NVEO
Natural Volatiles & Essential Oils

Analysis of Liquid Smoke Production Process From Palm Shell With Integrated Pyrolysis Method

Riman Sipahutar[1*], Irwin Bizzy[1], Darmawi[1], Muhammad Faizal[2], Baiti Hidayati[3]

[1]*Mechanical Engineering Department, Faculty of Engineering-University of Sriwijaya, South Sumatera, Indonesia*
[2]*Chemical Engineering Department, Faculty of Engineering-University of Sriwijaya, South Sumatera, Indonesia*
[3]*Doctor Program of Engineering Science, Faculty of Engineering-University of Sriwijaya, South Sumatera, Indonesia*
**Corresponding author, Email: rimansipahutar@ft.unsri.ac.id*

Abstract
The process of producing liquid smoke can be done by various methods. In this study, an analysis of the condensation of liquid smoke has been carried out using a refrigeration system with two different types of fluids, namely water and air, to obtain maximum results. The raw material used is palm shells which are crushed to a mesh size of -3+4, with a pyrolysis temperature of 300-400C, and a cooling fluid temperature of 10-15C. The results show that the process of producing liquid smoke by condensing using cold air cooling media is more productive. The products of the integrated pyrolysis process produced by condensation using cold air as a cooling medium are liquid smoke, charcoal and gas with percentages of 23.85%, 69.82% and 6.33%, respectively. It can be added that the products produced by condensation using cold water as a cooling medium are liquid smoke, charcoal and gas with percentages of 19.05%, 62.78% and 18.17%, respectively.
Keywords: Liquid smoke, condensation, cold air, cold water, refrigeration

Introduction

The production process of Crude Palm Oil (CPO) produces waste of 43%. The raw material for CPO production comes from oil palm plantations in Indonesia with a large area that can achieve community welfare [1]. Oil palm plantations in Indonesia have increased from 10.6 million ha in 2013 to 13.7 million ha in 2020 [2]. Palm shell waste for one year is 6,000 tons of palm kernel shells, 12 thousand tons of palm fiber, and 23 tons of empty fruit bunches, all of which are produced from 100,000 tons of fresh fruit bunches. Palm oil waste shows a significant amount so it really needs to be managed properly to produce high value products. [3]. Biomass is one of the wastes that must be managed properly in order to get sustainable benefits. One type of biomass that can be utilized is palm kernel shells. Palm shells can produce liquid smoke which has many benefits and has been studied by several researchers [4]–[6].

Palm shells are one type of biomass waste that is difficult to decompose because it has a hard texture, palm shells are considered industrial waste and must be processed into something that has benefits so as to minimize the waste of palm shells [7]. Palm shells contain lignin, cellulose, and hemicellulose which vary depending on the type. The average palm shell contains 26.6% cellulose, 27.7% hemicellulose, and 29.4% lignin. [3].

Palm shell waste is a potential raw material that can be used for the manufacture of activated carbon as a biosorbent in large enough quantities [8] . The raw materials used in the process of making liquid smoke contain lignin, cellulose, hemicellulose, and other carbon compounds [9], [10]. Liquid smoke has various benefits, including as a liquid to agglomerate latex, as a killer of insects and pests on plants, as a food preservative, even as a food flavoring [11]. Liquid smoke has been widely studied because it has the attraction to be able to turn waste into something that has a high value of benefits [12]–[21] and others.

Pyrolysis is the process of decomposition of chemical compounds through a heating process with little or no oxygen [22]. Decomposition of organic compounds can also be the cause of the formation of volatiles. Pyrolysis generally takes place at a temperature of 200 °C to 500 °C [23]. Biomass gasification is a good biomass processing process for energy production using conventional and renewable fuels. Gasification will produce hydrogen, carbon oxides, and methane. The resulting gas contains complex inorganic and organic compounds such as tar [24].

