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The effect of activated carbon on the adsorption of coconut shell liquid smoke on the coagulation process of latex clone PB 260

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ARTICLE INFO

Article history:

Received: 09 March 2026
Received in revised form: 22 April 2026
Accepted: 22 April 2026

Keywords:

Adsorption;
coagulant;
clone PB 260
latex

ABSTRACT

This study investigated the effectiveness of coconut shell–derived liquid smoke (CLS) and activated carbon–treated liquid smoke (CLSC) as natural coagulants for natural rubber latex clone PB 260, compared with 2% formic acid (FA). Rubber quality was assessed based on Total Solid Content (TSC), Dry Rubber Content (DRC), initial plasticity (Po), Plasticity Retention Index (PRI), ash content, dirt content, volatile matter, and Mooney viscosity according to the SNI 06-1903-2017 standard for Indonesian Standard Rubber (SIR 20). Experiments were conducted using fresh latex from clone PB 260 under the D3 tapping system, with 150 mL of latex treated with each coagulant. FA produced the fastest coagulation time (3.39 min), while CLS and CLSC required 4.37 and 4.29 min, respectively. CLS showed the highest DRC (15.33%), whereas CLSC provided better rubber stability with the highest PRI (85.83%) and high Mooney viscosity. All coagulants met SIR 20 limits for ash, dirt, and volatile matter, although Po values remained below the standard.

1. Introduction

Coconut shell, the hardest part of the coconut fruit, has significant economic value and has been widely utilized in various industrial applications. Traditionally, coconut shells are used as raw materials for activated carbon, fuel, construction materials, handicrafts, and other value-added products [1,2]. The large availability of coconut shell biomass in tropical countries provides substantial opportunities for sustainable biomass utilisation. However, improper disposal or open burning of coconut shells may cause environmental pollution and represents an inefficient use of biomass resources.

One promising approach to valorising coconut shell waste is through the production of liquid smoke via pyrolysis. Liquid smoke is produced by condensing the smoke generated during biomass thermal decomposition under limited oxygen conditions. This process produces a liquid rich in organic compounds such as phenols, organic acids, and carbonyl compounds, which exhibit antimicrobial, antioxidant, and coagulating properties [3]. Due to its high phenolic and acidic content, coconut shell–derived liquid smoke has attracted increasing attention as a natural coagulant in rubber latex processing.

Natural rubber latex coagulation is a critical stage in rubber processing that determines the quality of the final rubber product. Conventional coagulation typically uses chemical coagulants such as formic acid and acetic acid because of their rapid coagulation performance and high efficiency [4]. Nevertheless, excessive use of conventional chemical coagulants may lead to environmental pollution, wastewater contamination, and health risks for plantation workers. Therefore, the development of environmentally friendly and sustainable coagulant alternatives has become an important research focus in the rubber industry.

Recent studies have explored the utilization of biomass-derived liquid smoke as an alternative coagulant for natural latex processing. Liquid smoke derived from coconut shell contains high levels of phenolic compounds that can destabilise latex colloidal particles and accelerate coagulation [5]. In addition, purification of liquid smoke using activated carbon adsorption can remove undesirable compounds such as tar and polycyclic aromatic hydrocarbons, thereby improving the purity and effectiveness of liquid smoke for industrial applications [6]. Previous studies reported that liquid smoke treated with adsorption processes can achieve coagulation efficiencies of up to 90–95% and produce rubber with quality characteristics that meet Indonesian National Standard (SNI) requirements [7].

Despite these promising results, several challenges remain in optimizing the production and application of coconut shell–derived liquid smoke as a latex coagulant. Most previous

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http://dx.doi.org/10.20527/k.v15i1.25704

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studies mainly focused on the chemical composition or antimicrobial properties of liquid smoke, while limited research has investigated the combined effect of coconut shell–derived liquid smoke and activated carbon adsorption treatment on the quality parameters of natural rubber. Furthermore, comparative studies between purified liquid smoke and conventional chemical coagulants are still limited.

Therefore, this study aims to evaluate the performance of coconut shell–derived liquid smoke and activated-carbon-treated liquid smoke as natural coagulants in the coagulation of natural rubber latex. Unlike previous studies that mainly focused on the use of liquid smoke as a latex coagulant, this study investigates the effect of activated carbon adsorption on the purification of coconut shell liquid smoke and its impact on key rubber quality parameters, including plasticity retention index (PRI), Mooney viscosity, ash content, dirt content, and volatile matter. The findings of this study are expected to contribute to the development of environmentally friendly and sustainable coagulation technologies for the natural rubber industry.

2. Materials and Methods

This study examined the use of coconut shell–derived liquid smoke and a combination of coconut shell–derived liquid smoke with activated carbon as coagulants in the latex coagulation process, as well as their effects on the characteristics of natural rubber from the PB 260 clone.

The research was conducted at the Diagnostic Laboratory of PT Perkebunan Nusantara VII, Way Berulu Unit, Pesawaran, Indonesia. Latex samples were collected from the rubber plantation located in Afdeling 1 of the Way Berulu Unit. The rubber trees used in this study belonged to the PB 260 clone and were tapped using the D3 tapping system, which involves latex harvesting every three days.

The timing of latex sampling was determined based on the optimal tapping cycle to ensure that the collected latex was in optimal physiological condition, thereby improving the reliability and accuracy of the experimental results. Fresh latex obtained from the plantation was immediately transported to the laboratory for the coagulation experiments using the selected coagulants.

