Available online at:
Al-Fiziya: Journal of Materials Science, Geophysics, Instrumentation and Theoretical Physics
Website: http://journal.uinjkt.ac.id/index.php/al-fiziya
Vol.6 No. II 2023, 1-13

Ammonia (NH3) Gas Control System in Chicken Coops Using Fuzzy Logic Based Internet of Things (IoT) Method

Khasbianta Supriadi[1], Ambran Hartono[2,*], Salsabila Tahta Hirani Putri[3], Hanif Fakhrurraja[4]

[1,2]Physics Study Program, Faculty of Sciences and Technology, State Islamic University Syarif Hidayatullah Jakarta, Indonesia.
[3]Department of Information System, Faculty of Science and Technology UIN Syarif Hidayatullah Jakarta, Indonesia
[4]Research Center for Smart Mechatronics National Research and Innovation Agency of Indonesia Bandung, Indonesia

*ambran.hartono@uinjkt.ac.id

Submitted: ... ; Revised: ... ; Approved: .... ; Available Online:

Abstract. Chicken productivity increases every year, resulting in air pollution in the form of NH3 generated by chicken waste, which is felt by the residents living around the chicken coop. The purpose of this research is to design an ammonia gas control system using Matlab, with the ammonia gas sensor MQ-135 and the humidity sensor DHT11 as parameters, to minimize the ammonia gas levels. This system operates by transmitting information about the condition of ammonia gas levels using a fuzzy logic control system as the technical decision-making mechanism for driving the exhaust fan based on data from the DHT11 and MQ-135 sensors. In this research, the fuzzy logic method was employed to determine the membership functions for the DHT11 sensor (dry, moist, wet) and MQ-135 sensor (normal, moderate, high), resulting in decisions of safe, moderate, and dangerous levels. The data is monitored on a platform through the Blynk app and Thingspeak, thus connecting the Internet of Things (IoT) to the internet network using the NodeMCU ESP8266 as the microcontroller. This research yields an ammonia gas control system that effectively manages air quality affected by chicken waste, with sensor accuracy levels exceeding 97%.

Keywords: *Control System, Fuzzy Logic, Internet of Things (IoT), Thingspeak, Blynk***.**
DOI : 10.15408/fiziya.v6i2.34757

INTRODUCTION

In the context of food availability, livestock products play a crucial role as one of the sub-sectors of agriculture that significantly contribute to meeting food needs. Animal products, in particular, serve as the primary source of human nutrition and animal protein [1, 2, 3, and 4]. According to data from the Ministry of Agriculture of the Republic of Indonesia in 2020, the population of meat-type chickens reached an impressive figure of 2,970,494,000 individuals, with meat production totaling 3,275,326,000 tons [5].

The population size and production of broiler chickens must be balanced with an increase in farmer awareness to maintain cleanliness in the poultry houses and the farm environment to prevent pollution from chicken waste [6, 7, 8, 9, and 10]. Government Regulation of the Republic of Indonesia No. 28 of 2004 on the safety, quality, and nutrition of food reflects the importance of maintaining cleanliness in poultry houses as a step to reduce chicken waste pollution. Pollution is often caused by a lack of awareness among farmers in maintaining cleanliness and the environment within the poultry houses [11, 12, 13, 14, and 15]. Accumulated chicken waste leads to an increase in daily waste production, which, when multiplied by the chicken population, can significantly elevate the levels of chicken waste pollution. This results in the release of harmful gases such as ammonia and methane. Complaints from the surrounding community about the odor from the poultry houses are also a negative consequence of improper poultry house management [16, 17, 18, 19, and 20], which occurs due to sudden changes in feed that make the poultry house wet and emit a strong odor.

The primary sources of ammonia gas (NH3) include the chemical industry, oil refineries, coal furnaces, livestock barns, and fuel combustion [21, 22, 23, 24, and 25]. Ammonia in the atmosphere originates from various sources, including the decomposition of waste, fertilizer manufacturing industries, and fertilizer usage. From these sources, ammonia is founds in the air, soil, and water. Ammonia exists as a gas near industrial waste sites, in water solution in ponds or bodies of water near waste sites, and can also be found adhered to soil particles in waste disposal areas [26, 27, 28, 29, 30, and 31].

Ammonia (NH3) is a colour less gas with a boiling point of -33°C. Ammonia gas is lighter than air, with a density of approximately 0.6 times that of air at the same temperature. The sharp od or of ammonia can be detected at low concentrations of 1-5 ppm [32, 33, 34, 35, 36, 37, 38, 39, and 40]. One of the health impacts of high ammonia levels, above 50 ppm, is irritation of the eyes and nose, throat irritation, coughing, chest pain, and even shortness of breath [26].