The condensation process is a heat exchange process that can change the gas phase into a liquid phase. The higher the heat transfer process, the better the condensation process and the obtained liquid [25]. Entropy research on the refrigeration system has been carried out through the condensation process [26]. and the gas condensation process resulting from pyrolysis has been widely used using water media [15], [20], [21], [23], [27]–[29]. The process of changing the phase from smoke to liquid smoke still uses water which is pumped continuously using a pump. This still leaves a gas phase that has not been completely condensed so that when the valve is opened, liquid smoke comes out of the gas phase [28].

The refrigeration process is needed to transfer the heat absorbed by the refrigerant so that the coolant temperature is in accordance with the desired temperature, this process can change the temperature from high to low [30]. In general, this refrigeration process is used for freezing and preserving food [31].

In previous studies, condensation of smoke from pyrolysis reactor into liquid smoke was using flowing water channeled through a pump. This method is still conventional so that researchers carry out further research using low temperature water and air from a refrigeration system. This method is still conventional, so the researchers conducted further research using water and air low temperatures from a refrigeration system with a temperature of 10-15°C.

Materials and Method

The raw materials used in this research are palm shells from PT. Hindoli, South Sumatra Province, Indonesia.

Figure 1: Palm shell size -3+4 mesh

Figure 1 is the palm shell used in the research process. Palm shells with a size of -3+4 mesh are dried under the sunlight for 10 hours. Based on the results of laboratory tests, this palm shell contains compounds of cellulose, hemicellulose, water, ash and lignin, as much as 11.52%, 2.68%, 12.18%, 3.19% and 76.22%, respectively. Basically, palm shell processing to produce liquid smoke has been widely carried out [7], [12], [17], [19], [5], [13], [18], [21]. However, the condensation process is still carried out conventionally using plain water without controlling the temperature in the condensation process.

The process of condensing gas resulting from pyrolysis uses low temperature air which includes a refrigeration system.

.

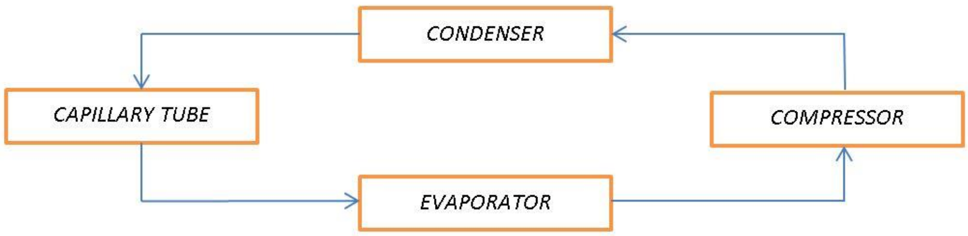

Figure 2: Vapor Compression Refrigeration Cycle

Figure 2 is a vapor compression refrigeration cycle in general which is used in the process of condensing gas resulting from pyrolysis, the evaporator is used as a device for distributing low temperature on air/water. The type of refrigerator used is AC with a cooling load capacity of 9000 Btu/h, the cold air is controlled at a temperature of 10-15ºC. Temperature control in the refrigeration system must be carried out to improve energy efficiency at the heart of the refrigeration system, which in this case is the compressor [32]–[36].