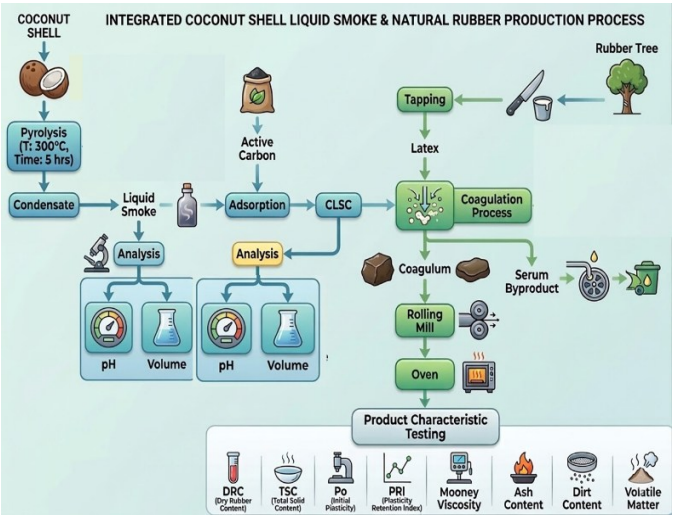

Fig. 1. Natural rubber coagulation method scheme using coconut shell–derived liquid smoke with activated carbon adsorption

The overall research procedure, including latex collection, coagulation treatment, and characterization of the resulting rubber, is illustrated in the research flowchart shown in Fig. 1.

2.1. Coagulant preparation

The coagulant used in this study was coconut shell–derived liquid smoke obtained from the pyrolysis of coconut shells. Initially, 75 mL of liquid smoke was measured using a graduated cylinder, and its pH was determined using a calibrated pH meter.

To obtain purified liquid smoke, activated carbon was added to the liquid smoke, and the mixture was allowed to stand for 24 h to facilitate the adsorption of tar fractions and other undesirable constituents. The suspension was then filtered through filter paper to separate the activated carbon from the treated liquid smoke, after which the pH of the filtrate was measured and recorded. The treated liquid smoke was designated as CLSC and used as the modified coagulant, whereas the untreated liquid smoke was designated as CLS and used as the reference coagulant. In this study, the effect of the adsorption treatment was evaluated primarily through changes in pH and coagulation-related performance parameters. More detailed compositional characterization, including GC-MS, total phenolic content, and quantitative acidity analyses before and after adsorption, was not included in the present experimental design and should be addressed in future studies to further elucidate the underlying adsorption mechanism.

2.2. Latex sampling process

Fresh natural rubber latex was obtained from rubber trees of the PB 260 clone through the tapping process. Approximately 600 mL of latex was collected using a clean latex collection cup. The latex was then filtered through a fine mesh filter to remove impurities such as bark particles and other foreign materials before further processing.

2.3. Latex coagulation process

An empty beaker was first weighed using an analytical balance. Subsequently, 150 g of fresh latex was placed into the beaker. The coagulant was added to the latex at a 1:2 (v/v) ratio, followed by gentle stirring using a glass stirring rod to ensure homogeneous mixing [8].

The coagulation time was recorded using a stopwatch from the moment the coagulant was added until the latex completely coagulated. After coagulation, the rubber coagulum was separated from the serum and transferred into a measuring cup. The pH and color of the resulting serum were measured and recorded to evaluate the characteristics of the coagulation process.

2.4. Rubber characteristic test

Rubber quality was evaluated through several physicochemical parameters, including Total Solid Content (TSC), Dry Rubber Content (DRC), initial plasticity (Po), Plasticity Retention Index (PRI), ash content, dirt content, and volatile matter. These analyses were conducted to assess the physical properties, purity, and durability of the rubber samples.

Mooney viscosity was determined according to the SNI 8384:2017 standard. Ash content was determined according to SNI ISO 247:2012, while dirt content analysis followed SNI 8383:2017. The volatile matter was measured based on SNI 8356:2017. Rubber durability was evaluated using initial plasticity (Po) and the Plasticity Retention Index (PRI) in accordance with SNI ISO 2013 [9,10,11,12,13].

3. Results and Discussion

3.1. Effect of coagulant type on latex coagulation pH

Coagulants are widely used in natural rubber processing to accelerate the destabilization of latex colloids and promote coagulation. The coagulation process occurs mainly due to a decrease in the pH of latex, which neutralizes the negative charges on the surface of rubber particles, thereby reducing electrostatic repulsion and allowing particle aggregation. Therefore, the pH value of a coagulant plays a crucial role in determining its effectiveness during the latex coagulation process. Measurement of pH also provides information about the acidity level and the concentration of hydrogen ions (H^+) present in each coagulant solution.

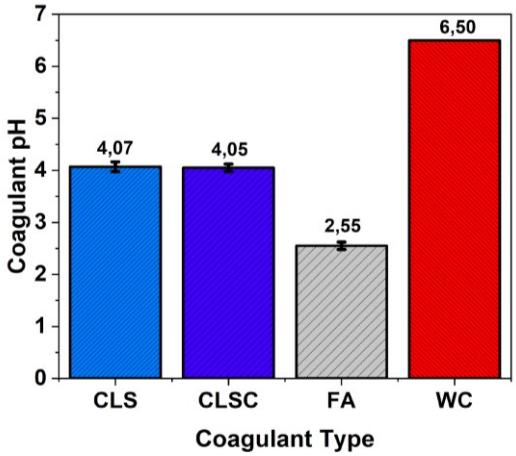

Fig. 2. Effect of coagulant type on latex coagulation pH

The effect of different coagulant types on the pH of latex during the coagulation process is presented in Fig. 2. As shown in Fig. 2, significant differences in pH values were observed among the coagulants used in this study. The highest pH value (6.50) was obtained for WC, while the lowest (2.55) was recorded for the conventional chemical coagulant containing 2% formic acid (FA). Meanwhile, the coconut shell–derived liquid smoke without adsorption treatment (CLS) had a pH value of 4.07, which decreased slightly to 4.05 after 24 hours of activated carbon adsorption treatment (CLSC).