Factors contributing to the presence of this chemical compound include the accumulation of chicken waste, temperature, and room humidity. Temperature and room conditions can influence the concentration of the formation of harmful gases that occur during the decomposition of chicken waste. This can result in health problems such as reduced appetite in animals, decreased chicken productivity, and respiratory disturbances in people near chicken coops [41, 42, 43, 44, 45, 46, and 47]. Inhaling ammonia gas can cause respiratory problems, irritation of the eyes, nose, and throat, and in severe cases, when it reaches a concentration measured in PPM (Parts Per Million), it can lead to death.

Farmers have been making significant efforts to reduce the pollution levels in chicken coops. These efforts encompass regular cleaning of the chicken coops, providing natural feed additives such as palm fruit for enhanced chicken performance [39, 41, and 43], converting waste into fertilizer, and attempting to control ammonia gas levels in chickens through the use of probiotics, prebiotics, pesticides, and basil flour [48, 49, and 50]. However, challenges arise due to the rapid formation of decomposed gases and the absence of effective tools to mitigate ammonia (NH_3) gas levels in the coops.

For this reason, the author proposes an integrated system in detecting the presence of ammonia gas. The writing team designed a good detection system that can monitor and control the gas to ensure the cage environment is maintained properly and safely. In this article, we will describe the ammonia gas control system. In its application, using an IoT-based approach ESP8266 integrated with fuzzy logic [51, 52, and 53]. This aspect is the novelty of this study.

The development of an NH_3 gas control system in chicken coops, utilizing the ESP8266-based IoT approach and incorporating fuzzy logic, offers an effective solution to prevent the formation of ammonia gas and maintain its levels. This system provides farmers with convenient access and control, enabling them to monitor temperature, humidity, and gas levels within the chicken coop, thanks to its integration with the Internet of Things (IoT).

METHODOLOGY

The research was conducted from August 21, 2021, to September 21, 2022, at the researcher's residence in Bekasi and at the Instrumentation Development Center of the Indonesian Research and Innovation Agency (BRIN), LIPI Complex Building 80, Sangkuriang Street, Bandung.

Hardware Design

The block diagram of this equipment system is as follows in **Figure 1** below:

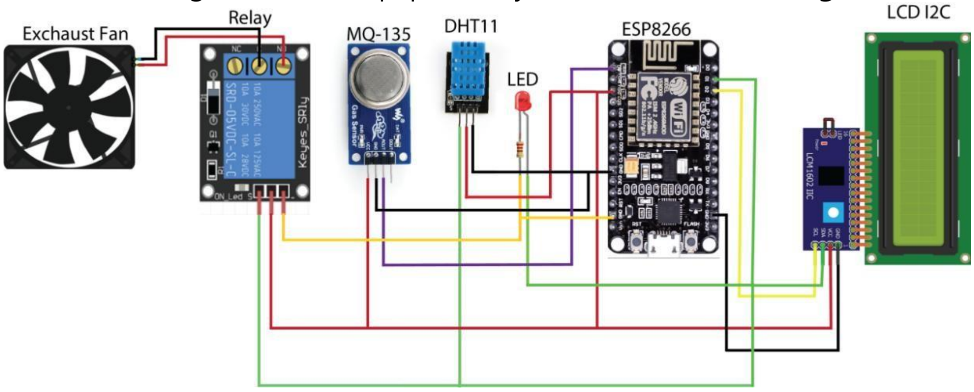


Figure. 1 The block diagram of the hardware design system

1. The explanation of the components contained in **Figure. 1**, including:
2. MQ-135 sensor is used to detect and measure the concentration of ammonia gas.
3. DHT11 sensor is used to detect the temperature and humidity of the environment.
4. Single relay module is used to control and supply electrical power.
5. LED indicators are used in the form of green and red lights.
6. Exhaust fan is used to circulate the ambient air.
7. ESP8266 is used to process and transmit data and connect to the internet.
8. LCD 16×2 is used to display the PPM value and temperature (in °C) and humidity.

Fuzzy Logic Design

In this study, the Sugeno fuzzy logic method is employed on a microcontroller that has acquired data from both sensors, namely MQ-135 and DHT11. Fuzzy logic is an approach for making decisions using calculations with linguistic variable outputs. The Sugeno method is a fuzzy inference method for rules represented in the form of IF-THEN, where the output of this fuzzy logic is not in the form of sets but in the form of constants.