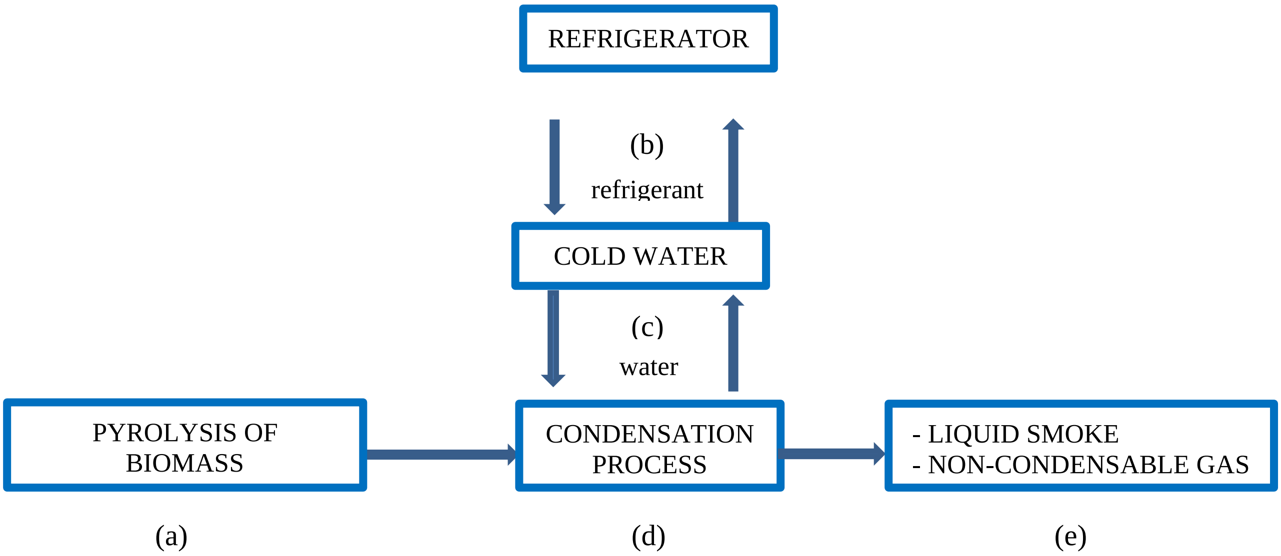

Figure 3: Gas condensation process using low temperature water

Figure 3 is a flow diagram of the process of condensing gas resulting from pyrolysis using low temperature water, (a) is a reactor where the pyrolysis process of biomass (palm shell) occurs, this pyrolysis process takes place at a temperature of 300-400ºC which then produces gas. (b) is a refrigerator that is used as a component to cool the water. (c) is a cold water storage container, where the evaporator pipe of the refrigeration system is immersed in water so that the water will become cold due to the heat exchange process from the water to the evaporator pipe, and then the cold water is pumped to the gas condensing container (d) is a place for the gas condensation process, which contains two types of fluids, namely gas fluid resulting from pyrolysis flowing inside the pipe while cold water flowing outside the pipe. (e) is a product resulting from the gas condensation process, and the product is in the form of liquid smoke and non-condensable gas.

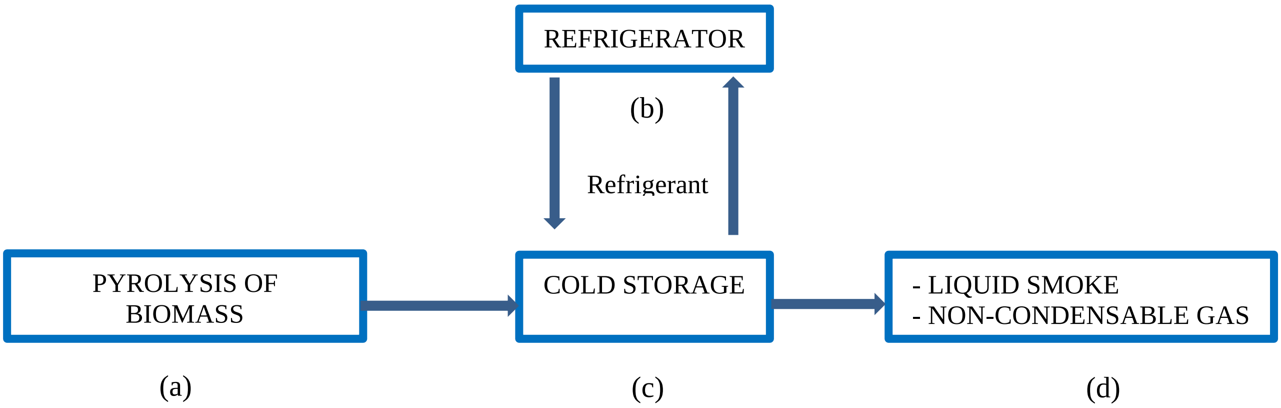

Figure 4: Gas condensation process using low temperature air

Figure 4 is a flow diagram of the process of condensing gas resulting from pyrolysis using low temperature water, (a) is a reactor where the pyrolysis process of biomass (palm shell) occurs, this pyrolysis process takes place at a temperature of 300-400ºC which then produces gas. (b) is a refrigerator that is used as a system to cool the air. (c) is a cold storage used for the gas condensation process, gas resulting from pyrolysis is directed to the cold storage. In the gas condensation process, there are two types of fluid, namely gas resulting from pyrolysis and cold air supplying from refrigerator and distributing by a fan in the cold storage. (d) is the products resulting from the gas condensation process, in the form of liquid smoke and non-condensable gas.