The very low pH observed in the formic acid treatment indicates strong acidity, which rapidly destabilises latex particles and promotes coagulation. Formic acid is commonly used as a conventional chemical coagulant in rubber processing because it provides a high concentration of hydrogen ions that neutralise the negative charges on latex particles, causing rapid aggregation and coagulum formation [13]. However, if not properly controlled, the excessive acidity of conventional chemical coagulants may lead to deterioration in rubber quality and environmental concerns.

In contrast, the liquid smoke coagulants (CLS and CLSC) exhibited moderate acidity, with pH values around 4.0. Liquid smoke produced from coconut shell pyrolysis contains various compounds, particularly organic acids, phenolic compounds and carbonyl derivatives. These organic acids contribute to the acidic properties of liquid smoke, enabling it to function as a natural latex coagulant [14,15].

Activated carbon pretreatment may influence the chemical composition of liquid smoke. However, because no compositional analysis was performed in this work, the small pH difference between CLS and CLSC is interpreted only as an indirect indication that adsorption may have modified the coagulant composition to a limited extent.

The relatively higher pH observed in WC indicates that this coagulant is less acidic and therefore less effective at rapidly destabilising latex particles. Effective latex coagulation typically occurs within a pH range of approximately 4–5, where the protective protein layer surrounding rubber particles becomes unstable and aggregation can occur [17,18,19,20]. Therefore, CLS and CLSC, which fall within this pH range, have the potential to function as environmentally friendly, natural coagulants for latex processing.

These results demonstrate that the type of coagulant significantly influences the pH conditions during latex coagulation. Natural coagulants, such as coconut shell–derived liquid smoke, offer a moderate level of acidity that is suitable for latex coagulation and could potentially reduce the environmental impact associated with synthetic conventional chemical coagulants.

3.2 *Effect of coagulant type on latex serum pH*

Coagulants play a crucial role in accelerating the coagulation of natural rubber latex by reducing its pH. Coagulation occurs when acidic compounds reduce the pH to a level at which the electrostatic stability of the rubber particles is disrupted. As discussed previously, latex particles are stabilzed by negatively charged proteins and phospholipids. However, when the pH decreases, these stabilising layers lose their charge, causing the particles to aggregate and form a rubber coagulum. Consequently, the pH of the latex serum after coagulation reflects the effectiveness with which the coagulant destabilises the latex colloidal system.

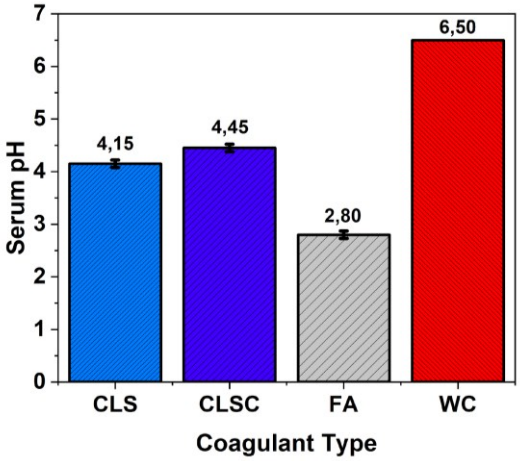

Fig. 3. Effect of coagulant type on latex coagulation Serum pH

Fig. 3 shows the effect of different coagulant types on the pH of latex serum during coagulation. As Fig. 3 illustrates, the type of coagulant significantly influences the serum pH

obtained after coagulation. The highest serum pH value (6.50) was observed in WC, indicating a very weak acidic environment. In contrast, the lowest pH value was obtained using the conventional chemical coagulant containing 2% formic acid (FA), producing a pH value of 2.80. Meanwhile, natural coagulants derived from coconut shell–derived liquid smoke exhibited intermediate acidity levels, with pH values of 4.15 and 4.45 for CLS and CLSC, respectively.

The low pH value observed in the formic acid treatment confirms the strong acidic nature of this coagulant. It is widely used in the rubber industry because it rapidly lowers the pH of latex to the isoelectric point of rubber particles (approximately pH 4.0–5.0), which leads to destabilisation and rapid coagulation. However, if not properly controlled, excessive acidity may lead to overly rapid coagulation and negatively affect certain physical properties of the rubber [21, 22].

In contrast, the liquid smoke coagulants (CLS and CLSC) exhibited moderate acidity, with serum pH values ranging from 4.15 to 4.45. Liquid smoke produced from the pyrolysis of coconut shells contains various chemical components, including organic acids (such as acetic acid and formic acid), phenolic compounds, carbonyl compounds and other oxygenated organic substances. These organic acids contribute to the acidity of liquid smoke, enabling it to function as a natural coagulant for latex [14].

Activated carbon pretreatment may also have affected the serum pH generated during coagulation. The marginally higher serum pH observed for CLSC relative to CLS may reflect the partial removal of acidic or reactive constituents during pretreatment, in agreement with interpretations reported in earlier studies [16,23]. Nevertheless, this explanation remains inferential because neither quantitative acidity determination nor detailed compositional characterization was conducted in the present work.

In addition to removing acidic compounds, the interaction between liquid smoke and latex proteins during coagulation also causes changes in serum pH. During coagulation, proteins and other non-rubber components present in the latex migrate into the serum phase. These components can act as buffering agents, slightly moderating the acidity of the system and thereby influencing the final serum pH.

The relatively high serum pH observed in WC indicates that this coagulant provides insufficient acidity to effectively destabilise latex particles. Generally, effective latex coagulation occurs when the pH decreases to around 4–5, corresponding to the isoelectric point of latex proteins. Within this pH range, electrostatic repulsion between rubber particles is minimised, enabling aggregation and coagulum formation [19].