The following are the stages of fuzzy logic design as shown in **Figure 2**

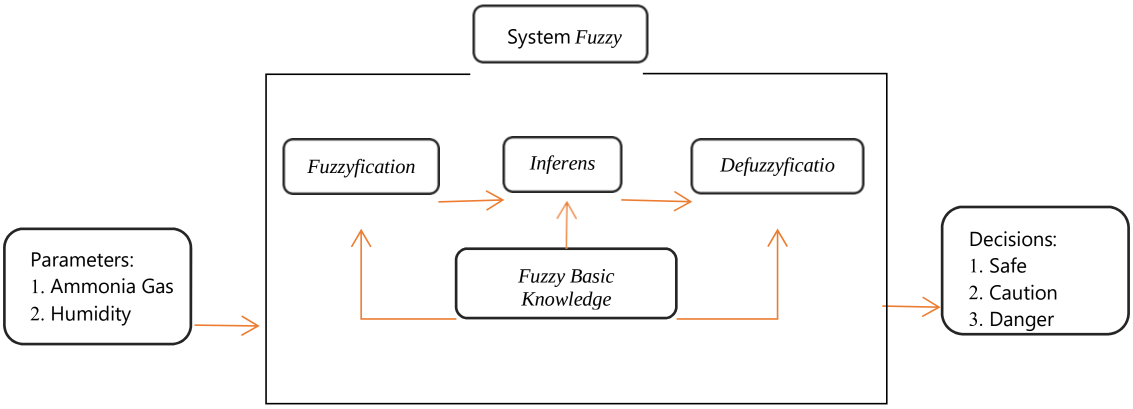


Figure. 2 Stages of Fuzzy Logic Design

Stage Design System

The following is a flow diagram of the ammonia gas detection system as shown in **Figure. 3.**

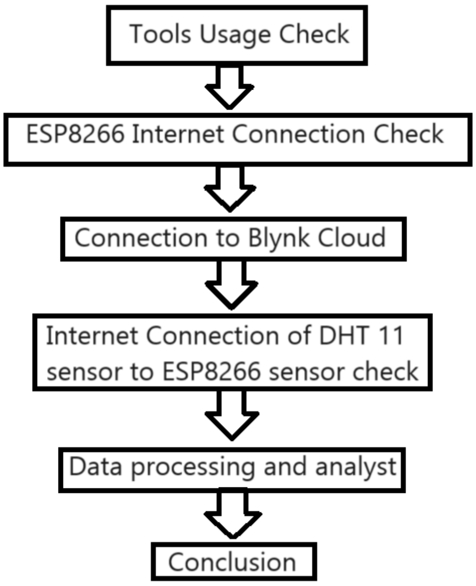


Figure. 3 Stage of the ammonia gas detection system

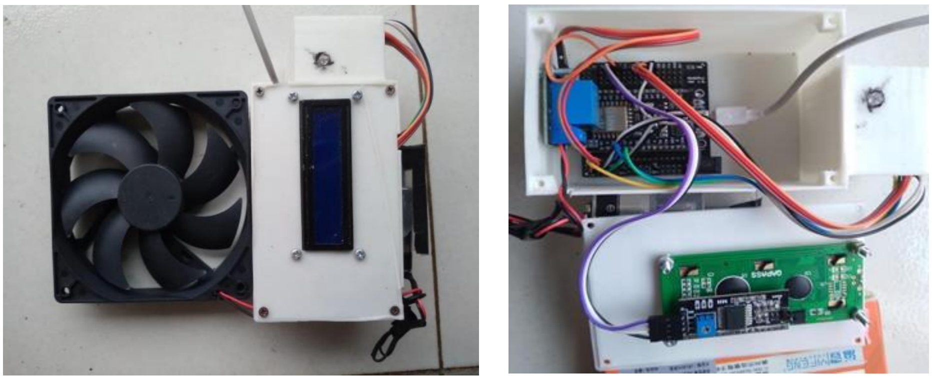
Vol.6 No. II 2023, 1-13
P-ISSN: 2621-0215, E-ISSN: 2621-489X

RESULTS AND DISCUSSIONS

A device with an ammonia gas control system using fuzzy logic has been successfully created. This system can provide Safe, Caution, and Danger decisions regarding ammonia gas levels in chicken coops using two sensors: the MQ-135 sensor and the DHT11 sensor.

The readings from both sensors will be transmitted via ThingSpeak with the internet serving as the data transmission medium. Subsequently, the data stored in ThingSpeak will be sent to the Blynk App to display the sensor values, decisions, suggestions, and recommendations for minimizing ammonia gas levels in the chicken coop based on the readings from both sensors. The exhaust fan and the red LED will turn "ON" if the fuzzy logic decision is Danger, and the red LED will turn "ON" if the fuzzy logic decision is Caution.

The overall view of the built device as shown in **Figure 4**.



(a) (b)

Figure. 4 (a) Exterior view (b) Interior view of device sensor built

Matlab is instrumental in simulating fuzzy logic methods using the Fuzzy Logic Design tool. The simulation involves inputting linguistic variable parameters and membership functions. With two inputs, ammonia gas and humidity, and an output decision based on these inputs, the process involves substituting the two inputs. The inference step contains rules to generate the output decision from the input, with the decisions {Safe, Caution, Danger} represented in binary values as Safe (0), Caution (0.5), and Danger (1).