Analysis

The percentage of products in the process of making liquid smoke using water and low temperature air can be calculated using the following equations:

$$m_s = m_l + m_c + m_g = 100\% \quad (1)$$

$$m_l(\%) = \frac{m_l\,(g)}{m_s\,(g)} \times 100\% \quad (2)$$

$$m_c(\%)=\frac{m_c\ (g)}{m_s\ (g)}x100\% \quad (3)$$

$$m_g(\%)=\frac{m_g\ (g)}{m_s\ (g)}x100\% \quad (4)$$

Equations 1-4 are equations that can be used to calculate the percentage of product in the process of making water smoke. ms is the percentage for biomass in this case is palm shells. ml is the percentage of liquid smoke, mc is the percentage of charcoal resulting from the pyrolysis process, mg is the percentage of gas that cannot be condensed after going through the gas condensation process. The lower the percentage of gas, the better the condensation process because with minimal non-condensable gas, the air contamination of the gas that escapes will be smaller.

Results And Discussion

The conditioned palm shells were tested in the laboratory with the following results:

Tabel 1. Compound of Palm Shell

Compound	Percentage (%)
Lignin	76,22
Selulosa	11,52
Hemiselulosa	2,68
Water Content	12,18
Ash	3,19

Table 1 is the result of laboratory tests on palm shells that have been dried, it can be seen that the water vapor content in the raw material is low at 12.18%, while the dominant lignin content is 76.22%.

The conditioned raw materials are then subjected to a pyrolysis process at a temperature of 300-400ºC so as to produce gas, the gas will then be condensed into Cold Storage, where the hot gas resulting from the pyrolysis will be condensed using low temperature water using a combination refrigeration system, then the gas condensation process also carried out using low temperature air with the help of a fan that distributes cold air to the pyrolysis gas pipe. Based on the research results of the liquid smoke production process using a water and low temperature air condensation system with a combination of a refrigeration system, the following results were obtained:

Table 2: Products of the process of making liquid smoke

Product of pyrolysis process	Air dingin	Udara dingin
	%	%
liquid smoke	19.02	23.87
Charcoal	62.95	69.80
Gas	18.03	6.33

Table 2 is the result of research on the production of liquid smoke with a gas condensation process using water and low temperature air. It can be seen from these results that the maximum liquid smoke production process can be obtained by condensing the gas produced by pyolysis using low temperature air. This is also supported by the amount of gas that cannot be condensed. In the gas condensing process using low temperature air, less gas is not condensed compared to the gas condensing process using low temperature water.

The amount of gas released into the environment is less than in other studies which released 22.9% of gas [17], and 19% of gas released with the same raw material, namely palm shells [18]. Other studies on palm kernel shells have also been carried out by using the pyrolysis method using microwave and conventional condensing 37.69% passed gas [21].