3.3. Effect of coagulant type on latex coagulation time

Coagulation time is the duration required for latex to transform from a stable colloidal dispersion into a solid rubber coagulum following the addition of a coagulant. This parameter is important because it reflects the effectiveness with which a coagulant destabilises the latex colloidal system. Natural rubber latex consists of rubber particles dispersed in an aqueous serum phase and stabilised by negatively charged proteins and phospholipids on the particle surface. Adding acidic coagulants reduces the system's pH, neutralising the surface charges and promoting particle aggregation. This ultimately leads to coagulation [13].

The effect of different coagulant types on latex coagulation time is presented in Fig. 4. As Fig. 4 shows, coagulation time varies significantly depending on the type of coagulant used. The fastest coagulation occurred when 2% formic acid (FA) was used as the conventional chemical coagulant, with a coagulation time of 3.39 minutes. By contrast, natural coagulants derived from coconut shell–derived liquid smoke produced slightly longer coagulation times: 4.37 minutes for CLS and 4.29 minutes for CLSC. Meanwhile, the absence of a coagulant (WC) resulted in a very slow coagulation process, taking approximately 40 minutes.

The rapid coagulation observed with formic acid is due to its strong acidity and high concentration of hydrogen ions (H^+). These quickly reduce the pH of the latex, destabilising the protective protein layer surrounding the rubber particles. These conditions promote faster aggregation and coagulum formation. Formic acid is therefore widely used in the rubber industry due to its effectiveness in inducing latex coagulation [13,24,25].

In contrast, coagulation times obtained using coconut shell–derived liquid smoke coagulants (CLS and CLSC) were slightly longer. Liquid smoke contains various organic compounds, including organic acids, phenolic compounds and carbonyl compounds, which are formed during the pyrolysis of lignocellulosic materials, such as coconut shells. Among these components, organic acids — particularly acetic acid and formic acid — play an important role in reducing latex pH and initiating coagulation [14,26].

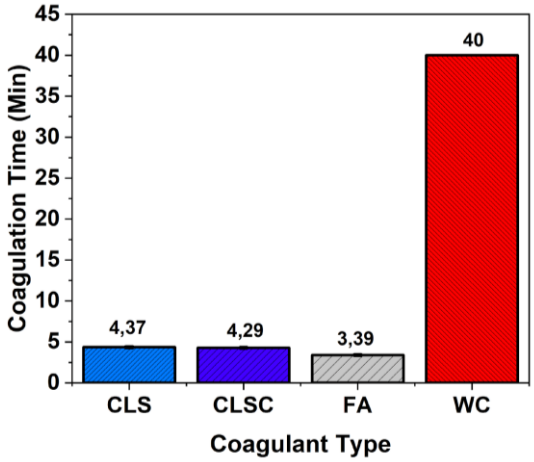

Fig. 4. Effect of coagulant type on latex coagulation time

Activated carbon pretreatment may also have influenced coagulation behavior; however, its effect appeared to be limited under the present experimental conditions. CLSC showed only a slightly shorter coagulation time than CLS (4.29 vs. 4.37 min), indicating that the adsorption step did not produce a substantial change in the acidity-driven coagulation kinetics. Accordingly, the role of activated carbon pretreatment in accelerating coagulation should be regarded as modest in the context of the present results.

The extremely long coagulation time observed in the WC treatment suggests that latex remains relatively stable in the absence of sufficient acidic compounds. Without the addition of a coagulant, natural destabilisation of the latex occurs slowly due to microbial activity or gradual chemical changes within the latex serum. This explains why the coagulation time is

significantly longer, at around 40 minutes.

The results demonstrate that the coagulation time of latex is strongly influenced by the acidity and chemical composition of the coagulant used. Those with higher acidity provide more hydrogen ions, accelerating the neutralisation of negatively charged latex particles and promoting faster aggregation and coagulation. While conventional chemical coagulants such as formic acid produce the fastest coagulation, natural coagulants derived from coconut shell–derived liquid smoke still provide relatively rapid coagulation and therefore show promise as an environmentally friendly alternative for latex processing.

3.4. Effect of coagulant type on dry rubber content (DRC)

Dry Rubber Content (DRC) is a key parameter in the natural rubber industry, representing the percentage of solid rubber present in fresh latex. It is widely used to determine the commercial value of latex, establish quality standards and guide the appropriate use of chemicals when processing rubber products such as ribbed smoked sheets (RSS), crepe rubber and concentrated latex. Accurate DRC determination is essential for optimising rubber plantation productivity and ensuring transparency in latex trading between farmers and processing factories. Reliable DRC measurements help to reduce discrepancies in pricing and minimise potential economic losses in latex buying and selling transactions [27].

Fig. 5 presents the effect of different coagulant types on the DRC of latex. As Fig. 5 shows, the DRC values obtained from different coagulant treatments were relatively similar, although slight variations were observed. The highest DRC value was obtained using the CLS coagulant (15.33%), followed closely by formic acid (FA) at 15.31%. Meanwhile, the CLSC treatment showed a slightly lower DRC value of 14.30%. In contrast, the latex did not undergo proper coagulation in the treatment without coagulant (WC), resulting in an unmeasurable DRC value.

