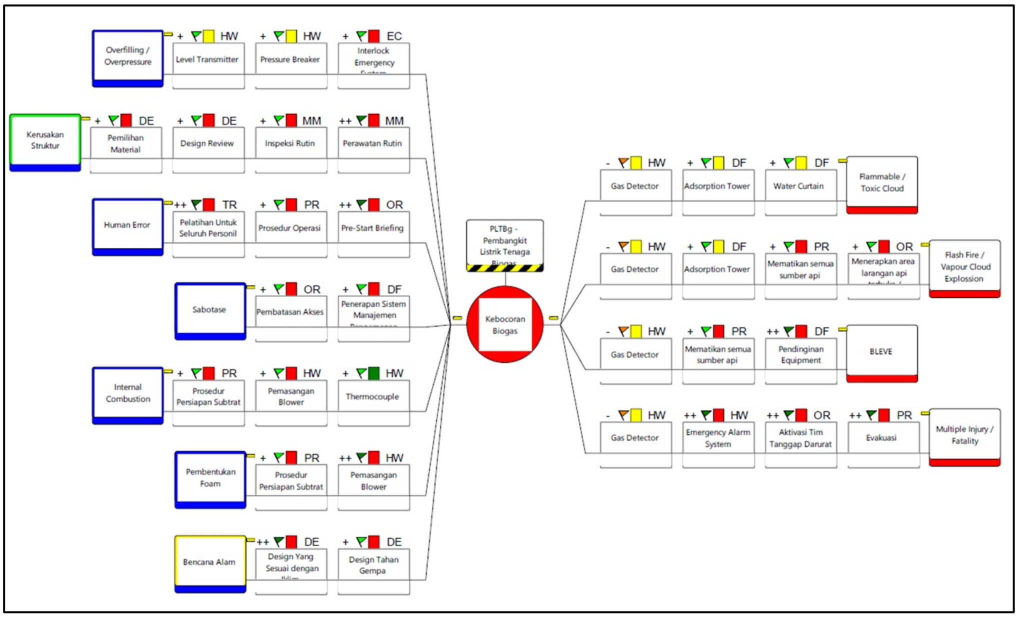

Figure 3. Bowtie analysis diagram

The researcher proposes an emergency-level decision matrix to help the operator to prioritize the control and mitigation actions based on gas concentration and release duration. This matrix can guide the operators on when to evacuate the facility, notify authorities, and implement emergency shutdown procedures.

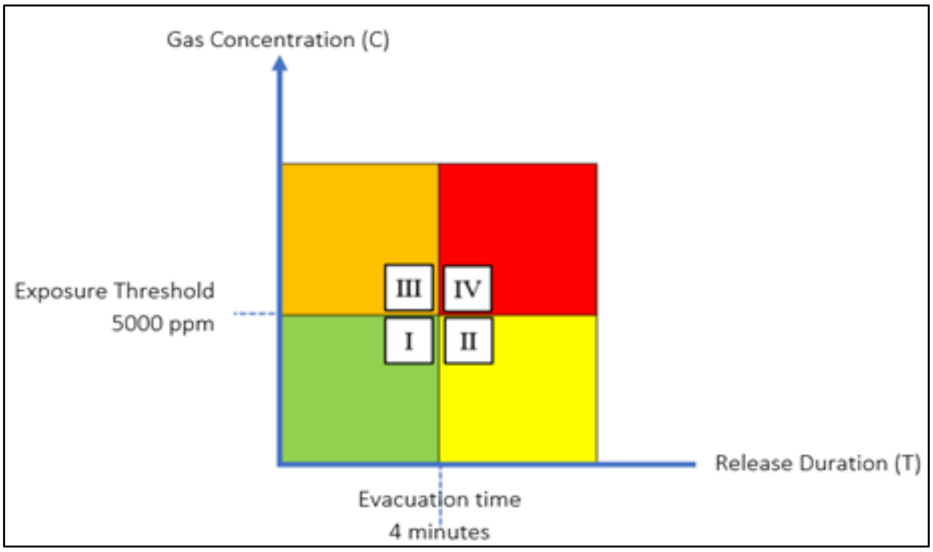

Figure 4. Emergency-level decision matrix

The National Fire Protection Association (NFPA) specifies that 4 minutes was required as an evacuation time. The concentration of 5,000 ppm is taken as a threshold value to conform with OSHA standards, where an atmosphere with a flammable vapor concentration above 10% LEL is considered a hazardous area.

This matrix can be used when:

1. When gas is released briefly, the dispersion area remains effectively contained, and the gas concentration stays below the safe threshold. If these conditions are met, seeking shelter indoors is recommended.
2. The gas release lasts for an extended period, dispersing around the plant perimeter; however, the gas concentration remains below the threshold level. In such circumstances, it is recommended to take shelter inside the building and await evacuation by the rescue team.
3. The gas was released briefly, with the dispersion area effectively contained; however, the concentration of the gas surpassed the acceptable limit. Under these conditions, it is advised to evacuate to the company's designated internal shelter situated beyond the reach of the gas dispersion area.
4. The prolonged release of gas and its spread around the plant perimeter results in a concentration that surpasses the allowable limit. When these conditions are met, evacuation to a shelter outside the gas dispersion area is advised.