The results of these fuzzy rules are implemented in the form of a rule viewer. As an example, by inputting an ammonia gas level of 72.3 PPM and humidity of 71.4%, following the fuzzy rules where an ammonia gas level above 50 PPM falls into the high ammonia linguistic value range in the membership function and humidity above 65% falls into the high humidity linguistic value range in the membership function, the defuzzified result is 1 (Danger).

Testing the Accuracy of the MQ-135 Sensor

The MQ-135 sensor undergoes testing by reading varying levels of ammonia gas concentration using 25% ammonia. The sensor is placed at different distances from the MQ-135 sensor, and calculations are performed to obtain the PPM (Parts Per Million) value for 25% ammonia.

Testing the Temperature Sensor DHT11

The DHT11 sensor's temperature reading is tested by exposing it to flame or a candle with temperatures ranging from 80°C to 90°C, at varying distances. **Table 1** shown the accuracy of temperature readings from the DHT11 sensor using an HTC 1 Hygrometer.

Tabel 1 Data of testing accuracy and Accuracy rate of sensor DHT11

No.	Spacing	DHT11 (%)	Hygrometer HTC 1 (%)	Error Percentage (%)
1.	5 cm	45	46	2.22
2.	10 cm	47	48	2.13
3.	15 cm	50	52	4.00
4.	20 cm	51	52	1.96
5.	25 cm	52	53	1.92
Deviation Standard		**2.92**	**3.03**	0.88
Mean Absolute Percentage Error (MAPE)				2.45
Accuracy rate (100% - MAPE)				97.55

Analysis and Performance Testing Results in Fuzzy Logic Method

The testing that has been conducted yielded results from the designed device, and the data transmitted via NodeMCU8266 was successfully received by ThingSpeak and the Blynk App. Data displayed on the Blynk App was recorded at intervals of every 4 seconds during three different times of the day: morning, noon, and evening.

Sampling data to measure ammonia gas levels in the chicken coop is conducted at various times: morning, noon, afternoon, and evening as shown as **Table 2** to **Table 5**. Data sent to the ThingSpeak cloud is recorded every 15 seconds, and the average is calculated for each time based on the incoming data. The following are the hourly averages and the resulting graphs from various data collection times as shown as **Figure 5** to **Figure 8.**

The results of the morning analysis at the Chicken Livestock Coop in Sukaraya, Cikarang, Bekasi Regency are as shown in Table 2 follows:

Table 2 **The average hourly data for the morning hours (from 04:00 to 09:00)**

Average Hour of	Temperature (°C)	Humidity (%)	NH_3 (PPM)
1	31.41	70.9	4.45
2	30.92	73.18	1.23
3	33.43	62.77	1.59
4	32.92	58.8	2.46
5	33.55	66	4.37
6	34.62	61.17	4.34

The results of the afternoon analysis at the Chicken Livestock Coop in Sukaraya, Cikarang, Bekasi Regency are as shown Table 3 follows:

Table 3 **The average hourly data for the noon hours (from 09:00 to 14:00)**

Average Hour of	Temperature (°C)	Humidity (%)	NH_3 (PPM)
1	33.22	60.5	2.5
2	33	56.67	2.22
3	33.4	55.8	2.77
4	34.97	49	2.4
5	35.88	49.31	4.38
6	35.59	48.67	4.16

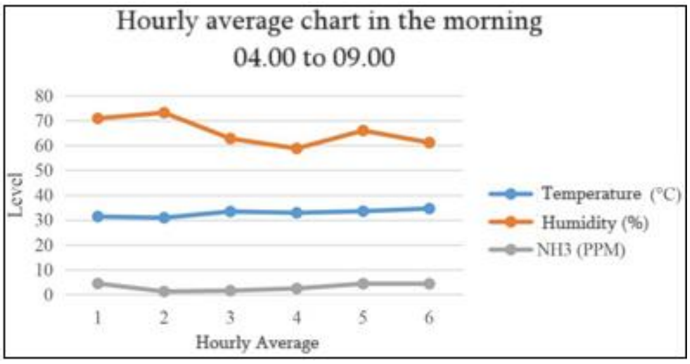


Figure. 5 Average Hourly Chart in the Morning (from 04:00 to 09:00)