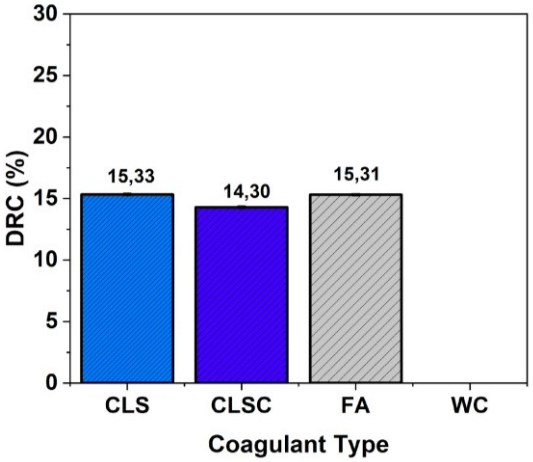

Fig. 5. Effect of coagulant type on DRC

The DRC values obtained for CLS and FA were broadly comparable, indicating that coconut shell-derived liquid smoke was capable of coagulating latex effectively under the experimental conditions applied. In the present study, DRC is interpreted as a process-related indicator reflecting coagulation performance and rubber recovery, rather than as a formal specification parameter for SIR 20 classification.

The slightly lower DRC observed for CLSC may suggest that activated carbon pretreatment altered certain coagulant characteristics that influenced rubber recovery during coagulation. However, because detailed compositional analyses, such as GC-MS, total phenolic content, and quantitative acidity measurements, were not conducted, the specific changes associated with the adsorption step could not be identified directly. Accordingly, the lower DRC of CLSC is more appropriately interpreted as a possible trade-off of the pretreatment process rather than as evidence of a consistently improved coagulant performance.

In addition to coagulant composition, the DRC value can be influenced by several factors, such as initial latex quality, dilution level, temperature and coagulation conditions. During coagulation, rubber particles aggregate to form a solid mass, while non-rubber components such as proteins, lipids and soluble minerals remain in the serum phase. An effective coagulant promotes efficient separation between the rubber phase and serum, resulting in higher DRC values [29].

3.5. Effect of coagulant type on initial plasticity (Po) and plasticity retention index (PRI)

Initial plasticity (Po) is an important parameter used to evaluate the natural rubber's inherent plasticity before any thermal or oxidative treatment. It is measured directly using a Wallace Plastimeter, reflecting the molecular weight and structural integrity of the rubber chains. Generally, higher Po values indicate better rubber quality and stronger polymer chains.

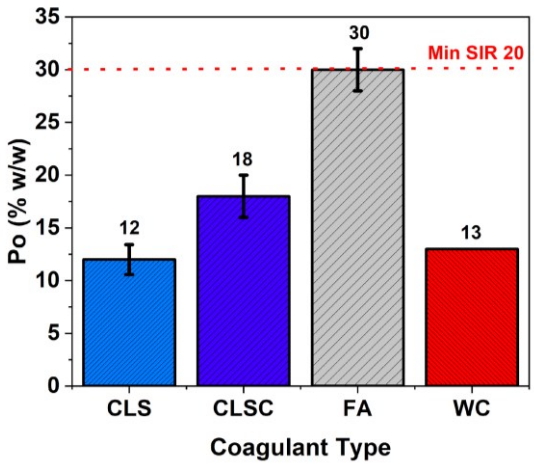

Fig. 6. Effect of coagulant type on Po

As shown in Fig. 6, the type of coagulant had a marked influence on the initial plasticity (Po) of the rubber samples. Among the coagulants evaluated, FA (formic acid) produced the highest Po value (30%), which satisfied the minimum requirement for Standard Indonesian Rubber (SIR) 20. In contrast, substantially lower Po values were obtained for CLS (12%), CLSC (18%), and WC (13%). These results indicate that, although coconut shell-derived liquid smoke demonstrated potential as a latex coagulant, its performance with respect to initial plasticity remained inferior to that of formic acid under the present experimental conditions. Accordingly, this represents an important limitation of the study, and CLS as well as CLSC cannot yet be regarded as direct substitutes for formic acid in applications where strict compliance with SIR 20 requirements is essential.

Previous studies have also reported that the choice of

coagulant strongly affects rubber plasticity. Using coconut shell-based materials, such as charcoal or liquid smoke derivatives, has been shown to affect coagulation behaviour and the resulting rubber properties. For instance, adding coconut shell charcoal has been shown to enhance Po values by improving latex coagulation efficiency and reducing impurities. Similarly, organic acids such as acetic acid have been shown to improve rubber plasticity by more effectively destabilising latex particles [30,31].

In addition to Po, the Plasticity Retention Index (PRI) is another important quality parameter used to evaluate the resistance of natural rubber to thermo-oxidative degradation. The PRI is determined by comparing the rubber's plasticity before and after accelerated ageing at 130 °C for 30 minutes, using a Wallace Plastimeter. Higher PRI values indicate greater resistance to oxidative degradation and improved durability during processing and storage [14].

As can be seen in Fig. 7, the type of coagulant had a significant influence on the PRI values of the rubber samples. The CLSC coagulant produced the highest value (85.83%), followed by CLS (83.22%) and FA (80.67%). All three treatments exceeded the minimum SIR 20 requirement of 40%, indicating good resistance to thermal oxidation. In contrast, the WC treatment produced the lowest PRI value (38.46%), failing to meet the SIR 20 standard.

The results indicate that, although FA provides better initial plasticity (Po), CLSC offers superior resistance to thermo-oxidative degradation, as reflected by its higher PRI values. Therefore, selecting the appropriate coagulant is crucial for determining the final quality characteristics of natural rubber.

The higher PRI values observed in CLS and CLSC may be attributed to the presence of phenolic compounds in coconut shell–derived liquid smoke. These compounds are known to possess natural antioxidant properties that can inhibit the oxidative degradation of rubber chains during heating. Additionally, the presence of activated carbon in the CLSC treatment may enhance rubber stability further by absorbing impurities and inhibiting oxidative reactions, thereby improving the rubber's plasticity retention [14, 29].

