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Experimental Analysis of Dust Explosion Potential in Indonesian Biomass Charcoal for Nickel Industry Applications

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Abstract. Indonesia, the world's leading nickel producer with 1.6 million tons produced and 55 million tons in reserves as of 2023, relies heavily on Rotary Kiln-Electric Furnace (RKEF) methods for processing its nickel ore, where coal serves as reductant and energy source, contributing to high CO_2 emissions. To support net-zero emissions by 2060, biomass charcoals from agricultural wastes (coconut shells, palm kernel shells, rubber wood, and mixed wood) offer a potential renewable alternative to coal. However, dust explosion risks in high-temperature RKEF environments necessitate evaluation. This study assesses explosibility parameters of these charcoals, pure and mixed with electrostatic precipitator (ESP) dust, using a 20 L explosion chamber per ASTM E1226-19 and E1515-22. Results indicate minimum explosible concentrations (MEC) of 155 g/m³ for pure rubber wood charcoal (Kst = 35 bar·m/s, weak explosion) with reductions upon Dust ESP mixing. Coconut and palm kernel shell charcoals showed no explosibility. Compared to coal (MEC ~60 – 100 g/m³), biomass charcoals generally pose lower risks, supporting safer integration in nickel processing.

1 Introduction

Indonesia, with its vast territory, ranks as the world's tenth-largest economy and fourth-most populous nation [1]. In 2021, it emitted 600 million tons of CO_2, placing it ninth globally, with industry as the second-largest contributor [2]. To achieve net-zero emissions by 2060, strategies include phasing out fossil fuels like coal and oil into solid biomass and other renewables [2]. Indonesia's abundant minerals, such as nickel and tin, are crucial for clean energy technologies like batteries and electric vehicles [2].

Nickel, a silvery-white, hard, and ductile metal (atomic number 28, melting point 1453 °C), exhibits similarities to iron in strength and copper in corrosion resistance [3]. Discovered in 1751 by Axel Cronstedt, it derives its name from the Saxon term "Kupfernickel" or "Devil's Copper" [4]. Nickel is used in over 30,000 consumer products and 3.000 alloys, primarily in stainless steel (70%), batteries (6%), and specialized alloys for aerospace and military applications [5]. Global nickel production exceeds 2.5 million tons annually, with Indonesia dominating reserves and output [5].

Nickel occurs naturally as oxides, sulfides, or silicates, with laterite ores (limonite and saprolite) comprising most Indonesian deposits. To produce ferronickel, one of the main processing methods used is the RKEF. The main stages of the RKEF process include rotary dryer, rotary kiln, and electric furnace. The current technology relies on carbon-based reductants and fuels, such as coal, for processing in rotary dryers and rotary kilns. However, this process produces CO_2 emissions and carries a risk of dust explosions [6, 7].

Dust explosions involve rapid combustion of fine particles, categorized by materials like organics, synthetics, coal, and metals [8]. The "fire triangle" (fuel, ignition, oxygen) expands to a "pentagon" for dust explosions, adding dispersion and confinement. Primary explosions occur in confined spaces, while secondary ones amplify from accumulated dust. Due to the various processes involved, the RKEF facility poses a potential explosion risk, particularly from the use of coal, whose dust is prone to explosion. Globally, 53 dust explosions and 263 fires were recorded in 2023, often occurring in silos, dryers, and dust collection systems [9]. Indonesia's nickel smelters have reportedly experienced several fire incidents [10].

As a preventive measure against coal dust explosion risks, biomass charcoals from wastes like coconut shells, palm kernels, and rubber wood offer sustainable alternatives via processes such as co-firing, pyrolysis, and gasification [11]. However, the review of existing literature indicates a gap in the analysis of biomass explosion risks within RKEF operations. This study presents a fundamental analysis of the explosibility of several biomass dust types intended for use in RKEF. The novelty of this research lies in the analysis of the

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effects of mixing ESP dust with biomass dust. The explosibility parameters, minimum explosion concentration (MEC) and explosibility index (Kst) were evaluated using a 20 L dust explosibility testing chamber. Through this study, the risk level of biomass dust explosions can be quantified, providing guidance for control and mitigation strategies in RKEF facilities.

2 Material and Methods

2.1 Materials preparations

2.1.1 Experimental materials

Two experimental scenarios will be evaluated: (1) a pure biomass dust sample, and (2) a mixed sample comprising biomass dust and ESP dust. Biomass samples were sourced from Indonesian suppliers: rubber wood charcoal, coconut shell charcoal, and palm kernel shell charcoal. ESP dust sourced from ESP Rotary Kiln.