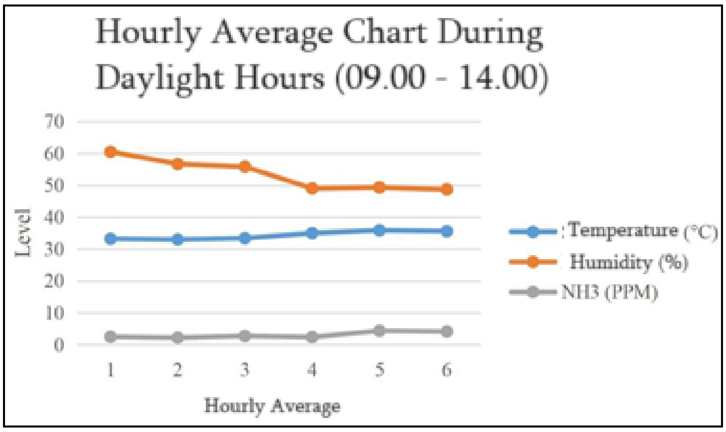


Figure. 6 Average Hourly Chart in the Noon (From 09.00 – 14.00)

The results of the afternoon analysis at the Chicken Livestock Coop in Sukaraya, Cikarang, Bekasi Regency are as shown Table 4 follows:

Table 4 The average hourly data for the afternoon hours (from 14:00 to 19:00)

Average Hour of	Temperature (°C)	Humidity (%)	NH_3 (PPM)
1	32.94	54.2	2.48
2	33.55	51.5	3.89
3	32.65	57.5	4.51
4	32.46	62	4.96
5	33.03	64.75	3.77
6	33.2	6433	4.68

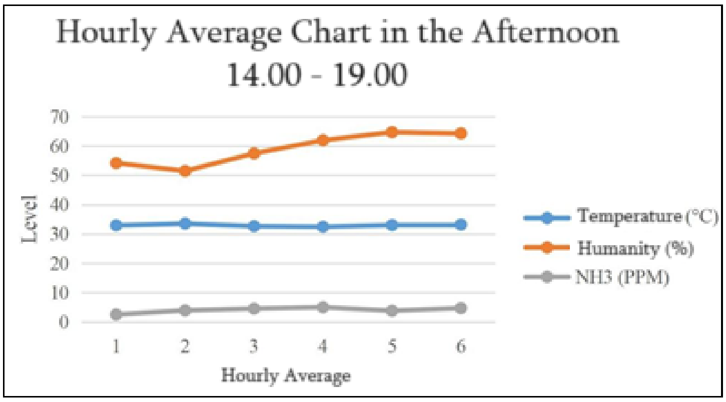


Figure. 7 Average Hourly Chart in the Afternoon (From 09.00 – 14.00)

The results of the evening analysis at the Chicken Livestock Coop in Sukaraya, Cikarang, Bekasi Regency are as shown as Table 5 follows:

Table 5 The average hourly data for the afternoon hours (from 19:00 to 04:00)

Average Hour of	Temperature (°C)	Humidity (%)	NH_3 (PPM)
1	33.72	62.67	4.73
2	34.6	62	4.76
3	34.58	62.6	4.8
4	34.42	62	4.76
5	34,17	60.22	4.17
6	34.2	60.8	4.26

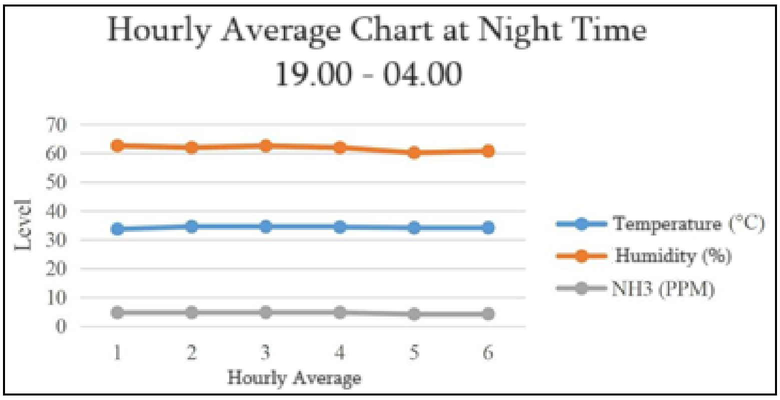


Figure. 8 Average Hourly Chart in the Afternoon (From 09.00 – 14.00)

Based on the data collected at the four different times throughout the 24 hours, it can be analyzed that each time has varying characteristics in temperature, humidity, and NH3 levels. However, the parameter levels remain within the acceptable range.