Conversely, the lower PRI value observed in the WC treatment suggests that the absence of antioxidant compounds may accelerate oxidative degradation during thermal exposure. This suggests that selecting appropriate coagulants affects not only coagulation efficiency, but also significantly influences the oxidative stability and long-term quality of natural rubber.

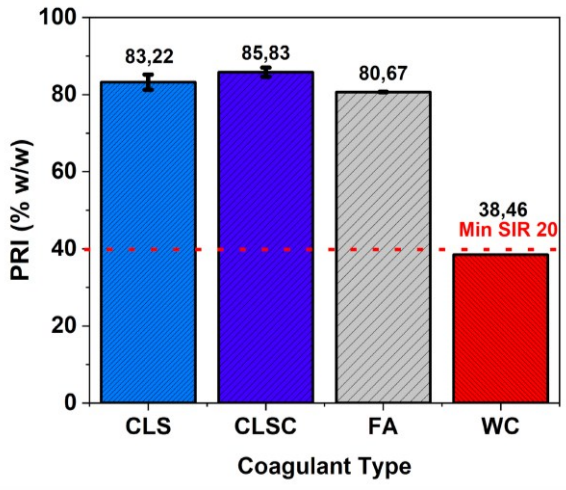

Fig. 7. Effect of coagulant type on PRI

The results demonstrate that CLSC is the most effective at maintaining rubber plasticity after thermal ageing, indicating its potential as an environmentally friendly coagulant for improving the quality of natural rubber.

3.6. Effect of coagulant type on Mooney viscosity

In addition to initial plasticity (Po) and the Plasticity Retention Index (PRI), Mooney viscosity is one of the key parameters used to evaluate the processing characteristics and molecular structure of natural rubber. It reflects the average molecular weight and degree of chain entanglement in rubber polymers, both of which strongly influence the rheological behaviour during processing. Generally, higher Mooney viscosity values indicate longer molecular chains and better rubber quality, while lower values suggest degradation of the polymer chains and reduced material performance [31, 32, 33].

Fig. 8 presents the Mooney viscosity values (ML 1+4, 100 °C) for the four coagulation methods: coconut shell–derived liquid smoke (CLS); liquid smoke treated with activated carbon adsorption for 24 hours (CLSC); formic acid (FA); and no coagulant (WC). The results show that rubber samples coagulated with CLS, CLSC and FA exhibited similar Mooney viscosity values of 67, 67.5 and 67.5, respectively. These values suggest that these coagulants effectively preserve the molecular structure of natural rubber during coagulation.

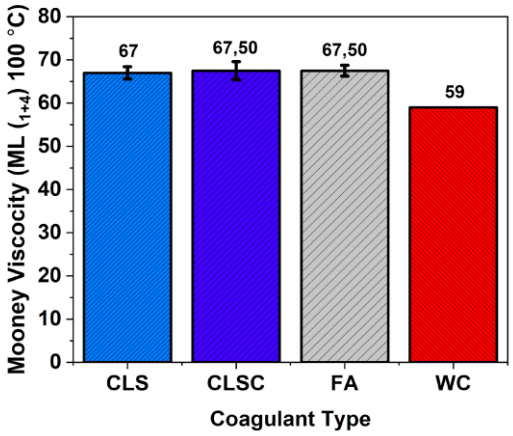

Fig. 8. Effect of coagulant type on Mooney viscosity

In contrast, the rubber sample produced without a coagulant showed a significantly lower value of 59. This decrease suggests the partial degradation of rubber polymer chains or a reduction in molecular weight, which may be caused by microbial activity or uncontrolled coagulation processes in the absence of a stabilising agent.

The comparable Mooney viscosity values obtained for CLS, CLSC, and FA indicate that coconut shell-derived liquid smoke was able to preserve rubber processability at a level similar to that achieved with formic acid under the experimental conditions employed. This finding suggests that the use of liquid smoke as a coagulant did not adversely affect the viscosity characteristics of the resulting rubber. Such behaviour is in line with previous studies reporting that liquid smoke constituents may contribute to limiting excessive rubber degradation during processing [4,5]. Nevertheless, because the chemical constituents potentially responsible for this effect were not quantitatively characterized in the present study, the underlying mechanism cannot yet be established with certainty.

From a comparative perspective, the results further show that the activated carbon pretreatment did not produce a substantial change in Mooney viscosity relative to untreated liquid smoke. Accordingly, the role of the adsorption step should be interpreted cautiously, namely as a selective pretreatment that may refine certain properties of the coagulant without necessarily leading to a pronounced improvement in viscosity-related performance.

3.7. Effect of coagulant type on ash content

Ash content is an important parameter used to evaluate the amount of inorganic residue present in natural rubber following combustion. This residue mainly originates from mineral elements such as potassium (K), magnesium (Mg), calcium (Ca) and sodium (Na), as well as other trace metals that may be present in the latex or introduced during processing. Ash may also derive from mineral compounds, such as silicates, and other inorganic contaminants. The ash content of natural rubber is usually analysed in accordance with Indonesian standards, such as SNI 06-1903-2000 and SNI 06-3730-1995, which are widely used for rubber quality control.

Fig. 9. illustrates the effect of different coagulant types on the ash content of natural rubber. The coagulants evaluated in this study were coconut shell–derived liquid smoke (CLS), liquid smoke treated with activated carbon adsorption for 24 hours (CLSC), formic acid (FA), and a control treatment without a coagulant (WC).

The results show that the lowest ash content, at 0.20% (w/w), was obtained using the FA coagulant. This was followed by CLS at 0.32% and CLSC at 0.76%. In contrast, the WC treatment produced the highest ash content at 1.08% (w/w), which exceeds the maximum limit of 1.0% (w/w) specified by the SIR 20 standard.