2.1.2 Sample Size Reduction

Size reduction aims to get a size that appropriate to ASTM E1515 standards [12], which at least 95% minus 200 mesh. Sequentially the process is as follows: crushing the biochar using a primary and secondary crusher, after the size is slightly smaller, the sample is grinding using a ball mill and finally the dust is sieving to get fine dust that minus 200 mesh.

2.1.3 Control of Moisture Content

As stated in ASTM E1515 [12], the moisture content of the test sample should not exceed 5%. To reduce the moisture content, samples were dried in oven at 110 °C for two hours (Fig. 1). To ensure that other properties of the sample have not changed, the sample is flown with nitrogen during the drying.

Fig. 1. Set of oven.

2.2 Methods of Explosibility Testing

Dust explosibility testing was carried out in a 20 L dust explosibility testing chamber (Fig. 2). The principles and procedures of the tests followed two primary standards, ASTM E1515 [12] and ASTM E1226 [13], which provide guidelines for determining the MEC and Kst parameters. The MEC (g/m3) is the minimum concentration of dust clouds that can cause an explosion. This parameter reflects the probability of the occurrence of explosion. Kst (bar·m/s) is the deflagration index, representing the maximum rate of pressure rise during an explosion. Its value reflects the severity of the explosion.

The procedure involved placing a sample into a 0.6 L chamber. To form a dust cloud in the 20 L chamber, the sample was pushed through an automatic valve that supplied 20 bar of pressurized air. The explosion was initiated by an ignitor placed at the center of the chamber, with energy of 8.4 kJ. During the explosion, a high-speed pressure sensor recorded 70 data points within 1 s. Data acquisition captured pressure-time profiles over 3.5 seconds. An example of the pressure changes inside the 20 L chamber is shown in Fig. 3.

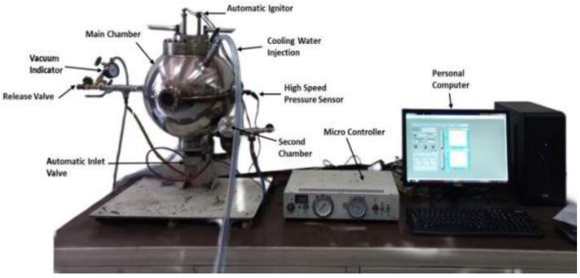
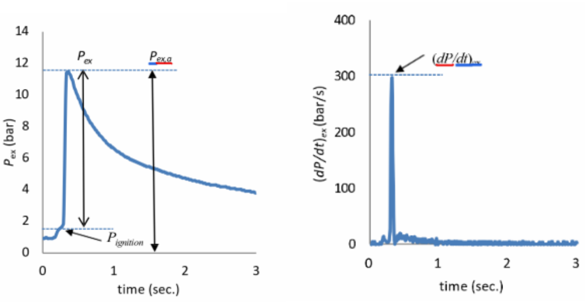


Fig. 2. Explosion chamber 20-L [14].



(a) Explosion pressure (*P*ex) vs. time (b) Rate of pressure increase $(dP/dt)_{ex}$ vs. time

Fig. 3. Typical graph of pressure changes inside 20 L chamber [14].

In Fig. 3, Pex,a denotes the maximum absolute pressure inside the chamber during a single test, Pignition the absolute pressure in the chamber at the time of ignition, Pex the pressure difference between Pex,a and Pignition, and $(dp/dt)_{ex}$ is the highest rate of pressure increase in a single test. The MEC and Kst values were determined using Equations 1 and 2, respectively.

$$PR = \frac{P_{ex,a} - \Delta P_{ignitor}}{P_{ignition}} \tag{1}$$

$$Ks_t = (dP/dt)_{max} V^{\frac{1}{3}} \tag{2}$$

where ΔPignitor is the pressure increase in the chamber caused by the ignitor, relative to the atmospheric pressure. A dust cloud explosion occurs (MEC) when PR > 2. V is the volume of the explosion test chamber (m^3).

3 Results and discussion

3.1 Rubber Wood Charcoal

The MEC was determined by plotting the PR values for each concentration of rubberwood charcoal dust. The results are presented in Fig. 4 and Fig. 5, representing the pure condition and the mixed condition with ESP dust, respectively.