CONCLUSIONS

The conclusion of this research is that a successfully integrated control system has been developed, incorporating Internet of Things technology. Furthermore, the system effectively displays data on the Blynk app and provides decision status on the LCD screen. The Fuzzy Logic method is capable of making decisions based on data from both sensors. In cases where the ammonia gas level exceeds 50 ppm, the Fuzzy Logic system triggers alerts on the ammonia gas control system's LCD screen, activates a red warning LED, and turns on the exhaust fan to control ammonia gas levels. Based on data collected from the chicken coop at various times throughout the day, including morning, noon, and evening, efforts have been made to minimize ammonia gas levels. This research represents a significant advancement in the management and control of ammonia gas levels in poultry farms, demonstrating the potential for real-time monitoring and intervention through the integration of IoT technology and Fuzzy Logic methodology.

REFERENCES

[1] Li Day, Julie A. Cakebread, Simon M. Loveday, *Food proteins from animals and plants: Differences in the nutritional and functional properties,* Trends in Food Science & Technology Vol. 119, pp. 428-442, 2022.

[2] A.C. Alves et al., Mixing animal and plant proteins: Is this a way to improve protein techno-functionalities?, Food Hydrocolloids Vol. 97, 105171, December 2019.

[3] J.A. Cakebread et al., *Supplementation with Bovine milk or soy beverages recovers bone mineralisation in young growing rats fed an insufficient diet, in contrast to an almond beverage*, Curr Dev Nutr. Vol. 3, nzz115, Nov. 2019.

[4] C.-C. Chuang et al. *Hemp globulin heat aggregation is inhibited by the chaperone-like action of caseins*, Food Hydrocolloids, Vol. 93, pp. 46-55, 2019.

[5] A. Ramdhany and L. Ermansyah, *Statistik Peternak dan Kesehatan Hewan*, Jakarta: Direktorat Jenderal Peternakan dan Kesehatan Hewan Kementreian Pertanian RI, 2020.

[6] Luca Ferrari, Stefan-Alexandru Panaite, *Antonella Bertazzo and Francesco Visioli , Animal- and Plant-Based Protein Sources*: A Scoping Review of Human Health Outcomes and Environmental Impact, Nutrients, Vol. 14, 5115, 2022.

[7] M. K. Umam, H. S. Prayogi, and A. Nurgiartiningsih, *Penampilan Produksi Ayam Pedaging yang dipelihara pada Sistem kandang Lantai Kandang Panggung dan Kandang Bertingkat,* J. Ilmu-ilmu Peternak, Vol. 24, No. 3, pp. 79-87, 2015.

[8] Willett, W.; Rockström, J.; Loken, B.; Springmann, M.; Lang, T.; Vermeulen, S.; Garnett, T.; Tilman, D.; DeClerck, F.; Wood, A.; et al. *Food in the Anthropocene: The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems*, Lancet, Vol. 393, pp. 447–492, 2019.

[9] Adhikari, S.; Schop, M.; de Boer, I.J.M.; Huppertz, T., *Protein Quality in Perspective: A Review of Protein Quality Metrics and Their Applications*, Nutrients, Vol. 14, pp. 947, 2022.

[10] Goran Gržinić et al., *Intensive poultry farming: A review of the impact on the environment and human health,* Science of The Total Environment, Vol. 858, Part 3, No. 160014, February 2023

[11] B. P. H. N. (BPHN), *Tentang Keamanan, Gizi dan Mutu,* Indonesia 2004.

[12] M.E. Abd El-Hack, M.T. El-Saadony, A.M. Shehata, M. Arif, V.K. Paswan, G.E.-S. Batiha, A.F. Khafaga, A.R. Elbestawy, *Approaches to prevent and control Campylobacter spp. colonization in broiler chickens: a review,* Environ. Sci. Pollut. Res., Vol. 28, pp. 4989-5004, 2021.

[13] A.O. Adekiya et al., *Different organic manure sources and NPK fertilizer on soil chemical properties, growth, yield and quality of okra,* Sci. Rep., Vol. 10, 2020.

[14] K. Anderson, P.A. Moore, J. Martin, A.J. Ashworth, *Evaluation of a novel poultry litter amendment on greenhouse gas emissions*, Atmosphere, Vol. 12, p. 563, 2021.

[15] Ashraf, G. Liu, B. Yousaf, M. Arif, R. Ahmed, S. Irshad, A.I. Cheema, A. Rashid, H. Gu Izaman, *Recent trends in advanced oxidation process-based degradation of erythromycin: pollution status, eco-toxicity and degradation mechanism in aquatic cosystems*, Sci. Total Environ, Vol. 772, No. 145389, 2021.

[16] J. Astill, R.A. Dara, E.D.G. Fraser, B. Roberts, S. Sharif, *Smart poultry management: smart sensors, big data, and the internet of things*, Comput. Electron. Agric., Vol. 170, No. 105291, 2020.

[17] C.G. Awuchi, et al., *Mycotoxins' toxicological mechanisms involving humans, livestock and their associated health concerns*: a review Toxins, 14, No. 10.3390, pp. 167, 2022.