In the simulation, the researcher uses gas release time for 60 minutes, and the gas concentration exceeds 5,000 ppm. The gas leak event is included in category (IV), which is all employees and the affected community must be evacuated to an external shelter facility.

In this study, the evacuation area was determined to be outside the gas dispersion radius with an angle of 360° (all directions) from the leak source based on the worst-case release scenario (Johnstone et al., 2015). The wind direction can change up to 90°, and there is a possibility that the wind direction can change more than 90° due to turbulence and local weather patterns (Ding, 2021).

An emergency evacuation plan for the community, employees, and employees of neighboring companies should be developed. The evacuation plan should cover factors such as early warning systems, evacuation routes, assembly points, and coordination with local authorities.

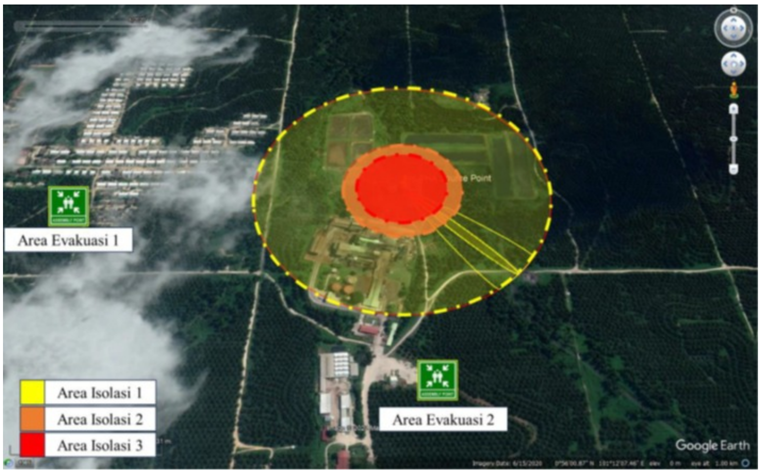

Figure 5. Isolation and Evacuation area

The researcher proposed 2 locations as evacuation areas with different directions from the location of the biogas powerplant facility, which is placed outside the gas dispersion area according to the simulation results and has proper access to mobilizing personnel and logistics, as shown in Figure 9. The isolation area is proposed to be divided into 3 to separate the hazard exposure in each area so that they can determine the competence and personal protective equipment needed by the emergency response team who will enter the area, the proposed personal protective equipment to be used was:

- Isolation Area 1 : N95/P100 Mask, Heat Resistant Clothes
- Isolation Area 2: Powered Air Purifier Respirator (PAPR), Heat Resistant Clothes
- Isolation Area 3: Self-Contained Breathing Apparatus (SCBA), Heat Resistant Clothes

Each emergency level indicates a specific set of actions to be taken, ranging from increased vigilance to full-scale evacuation. Strategies for dealing with emergencies are further elaborated through the development of emergency response procedures.

Emergency action plans not only address accident scenarios, but also help in prevention and mitigation of risks. Overall, this combined approach of gas dispersion modeling and bowtie analysis provides a comprehensive framework for managing the gas leakage risks at biogas plants. This action plan is part of the pre-planning technique, which is widely used in the chemical industry. The action plan is presented in tabular form, which shows a series of steps (based on the emergency response strategy) that need to be followed in responding to an emergency based on the map of its distribution (zone of impact) and the level of emergency evaluated at each facility within the industrial area.

This study highlights several gaps in previous research that form the basis of its contribution and novelty:

1. **Limited Use of ALOHA in the Renewable Energy Sector**

Most previous studies using ALOHA software for gas dispersion modeling have focused on the natural gas, oil, and other fossil fuel industries. Although ALOHA has proven effective in simulating gas leakage risk in these sectors, there is a lack of studies that apply this technique specifically to biogas power plants, which have different gas characteristics and operating conditions. This study fills this gap by focusing the analysis on biogas facilities.

2. **Lack of Integration of ALOHA and Bowtie Analysis in the Biogas Sector**

Previous studies have mostly used ALOHA or Bowtie separately in gas leakage risk analysis. However, only a few studies have integrated these two methods to gain a more comprehensive picture of gas leakage risk. The integration of ALOHA and Bowtie in this study is a step forward that has not been widely adopted in the renewable energy sector, especially for biogas power plants.