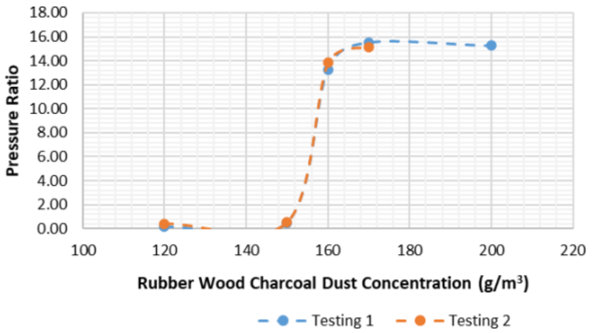


Fig. 4. Plotting pressure ratio to rubber wood charcoal dust concentration under pure condition

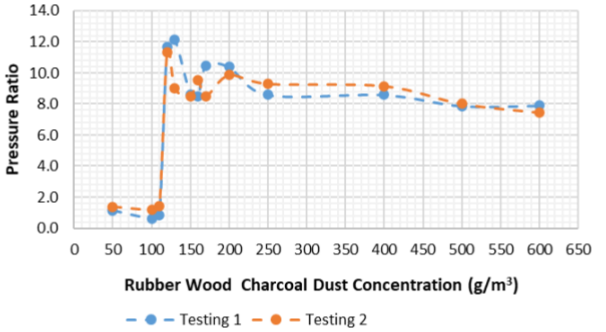


Fig. 5. Plotting pressure ratio to rubber wood charcoal dust concentration mixed with ESP dust

In pure conditions (Fig. 4), PR exceeding 2 at concentrations ≥155 g/m^3, its mean MEC was determined as 155 g/m^3. When mixed with 50 g/m^3 ESP dust, MEC decreased to 115 g/m^3 (Figure 5), indicating heightened sensitivity (PR >2 starting at 120 g/m^3, peaking at 3.2 at 600 g/m^3). The determination of the Kst value was conducted by plotting the maximum rate of pressure rise ($(dP/dt)_{max}$) for each dust concentration (Fig. 6 and Fig. 7).

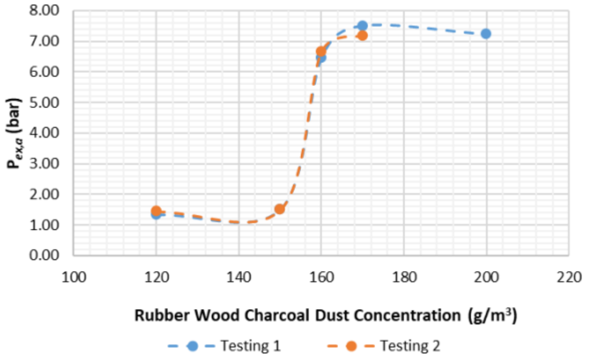


Fig. 6. Plotting rate of pressure rise to rubber wood charcoal dust concentration under pure condition.

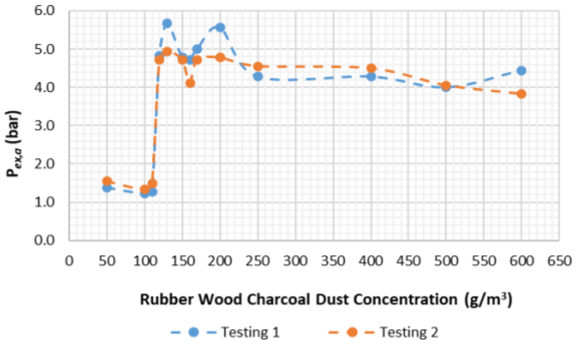


Fig. 7. Plotting rate of pressure rise to rubber wood charcoal dust concentration mixed with ESP dust.

For the pure conditions, $(dP/dt)_{max}$ reached 128 bar/s at optimal concentrations, yielding Kst = 34.8 bar·m/s (Fig. 6). Rate of pressure rise increased nonlinearly with concentration, from 50 bar/s at 120 g/m^3 to 128 bar/s at 200 g/m^3. When mixed with 50 g/m^3 ESP dust, $(dP/dt)_{max}$ escalated to 273 bar/s at higher concentrations, resulting in Kst = 74.14 bar·m/s (Figure 7). The rate of pressure rise plot showed a steeper incline post-MEC, from 100 bar/s at 110 g/m^3 to 273 bar/s at 600 g/m^3, suggesting ESP dust enhances flame propagation.

3.2 Coconut Shell Charcoal

The same tests were conducted on coconut shell charcoal dust samples under both pure conditions and conditions mixed with ESP dust. Compared to ΔPignitor, no significant pressure rise was observed under pure conditions across the concentration range of 400 – 2000 g/m^3 (Fig. 8), indicating non-explosible behaviour.