[18] J. Baker, W.H. Battye, W. Robarge, S. Pal Arya, V.P. Aneja, *Modeling and measurements of ammonia from poultry operations: their emissions, transport, and deposition in the Chesapeake Bay,* Sci. Total Environ., Vol. 706, No. 135290, 2020.

[19] O. Bamidele, et al., *Antimicrobial usage in smallholder poultry production in Nigeria*, Vet. Med. Int., p. 7746144, 2022.

[20] L. Baskin-Graves, et al., *Rapid health impact assessment of a proposed poultry processing plant in Millsboro, Delaware,* Int. J. Environ. Res. Public Health, Vol. 16, no. 10.3390, p. 3429, 2019.

[21] B. Chandra, *No. Title Pengantar Kesehatan Lingkungan*, Jakarta: EGC, 2004.

[22] Ghavam, S.; Vahdati, M.; Wilson, IG; Styring, P., *Proses Produksi Amonia Berkelanjutan*. Depan. Res Energi. Vol. 9, No. 580808, 2021.

[23] Kojima, Y. *Sifat Fisika dan Kimia Amoniak sebagai Pembawa Energi dan Hidrogen. Dalam Amonia Bebas CO_2 sebagai Pembawa Energi: Wawasan Jepang* ; Springer: Berlin/Heidelberg, Jerman, hlm. 17-28, 2022.

[24] Smith, C.; Bukit, AK; Torrente-Murciano, L. *Peran Amonia Haber-Bosch Saat Ini dan Masa Depan dalam Lanskap Energi Bebas Karbon*. Lingkungan Energi. Sains. Vol. 13, pp. 331-344, 2020.

[25] Liu, B.; Manavi, N.; Deng, H.; Huang, C.; Shan, N.; Chikan, V.; Pfromm, P. *Aktivasi N_2 pada Cluster Ni_3 dan Fe_3 yang Didukung Mangan Nitrida dan Relevansinya dengan Pembentukan Amonia*. J.Fisika. kimia. Biarkan. Vol. *12* , pp. 6535–6542, 2021.

[26] N. Roney and L. Fernando, *Toxicological Profile For Ammonia*. Atlanta: Agency for Toxic Substances and Disease Registry, 2004.

[27] Ben Hassen, T.; El Bilali, H. *Dampak Perang Rusia-Ukraina terhadap Ketahanan Pangan Global: Menuju Sistem Pangan yang Lebih Berkelanjutan dan Berketahanan?* Makanan, Vol. 11, No. 2301, 2022.

[28] Abdullah Emre Yüzbas¸ıoglu , Cemre Avs¸ar , Ahmet Ozan Gezerman, *Current Research in Green and Sustainable Chemistry The current situation in the use of ammonia as a sustainable energy source and its industrial potential Current Research in Green and Sustainable*, Chemistry, Vol. 5, No. 100307, 2022.

[29] J.A. Faria, *Renaissance of ammonia synthesis for sustainable production of energy and fertilizers, Curr. Opin. Green Sustain*. Chem. Vol. 29, No. 100466, 2021.

[30] D.R. MacFarlane, P.V. Cherepanov, J. Choi, B.H.R. Suryanto, R.Y. Hodgetts, J.M. Bakker, F.M. Ferrero Vallana, A.N. Simonov, *A roadmap to the ammonia economy*, Joule, Vol. 4, pp. 1186–1205, 2020.

[31] J. Humphreys, R. Lan, S. Tao, S. *Development and recent progress on ammonia synthesis catalysts for Haber-Bosch process*, Adv. Energy Sustain. Res. Vol. 2, No. 2000043, 2020.

[32] G. Qing, R. Ghazfar, S.T. Jackowski, F. Habibzadeh, M.M. Ashtiani, C.P. Chen, M.R. Smith, T.W. Hamann, *Recent advances and challanges of electrocatalytic N2 reduction to ammonia*, Chem. Rev. Vol. 120, No. 9b00659 , 2020.

[33] K. Brigden and R. Stringer, "*Ammonia and Urea Production : Incidents of Ammonia Release From The Profertil Urea and Ammonia Facility*," *GreenPeace*. Greenpeace Research Laboratories, Department of Biological Sciences, Exeter, UK, 2000.

[34] G.F. Han, F. Li, Z.W. Chen, C. Coppex, S.J. Kim, H.J. Noh, Z. Fu, Y. Lu, C.V. Singh, S. Siahrostami, Q. Jiang, J.B. Baek, *Mechanochemistry for ammonia synthesis under mild conditions*, Nat. Nanotechnol. Vol. 16, No. 325–330, 2021.

[35] P. Bodhankar, S. Patnaik, G.R. Kale, *Thermodynamic analysis of autothermal steamreforming of methane for ammonia production*, Int. J. Energy Res. Vol. 45, pp. 6943–6957, 2020.