The lower ash content observed in FA-coagulated rubber may be due to coagulation being a more efficient and rapid process, which minimises the incorporation of inorganic impurities during rubber formation. Meanwhile, the relatively higher ash content observed in CLSC may be associated with residual inorganic components originating from the activated carbon used during the adsorption process. In the WC treatment, the absence of an effective coagulation agent can result in slower coagulation and increased contamination from environmental impurities, leading to higher ash content.

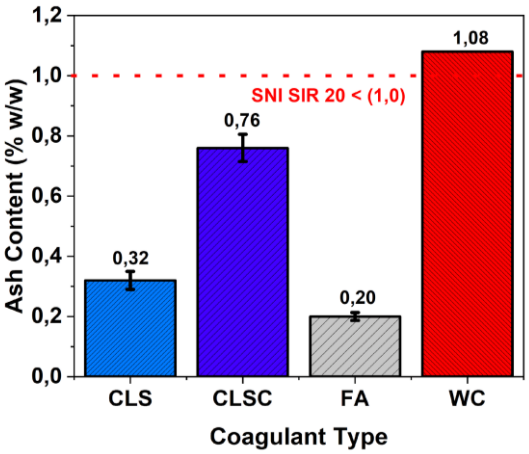

Fig. 9. Effect of coagulant type on ash content

These results confirm that selecting an appropriate coagulant is crucial for controlling inorganic contamination and ensuring compliance with industrial rubber standards. Similar findings were reported by Achmad et al. (2024), who emphasised that the ash content of natural rubber is significantly affected by the presence of inorganic residues introduced during coagulation and processing [20].

The results suggest that formic acid (FA) is the most effective coagulant for minimising ash content. However, CLS-based coagulants also produce acceptable levels of ash within the SIR 20 standard, indicating their potential as an environmentally friendly alternative.

3.8. Effects of coagulant type on dirt content

The dirt content of natural rubber is an important quality parameter representing the amount of non-rubber impurities that cannot pass through a 325-mesh sieve. These impurities may include soil particles, bark fragments, sand, coagulated proteins and other foreign materials introduced during the collection and processing of latex. High levels of dirt content can have a negative impact on the physical and dynamic properties of natural rubber, such as elasticity, resilience, and tensile strength. Furthermore, impurities can interfere with the vulcanisation process, resulting in defects in the final rubber products. Therefore, controlling impurity levels during coagulation and processing is essential for producing high-quality rubber.

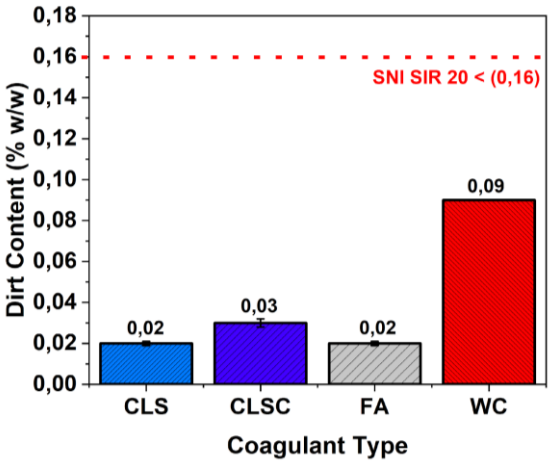

Fig. 10. Effect of coagulant type on dirt content

Fig. 10 shows the effect that different types of coagulant have on the dirt content of natural rubber. The coagulants evaluated in this study were coconut shell–derived liquid smoke (CLS), liquid smoke treated with activated carbon adsorption for 24 hours (CLSC), formic acid (FA) and a control treatment without a coagulant (WC).

The results show that rubber samples coagulated using CLS, CLSC and FA exhibited consistently low dirt content values ranging from 0.02% to 0.03% (w/w). These values are significantly lower than the maximum limit of 0.16% (w/w) specified by the SNI SIR 20 standard, indicating that these coagulants are effective in producing cleaner rubber with minimal contamination.

In contrast, rubber produced without a coagulant showed a much higher dirt content of 0.16% (w/w), close to the SIR 20 standard's maximum limit. The higher impurity level in the WC treatment may be due to slower and less controlled coagulation,

increasing the likelihood of contamination from environmental particles during rubber formation.

The low dirt content observed in both the CLS and CLSC treatments indicates that liquid smoke-based coagulants were able to promote latex coagulation without substantially increasing contamination by extraneous particulate matter. The slightly lower dirt content obtained with CLSC may suggest a beneficial effect of the activated carbon pretreatment on improving coagulant cleanliness. However, this interpretation should be made with caution, as the specific impurities removed during the adsorption process were not quantitatively characterized in the present study.

These results highlight the importance of using appropriate coagulants to reduce impurity levels in natural rubber. CLS and CLSC in particular show promising potential as alternative coagulants that can maintain low dirt content while supporting more environmentally friendly rubber processing practices.

3.9. Effect of coagulant type on volatile matter

The content of volatile matter is an important parameter used to determine the amount of moisture, serum and other volatile substances present in natural rubber. High levels of volatile matter can negatively affect the quality of rubber, as excessive moisture and residual serum can accelerate microbial degradation and reduce storage stability. Therefore, an effective drying process is required to minimize these volatile components and ensure compliance with industrial quality standards.

In this study, rubber samples were dried in an oven at 100 °C for two hours, which was effective in reducing the volatile components in the rubber. This process facilitates the evaporation of moisture, residual serum and other low-molecular-weight compounds, thereby improving the rubber's stability and quality. The reduction in volatile matter indicates that the applied drying method is capable of producing rubber suitable for further processing.