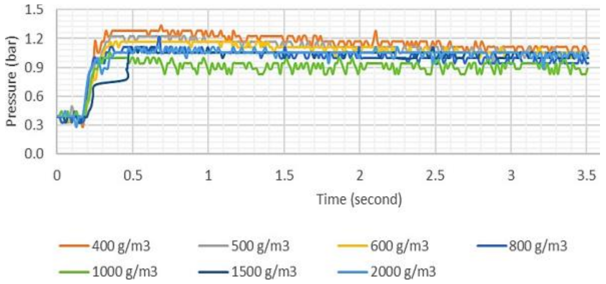


Fig. 8. Pressure rise of pure coconut shell charcoal.

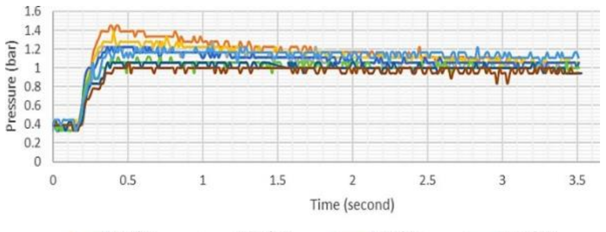


Fig. 9. Pressure rise of pure coconut shell charcoal mixed with ESP dust.

With the addition of ESP dust, the concentration range was extended to 100 – 2000 g/m^3 (Fig. 9). The results still showed no explosion, confirming inertness even with contaminants.

3.3 Palm Shell Charcoal

A distinctive characteristic of this sample is the absence of a significant pressure increase, indicating that no explosion occurred (Fig. 10 and Fig. 11).

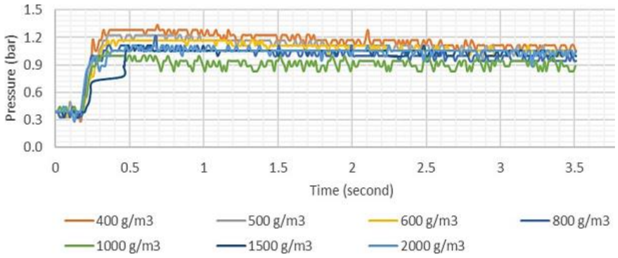


Fig. 10. Pressure rise of pure palm shell charcoal.

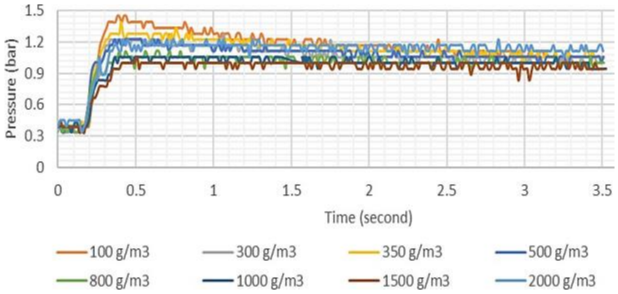


Fig. 11. pressure rise of palm shell charcoal mixed with ESP dust.

Across a wide concentration range (100 g/m³ – 2000 g/m³), the maximum pressure generated by the sample reached only 1.5 bar, equivalent to the pressure produced by the ignitor. This indicates that no explosion occurred in the palm shell charcoal dust sample.

4 Discussion

MEC of biomass samples compared to MEC of some coal samples, the results are shown in Fig. 12.

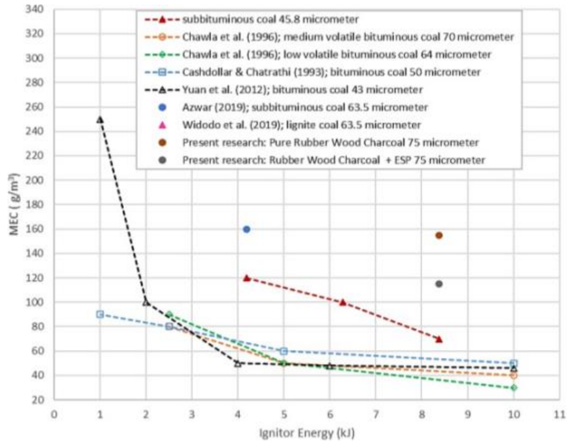


Fig. 12. Comparison of MEC biomass samples with coal samples.

At higher ignitor energies, the MEC of rubberwood charcoal dust exceeds that of bituminous coal dust, suggesting lower reactivity. This may be caused by the condition of biomass samples that have been in the form of charcoal, which some combustible gases (volatile matter) have been reduced. The following Table 1 is a summary of the explosibility tests on various biomass samples.