[36] H. Zhang, L. Wang, J. Van Herle, F. Marechal, U. Desideri, *Techno-economic comparison of green ammonia production processes*, Appl. Energy, Vol. 259,

No. 114135, 2020.

[37] Valera-Medina, F et al., *Review on ammonia as a potential fuel: from synthesis to economics*, Energy Fuel, Vol. 35, PP. 6964–7029, 2021.

[38] D. Schonvogel, J. Büsselmann, H. Schmies, H. Langnickel, P. Wagner, A. Dyck, *High temperature polymer electrolyte membrane fuel cell degradation provoked by ammonia as ambient air contaminant*, J. Power Sources, Vol. 502, No. 229993, 2021.

[39] J. Zheng, L. Jiang, Y. Lyu, S.P. Jian, S. Wang, *Green synthesis of nitrogen-toammonia fixation: past, present, and future, Energy & Environ.* Mater. Pp. 1-6, 2021.

[40] M. Wang, M.A. Khan, I. Mohsin, J. Wicks, A.H. Ip, K.Z. Sumon, C.-T. Dinh, E.H. Sargent, I.D. Gates, M.G. Kibria, *Can sustainable ammonia synthesis pathways compete with fossil-fuel based Haber- Bosch processes?* Energy Environ. Sci. Vol. 14, pp. 2535–2548, 2021.

[41] O. Sumarna, *Kimia fisika 1 Modul: Sifat-sifat Gas*. Jakarta: Universitas Terbuka Press, 2009.

[42] N. Ulupi and S. K. Inayah, "Performa Ayam Broiler dengan Pemberian Serbuk Pinang sebagai Feed Aditive," *J. Ilmu Produksi dan Teknol. Has. Peternak.*, vol. 3, no. 1, pp. 8–11, 2015.

[43] Bray, C.D., et al., *Global emissions of NH3, NOx, and N2O from biomass burning and the impact of climate change*. J. Air Waste Manag. Assoc. Vol. 71 No. 1, pp. 102–114, 2021.

[44] Domingo, N.G.G.,et al., *Air quality-related health damages of food*. Proc. Natl. Acad. Sci. U. S. A, Vol. 118, No.20, 2021.

[45] Gu, B., Zhang, et al.. *Abating ammonia is more cost-effective than nitrogen oxides for mitigating PM2.5 air pollution*. Science Vol. 374, No. 6568, pp. 758–762, 2021.

[46] Han, X., Zhu, L., Liu, M., Song, Y., Zhang, M., *Numerical analysis of the impact of agricultural emissions on PM2.5 in China using a high-resolution ammonia emissions inventory*. Atmos. Chem. Pys. Discuss. Vol. 3, pp. 1–31, 2020.

[47] Kanter, D.R., Chodos, O., Nordland, O., Rutigliano, M., Winiwarter, W., *Gaps and opportunities in nitrogen pollution policies around the world. Nat. Sustain*. Vol. 3, No. 11, pp. 956–963, 2020.

[48] O. P. Hulu, M. Sihombing, R. H. Saputro, A. Darmawan, and Y. Herbani, "*Aplikasi Teknologi Nanopartikel Perak (AgNPs) dalam Air Minum dan Bentuk Kabut terhadap Kadar Amonia Ekskreta Broiler*," J. Ilmu Nutr. dan Teknol. Pakan, vol. 17, no. 2, pp. 26–31, 2019.

[49] Ravi Kant Jain, *Experimental performance of smart IoT-enabled drip irrigation system using and controlled through web-based applications*, Smart Agricultural Technology, Vol. 4, No. 100215, 2023.

[50] A. Ullah, O. B. Kharisma, and I. Santoso, "*Fuzzy Logic Implementation to Control Temperature andHumidity in a Bread Proofing Machine*," Indones. J. Artif. Intell. Data Min., vol. 1, no. 2, p. 66, 2018.

[51] Rajesh Bose, Sandip Roy, Haraprasad Mondal, *A novel algorithmic electric power saver strategies for real-time smart poultry farming,* e-Prime - Advances in Electrical Engineering, Electronics and Energy, Vol. 2, No. 1000053, 2022.

[52] G. Patel, V. Pillai, P. Bhatt, S. Mohammad, *Application of nanosensors in the food industry*, in:, Micro and Nano Technologies, Nano sensors For Smart Cities, Elsevier, pp. 355–368, 2020.

[53] O. Debauche, S. Mahmoudi, S. Ahmed Mahmoudi, P. Manneback, J. Bindelle, F. Lebeau, Edge computing and artificial intelligence for real-time poultry monitoring, Procedia Compu.t Sci., Vol. 175, pp. 534-541, 2020.