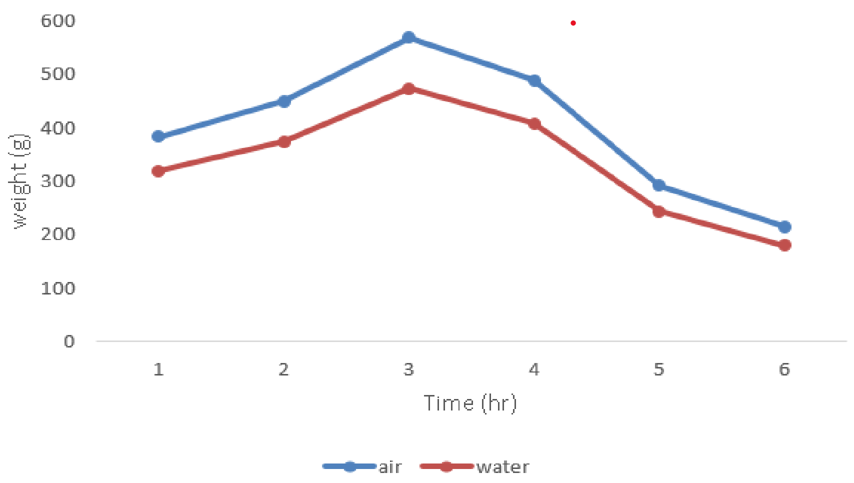

Figure 5: Graph of the amount of liquid smoke per hour

Figure 5 shows the results of the production of liquid smoke every hour for 6 h of the production process. It can be seen that the maximum amount of liquid smoke is obtained by a gas condensation system using low temperature air. The production process for the first 3 h has maximum results, this happens because the compounds in the palm shell have just decomposed. At the 3rd hour the condensation process using low temperature water reached 1989.2 g and at the 3rd hour the condensation process using low temperature air reached 2387 g.

Conclusion

Based on the results of the research on the gas condensation process using low temperature water and air on the liquid smoke production process, it is better to condense gas from pyrolysis using low temperature air. It can be seen that the amount of liquid smoke obtained was 23.87% and the gas that comes out was 6.33% in the production process for 6 hours, at a temperature of 300-400ºC and the use of cold air as a cooling medium in the condensation process. In the production process for 6 hours, at a temperature of 300-400ºC and the use of cold water as a cooling medium in the condensation process, the amount of liquid smoke obtained was only 19.02% and the non-condensable gas was 18.03%.

References

[1] J. Elisabeth and P. S. Ginting, "Utilization of palm oil industry by-products as beef cattle feed ingredients," *Oil Palm-Cattle Integr. Syst. Work.*, vol. 15, pp. 110–119, 2003.

[2] M. A. Shahputra and Z. Zen, "Positive and Negative Impacts of Oil Palm Expansion in Indonesia and the Prospect to Achieve Sustainable Palm Oil," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 122, no. 1, pp. 9–16, 2018, doi: 10.1088/1755-1315/122/1/012008.

[3] Fauziati, A. Priatni, and Y. Adiningsih, "the effect of various pyrolisis temperature of liquid smoke from palm shells as latex coagulant," *J. Ris. Teknol. Ind.*, vol. 12, no. 2, pp. 139–149, 2018.

[4] V. Kumar, P. Binod, R. Sindhu, E. Gnansounou, and V. Ahluwalia, "Bioconversion of pentose sugars to value added chemicals and fuels: Recent trends, challenges and possibilities," *Bioresour. Technol.*, vol. 269, pp. 443–451, 2018, doi: 10.1016/j.biortech.2018.08.042.

[5] H. M. Morgan *et al.*, "A review of catalytic microwave pyrolysis of lignocellulosic biomass for value-added fuel and chemicals," *Bioresour. Technol.*, vol. 230, pp. 112–121, 2017, doi: 10.1016/j.biortech.2017.01.059.

[6] C. L. Yiin, A. T. Quitain, S. Yusup, Y. Uemura, M. Sasaki, and T. Kida, "Sustainable green pretreatment approach to biomass-to-energy conversion using natural hydro-low-transition-temperature mixtures," *Bioresour. Technol.*, vol. 261, pp. 361–369, 2018, doi: 10.1016/j.biortech.2018.04.039.

[7] A. sampepana Fauziati, "Characterization of the active component of the refined palm shell liquid smoke," *J. Ris. Teknol. Ind.*, pp. 64–72, 2015.

[8] Yuliusman, Nasruddin, F. . Afdol, R. . Amiliana, A. Hanafi, and B. Rahmanda, "Preparation of Activated Carbon from Palm Shells using KOH and ZnCl2 as the Activating Agent," *J. Phys. Conf. Ser.*, vol. 755, no. 1, 2017, doi: 10.1088/1742-6596/755/1/011001.