CONCLUSION

This research attempts to analysing the risk of gas leak disaster on the biogas powerplant. From the dispersion modeling, the farthest exposure distance reached 293 meters. Biogas leakage at the biogas powerplant facility is classified as an intolerable risk (red) and requires further control. Several mitigation measures that can be taken for the occurrence of biogas leaks at biogas power plant facilities include installing alarm systems, installing safety devices, installing gas detectors, installing adsorption towers, installing water curtains, training personnel, inspections, routine maintenance, operating procedures, and emergency evacuation plan. An Emergency Evacuation Plan for the occurrence of a Biogas leak at a biogas powerplant facility can be prepared in several stages, namely determining the level of emergency, determining the evacuation area and isolation área, to preparing an Emergency Response and Evacuation Plan. For biogas leaks, it can be categorized as an emergency level (IV).

REFERENCES

Afebu, K. O., Abbas, A. J., Nasr, G. G., & Kadir, A. (2015). Integrated Leak Detection In Gas Pipelines Using OLGA Simulator And Artificial Neural Networks. *Abu Dhabi International Petroleum Exhibition And Conference*, D011S016R007.

Chaiklieng, S. (2021a). Risk Assessment Of Workers' Exposure To BTEX And Hazardous Area Classification At Gasoline Stations. *Plos One*, *16*(4), E0249913.

Chaiklieng, S. (2021b). Risk Assessment Of Workers' Exposure To BTEX And Hazardous Area Classification At Gasoline Stations. *Plos One*, *16*(4), E0249913.

Del Rosario Rodero, M., Carvajal, A., Arbib, Z., Lara, E., De Prada, C., Lebrero, R., & Muñoz, R. (2020). Performance Evaluation Of A Control Strategy For Photosynthetic Biogas Upgrading In A Semi-Industrial Scale Photobioreactor. *Bioresource Technology*, *307*, 123207.

Ding, C. (2021). Study On Influence Characteristics Of Natural Gas Leakage In Long-Distance Pipelines. *IOP Conference Series: Earth And Environmental Science*, *687*(1), 012125.

Gholizadeh, T., Vajdi, M., & Rostamzadeh, H. (2019). A New Biogas-Fueled Bi-Evaporator Electricity/Cooling Cogeneration System: Exergoeconomic Optimization. *Energy Conversion And Management*, *196*, 1193–1207.

Hassaneen, F. Y., Abdallah, M. S., Ahmed, N., Taha, M. M., Abd Elaziz, S. M. M., El-Mokhtar, M. A., Badary, M. S., & Allam, N. K. (2020). Innovative Nanocomposite Formulations For Enhancing Biogas And Biofertilizers Production From Anaerobic Digestion Of Organic Waste. *Bioresource Technology*, *309*, 123350.

Johnstone, J. E. E., Spangler, M. D. D., Heitzman, C. S. S., Wimberley, G. A. A., & Flores, A. R. R. (2015). Engineering Safe Distances Between Occupied Structures And Processing Equipment. *SPE Health, Safety, Security, Environment, & Social Responsibility Conference-North America*, SPE-173507.

Nyifi, I. A., Irtwange, S. V., & Bako, T. (2018). Design And Construction Of A Tube Storage Device For Biogas Using Motorized Compressor. *International Journal Of Science And Qualitative Analysis*, *4*(1), 20–26.

Pacsi, A. P., Ferrara, T., Schwan, K., Tupper, P., Lev-On, M., Smith, R., & Ritter, K. (2019). Equipment Leak Detection And Quantification At 67 Oil And Gas Sites In The Western United States. *Elem Sci Anth*, *7*, 29.

Pettitt, G., & Pennicott, P. (2016). Use Of Bowties For Pipeline Safety Management. *International Pipeline Conference*, *50266*, V002T01A011.

Prisilia, H., & Purnomo, D. A. (2022). Manajemen Risiko K3 Dengan Metode Failure Mode And Effect Analysis (FMEA) Dan Fault Tree Analysis (FTA) Untuk Mengidentifikasi Potensi Dan Penyebab Kecelakaan Kerja (Studi Kasus: Tahap Ii Pembangunan Gedung Laboratorium DLH Banyuwangi). *Tekmapro*, *17*(2).

Shan, X., Liu, K., & Sun, P.-L. (2017). Risk Analysis On Leakage Failure Of Natural Gas Pipelines By Fuzzy Bayesian Network With A Bow-Tie Model. *Scientific Programming*, *2017*(1), 3639524.

Turgut, P., Gurel, M. A., & Pekgokgoz, R. K. (2013). LPG Explosion Damage Of A Reinforced Concrete Building: A Case Study In Sanliurfa, Turkey. *Engineering Failure Analysis*, *32*, 220–235.

Yudiartono, Y., Fitriana, I., Dewi, R. E. P., Wijaya, P. T., Niode, N., & Gustriani, N. (2018). ANALISA TEKNO-EKONOMI BIO-CNG SEBAGAI BAHAN BAKAR GAS TERBARUKAN DI INDONESIA. *Jurnal Energi Dan Lingkungan (Enerlink)*, *14*(2).