Table 1. Explosibility parameters of various biomass samples.

No	Sample Type	*Explosibility Parameters*			
		Minimum Explosible Concentration (g/m³)	*Maximum Explosion Pressure* (bar)	*Explosibility Index* (bar.m/s)	*Dust Explosion Class (OSHA, 2009)*
1	Rubber Wood Charcoal	155	6.3	34.8	St 1 (Weak Explosion)
2	Rubber Wood Charcoal + ESP	115	4.3	74.14	St 1 (Weak Explosion)
3	Coconut Shell Charcoal	Not exploded			No explosion
4	Coconut Shell Charcoal + ESP	Not exploded			No explosion
5	Palm Shell Charcoal	Not exploded			No explosion
6	Palm Shell Charcoal + ESP	Not exploded			No explosion

Among the biomass samples tested (Table 1), only coconut shell charcoal exhibited explosibility. The presence of ESP dust influenced the risk factors in two effects: it increased the probability of an explosion by reducing the MEC value, and it increased the severity of the explosion by raising the $(dP/dt)_{max}$. According to OSHA classification [15], coconut shell charcoal dust falls under the category of a weak explosion

5 Conclusion

The results highlight that rubber wood charcoals pose minimal explosion hazards (weak St-1 classifications), with MECs significantly higher than coal, supporting their use as safer alternatives in nickel processing. Non-explosible shell charcoals offer the safest option, although operational factors such as dust concentration and ventilation must still be managed to prevent risks. A limitation in the implementation of biomass charcoal is that its use has been validated only through laboratory-scale testing. Future studies should validate these findings in full-scale kilns. Overall, biomass charcoals align with sustainable metallurgy goals by reducing both environmental impact and safety concerns.

References

1. Ministry of Finance Republic of Indonesia and Asian Development Bank, "Innovate Indonesia Unlocking Growth Through Technological Transformation March," 2020.
2. P. IEA, "World energy outlook 2022," Paris, France: International Energy Agency (IEA), 2022.
3. J. W. Anthony, R. A. Bideaux, K. W. Bladh, and M. C. Nichols, Handbook of mineralogy, 1. Mineral Data Publ., 2001.
4. J. Emsley, Nature's building blocks: an AZ guide to the elements. Oxford University Press, 2011.
5. International Nickel Study Group, "The World Nickel Factbook," 2024.
6. A. E. M. Warner, C. M. Diaz, A. D. Dalvi, P. J. Mackey, and A. V Tarasov, "JOM world nonferrous smelter survey, part III: Nickel: Laterite," Jom, **58**, no. 4, pp. 11 – 20, 2006.
7. B. C. Pamungkas and H. Hadi, "Potential of biomass utilization in rotary kiln of nickel processing plant," in IOP Conference Series: Materials Science and Engineering, IOP Publishing, 2019, p. 012006.

8. R. K. Eckhoff, “Dust explosions: Fundamentals,” in Methods in Chemical Process Safety, **3**, Elsevier, 2019, pp. 7 – 32.
9. Chris Cloney, “Combustible Dust Incident Report,” 2023.
10. M. S. Ramadhani, I. Mufidah, and A. Kusnayat, “Evaluasi Iklim Keselamatan Menggunakan Kuisioner Nosacq-50 Pada Tambang Nikel Pt. Sumber Bumi Putera,” eProceedings of Engineering, **12**, no. 2, pp. 2922 – 2926, 2025.
11. T. Bhattacharya, A. Khan, T. Ghosh, J. T. Kim, and J.-W. Rhim, “Advances and prospects for biochar utilization in food processing and packaging applications,” Sustainable Materials and Technologies, **39**, p. e00831, 2024.
12. ASTM International, “Test Method for Minimum Explosible Concentration of Combustible Dusts,” Jun. 01, 2022, ASTM International, West Conshohocken, PA. doi: https://doi.org/10.1520/E1515-14R22.
13. ASTM International, “Test Method for Explosibility of Dust Clouds,” Dec. **15**, 2019, ASTM International, West Conshohocken, PA. doi: https://doi.org/10.1520/E1226-19.
14. N. P. Widodo et al., “The study of coal dust minimum explosion concentration of subbituminous coal,” Process Safety and Environmental Protection, **177**, pp. 1387 –1392, 2023.
15. OSHA, “Hazard communication guidance for combustible dusts,” US Department of Labor, Occupational Safety and Health Administration, Washington, DC, USA, 2009.