[9] N. Aprianti, M. Faizal, M. Said, and S. Nasir, "Catalytic gasification of oil palm empty fruit bunch by using Indonesian bentonite as the catalyst," *J. Appl. Eng. Sci.*, pp. 1–10, 2021, doi: 10.5937/jaes0-28781.

[10] L. Ni'Mah, M. F. Setiawan, and S. P. Prabowo, "Utilization of Waste Palm Kernel Shells and Empty Palm Oil Bunches as Raw Material Production of Liquid Smoke," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 366, no. 1, 2019, doi: 10.1088/1755-1315/366/1/012032.

[11] B. Kılınç and Ş. Çaklı, "Growth of Listeria monocytogenes as Affected by Thermal Treatments of Rainbow Trout Fillets Prepared with Liquid Smoke," *Turkish J. Fish. Aquat. Sci.*, vol. 290, pp. 285–290, 2012, doi: 10.4194/1303-2712-v12.

[12] J. E. Omoriyekomwan, A. Tahmasebi, and J. Yu, "Production of phenol-rich bio-oil during catalytic fixed-bed and microwave pyrolysis of palm kernel shell," *Bioresour. Technol.*, vol. 207, pp. 188–196, 2016, doi: 10.1016/j.biortech.2016.02.002.

[13] M. Faisal and A. Gani, "The effectiveness of liquid smoke produced from palm kernel shells pyrolysis as a natural preservative in fish balls," *Int. J. GEOMATE*, vol. 15, no. 47, pp. 145–150, 2018, doi: 10.21660/2018.47.06109.

[14] Arief Rachmawan, Wijaya, and Andi, "Liquid Smoke Plus As A Latex Clotter," *J. agro estate*, vol. 1, 2017, [Online]. Available: https://ejurnal.stipap.ac.id/index.php/JAE/article/view/56/47.

[15] I. Kresnawaty, S. M. Putra, A. Budiani, and T. Darmono, "Conversion of Oil Palm Empty Bunches (TKKS) into Biological Charcoal and Liquid Smoke," *J. Postharvest Agric. Res.*, 2018, doi: 10.21082/jpasca.v14n3.2017.171-179.

[16] A. Asmawit, H. Hidayati, and N. Supriyatna, “Utilization of Liquid Smoke from Oil Palm Empty Bunches in Raw Rubber Processing,” *Biopropal Ind.*, vol. 02, no. 01, pp. 7–12, 2011.

[17] S. J. Oh, G. G. Choi, and J. S. Kim, “Characteristics of bio-oil from the pyrolysis of palm kernel shell in a newly developed two-stage pyrolyzer,” *Energy*, vol. 113, pp. 108–115, 2016, doi: 10.1016/j.energy.2016.07.044.

[18] A. Priatni, Y. Adiningsih, B. Riset, D. Standardisasi, and I. Samarinda, “The effect of various pyrolisis temperature of liquid smoke from palm shells as latex coagulant,” *J. Ris. Teknol. Ind.*, vol. 12, no. 2, pp. 139–149, 2018.

[19] G. Chang *et al.*, “The lignin pyrolysis composition and pyrolysis products of palm kernel shell, wheat straw, and pine sawdust,” *Energy Convers. Manag.*, vol. 124, pp. 587–597, 2016, doi: 10.1016/j.enconman.2016.07.038.

[20] M. Nayaggy and Z. A. Putra, “Process simulation on fast pyrolysis of palm kernel shell for production of fuel,” *Indones. J. Sci. Technol.*, vol. 4, no. 1, pp. 64–73, 2019, doi: 10.17509/ijost.v4i1.15803.

[21] Y. An, A. Tahmasebi, X. Zhao, T. Matamba, and J. Yu, “Catalytic reforming of palm kernel shell microwave pyrolysis vapors over iron-loaded activated carbon: Enhanced production of phenol and hydrogen,” *Bioresour. Technol.*, vol. 306, no. January, p. 123111, 2020, doi: 10.1016/j.biortech.2020.123111.

[22] K. Endang, G. Mukhtar, Abed Nego, and F. X. A. Sugiyana, “Processing of Plastic Waste with the Pyrolysis Method into Fuel Oil,” *Dev. Chem. Technol. Process. Indones. Nat. Resour.*, vol. ISSN 1693-, pp. 1–7, 2016.