Fig. 11 presents the volatile matter (% w/w) of rubber coagulated using different coagulants: coconut shell–derived liquid smoke (CLS), liquid smoke treated with activated carbon adsorption (CLSC), formic acid (FA) and no coagulant (WC). The results show that the volatile matter for CLS, CLSC and FA was 0.43%, 0.45% and 0.29% respectively. All of these values are well below the maximum limit of 0.80% specified by the SNI SIR 20 standard, indicating that the rubber produced using these coagulants meets the required quality criteria.

Among the tested coagulants, FA produced the lowest volatile matter, suggesting that this coagulant facilitates faster and more complete latex coagulation, thereby reducing the amount of trapped serum and moisture in the rubber matrix. In contrast, the WC treatment showed a higher volatile matter of 0.65%, although this value still remained within the acceptable SIR 20 limit. The relatively higher value observed in the WC sample may be attributed to slower and less controlled coagulation, which allows more moisture and serum to remain trapped within the rubber structure.

These findings demonstrate that the selection of coagulant influences the volatile matter content of natural rubber. CLS and CLSC show comparable performance to FA in maintaining volatile matter within acceptable limits, indicating their potential as alternative coagulants for producing high-quality rubber, while supporting more environmentally friendly processing methods [29,33].

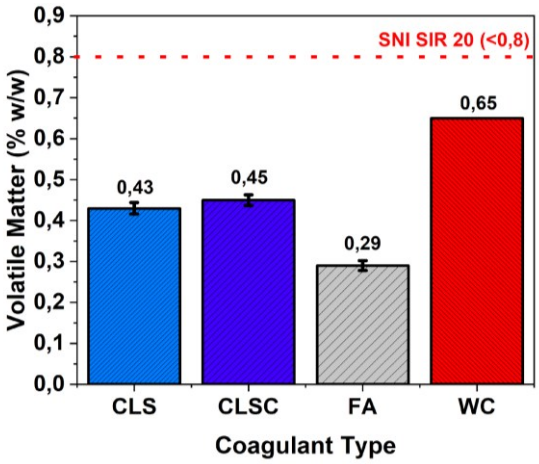

Fig. 11. Effect of coagulant type on volatile matter

3.10. Advantages and disadvantages of natural and conventional chemical coagulants

This study investigated the performance, advantages, and limitations of natural and conventional chemical coagulants used in the coagulation process of natural rubber latex, as summarised in Table 1. The coagulants tested included coconut shell–derived liquid smoke (CLS), coconut shell–derived liquid smoke treated with activated carbon adsorption (CLSC), and the conventional chemical coagulant formic acid (FA).

Table 1. Advantages and disadvantages of natural coagulants

	Coagulant Type		
Parameter	CLS	CLSC	Formic Acid
Compliance with SNI SIR 20	Ash, dirt, volatile matter, and PRI comply; Po does not comply; DRC is not a SIR 20 criterion	Ash, dirt, volatile matter, and PRI comply; Po does not comply; DRC is not a SIR 20 criterion	Complies with the evaluated SIR 20 specification parameters
Color of Coagulum	Dark brown	brown	white
Environmental impact	Environmentally friendly	Environmentally friendly	Less Environmentally friendly
Raw material availability	Seasonal	Seasonal	Available year-round

Overall, most of the rubber quality parameters obtained from all coagulants complied with the requirements of the SNI 06-1903-2017 standard for Indonesian Standard Rubber (SIR 20), particularly for ash content, dirt content, volatile matter, and PRI. However, the Po values obtained from the natural coagulants (CLS and CLSC) remained below the minimum requirement. In contrast, DRC is presented here as a coagulation/process indicator and not as a formal SIR 20 specification parameter.

From an environmental perspective, natural coagulants such as CLS and CLSC offer significant advantages. These materials are derived from renewable biomass resources and are safer for rubber plantation workers, making them more environmentally friendly and sustainable alternatives to conventional chemical

coagulants. Nevertheless, their application may be limited by the availability of raw materials, which often depend on seasonal agricultural residues such as coconut shells.

On the other hand, formic acid provides consistent availability throughout the year and exhibits faster coagulation performance. However, its use may pose environmental and safety concerns due to its corrosive and chemical nature. The coagulum produced in this study also showed differences in colour depending on the type of coagulant used, ranging from white for formic acid to brown and dark brown for the natural coagulants.

4. Conclusion

In conclusion, the type of coagulant has a significant impact on the physicochemical properties and overall quality of natural rubber. The results show that formic acid produced the highest initial plasticity (Po), which indicates the effective preservation of rubber's molecular structure during coagulation. However, liquid smoke-based coagulants, particularly CLSC, demonstrated superior performance in terms of the Plasticity Retention Index (PRI), suggesting enhanced resistance to thermo-oxidative degradation thanks to the presence of antioxidant phenolic compounds.

Furthermore, the Mooney viscosity values of rubber produced using CLS and CLSC were comparable to those obtained using formic acid, suggesting that liquid smoke can preserve the molecular weight and processing characteristics of natural rubber. Evaluation of other quality parameters, including ash content, dirt content and volatile matter, showed that most treatments met the SIR 20 standard requirements, confirming the suitability of these coagulants for industrial applications.

Overall, the results demonstrate that coconut shell–derived liquid smoke, particularly after activated carbon adsorption, has strong potential as a sustainable and environmentally friendly alternative coagulant for natural rubber processing. Using this biomass-based coagulant improves rubber stability and quality, and contributes to the development of greener rubber processing technologies.

5. Acknowledgments

The authors would like to thank PT Perkebunan Nusantara VII, Sub-Division 1 Unit Way Berulu, Pesawaran, Lampung. for providing the facilities that supported the successful completion of this research.

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