[23] P. N. Sheth and B. V Babu, “Kinetic Modeling of the Pyrolysis of Biomass,” *Environ. Eng. –*, vol. 4, no. January, pp. 453–458, 2006.

[24] A. Kwiecińska, T. Iluk, and M. Kochel, “Utilization of aqueous-tar condensates formed during gasification,” *J. Ecol. Eng.*, vol. 17, no. 5, pp. 132–137, 2016, doi: 10.12911/22998993/65462.

[25] X. Li, J. Ma, and X. Ling, “Design and dynamic behaviour investigation of a novel VOC recovery system based on a deep condensation process,” *Cryogenics (Guildf).*, vol. 107, no. 30, p. 103060, 2020, doi: 10.1016/j.cryogenics.2020.103060.

[26] M. Sheikholeslami, M. Darzi, and Z. Li, “Experimental investigation for entropy generation and exergy loss of nano-refrigerant condensation process,” *Int. J. Heat Mass Transf.*, vol. 125, pp. 1087–1095, 2018, doi: 10.1016/j.ijheatmasstransfer.2018.04.155.

[27] M. Faisal, A. Gani, F. Mulana, H. Desvita, and S. Kamaruzzaman, “Effects Of Pyrolysis Temperature On The Composition Of Liquid Smoke Derivied From Oil Palm Empty Fruit Bunches,” *Rayasan J.*, vol. 13, no. 1, pp. 514–520, 2020.

[28] K. Ridhuan, D. Irawan, and R. Inthifawzi, “Pyrolysis Combustion Process with Biomass Types and Characteristics of the Produced Liquid Smoke,” *J. Progr. Stud. Tek. Mesin UM Metro*, vol. 8, no. 1, pp. 69–78, 2019.

[29] Lisa Ginayati, M. Faisal, and Suhendrayatna, “Utilization of Liquid Smoke from Oil Palm Shell Pyrolysis as Natural Preservative of Tofu,” *J. Chem. Eng.*, vol. 4, no. 3, pp. 7–11, 2015, doi: 10.32734/jtk.v4i3.1474.

[30] A.R.Trott and T.C.Welch, *Refrigeration and Air Conditioning*. Butterworth-Heinemann: f Reed Educational and Professional Publishing, 2000.

[31] A. Mota-Babiloni, J. Navarro-Esbrí, Á. Barragán-Cervera, F. Molés, B. Peris, and G. Verdú, “Commercial refrigeration - An overview of current status,” *Int. J. Refrig.*, vol. 57, pp. 186–196, 2015, doi: 10.1016/j.ijrefrig.2015.04.013.

[32] B. Withman and B. Johnson, *Refrigeration and Air Conditioning Technology*, 6 th. Delmar, 2009.

[33] H. Rostamzadeh, T. Gholizadeh, S. Rostamzadeh, S. Vosoughi, and A. A. Farshad, "Role of ejector expander in optimal inherently safety design of cascade NH3/Propane/CO2 vapor compression refrigeration systems," *Process Saf. Environ. Prot.*, vol. 146, pp. 745–762, 2021, doi: 10.1016/j.psep.2020.12.009.

[34] T. Łokietek, S. Jaszczak, and P. Nikończuk, "Optimization of control system for modified configuration of a refrigeration unit," *Procedia Comput. Sci.*, vol. 159, pp. 2522–2532, 2019, doi: 10.1016/j.procs.2019.09.427.

[35] K. Chen, T. P. Xiao, P. Santhanam, E. Yablonovitch, and S. Fan, "High-performance near-field electroluminescent refrigeration device consisting of a GaAs light emitting diode and a Si photovoltaic cell," *J. Appl. Phys.*, vol. 122, no. 14, 2017, doi: 10.1063/1.5007712.

[36] B. Saleh and A. A. Aly, "Flow Control Methods in Refrigeration Systems : A Review Flow Control Methods in Refrigeration Systems : A Review," *Int. J. Control. Autom. Syst.*, vol. 4, no. 1, p. 12, 2015.