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SUSTAINABLE COCONUT OIL-BASED BIO-DAMPING FLUID IN MOTORCYCLE SUSPENSION SYSTEMS: EXPERIMENTAL EVALUATION OF DAMPING FORCE AND RIDE COMFORT

YOGA AHDIAT FAKHRUDI[1], DENI NUR FAUZI[2], PRADHANA KURNIAWAN[3], AGUS CHOIRUL ARIFIN[4], DITO OKY SYAHRIAL[5]

Abstract

This study aims to analyze the effect of adding bio coconut oil to 20W synthetic oil on the damping force characteristics and comfort of the rear shock absorber of a Honda Vario 125 cc motorcycle. The bio coconut oil uses a refined, bleached, and deodorized (RBD) type. The mixing percentage of bio coconut oil is 15%, 30%, and 45%. Damping force analysis uses a damper test with temperatures of 27°C and 31°C. The results of the damper test are used in the analysis of the damping coefficient calculation. The damping coefficient is then entered into the half-vehicle suspension model in Simulink MATLAB with sinusoidal excitation. Furthermore, an analysis of the RMS (Root Mean Square) acceleration value is carried out to assess comfort based on the ISO 2631 standard. The results show that 15% (15% coconut oil) produces the highest rebound force compared to other mixtures, namely 489.53 N at 27°C and 392.10 N at 31°C. The simulation results show that the 15% variation also produces an RMS acceleration that is almost equivalent to the original oil. Therefore,

[1] Automotive Engineering Technology, Politeknik Negeri Madiun, Madiun, Indonesia, email: yoga@pnm.ac.id, ORCID: 0009-0007-9581-4355

[2] Automotive Engineering Technology, Politeknik Negeri Madiun, Madiun, Indonesia, email: deninurfauzi@pnm.ac.id, ORCID: 0009-0004-4563-7715

[3] Automotive Engineering Technology, Politeknik Negeri Madiun, Madiun, Indonesia, email: pradhanakurniawan@pnm.ac.id, ORCID: 0000-0001-5643-1836

[4] Automotive Engineering Technology, Politeknik Negeri Madiun, Madiun, Indonesia, email: arifin07@pnm.ac.id, ORCID: 0000-0002-7909-3865

[5] Automotive Engineering Technology, Politeknik Negeri Madiun, Madiun, Indonesia, email: solusibimbel1@gmail.com, ORCID: 0009-0000-2385-9545

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a mixture of 15% coconut oil is proven to maintain comfort levels according to ISO 2631 standards.

Keywords: biococonut fluid; motorcycle suspension system; damping force characteristic; ride comfort analysis; viscosity stability

1. Introduction

Shock absorbers play a crucial role in the suspension system by attenuating vibrations resulting from road surface irregularities. [1, 2]. High vibrations can result in driving discomfort, safety issues, and component damage [3–5]. Generally, shock absorbers operate by transferring fluid through an orifice, so damping characteristics are heavily influenced by fluid properties such as viscosity and heat resistance [6, 7].

The fluid commonly used in shock absorbers is synthetic oil due to its good characteristics, such as resistance to various shocks, stronger damping, and relatively stable viscosity and temperature [8]. However, the use of this type of oil has drawbacks, including dependence on non-renewable natural resources, thermal degradation, and the impact of environmental pollution from its production process [9]. Therefore, alternative, more environmentally friendly and sustainable damping fluids are crucial.

Coconut oil is a potential candidate for a biolubricant due to its physical and chemical characteristics that are highly supportive for lubrication applications [10, 11]. Generally, coconut oil has a high saturated acid content, which makes it more stable against oxidation than other vegetable oils. The most dominant physical property of coconut oil is its high viscosity, which prevents drastic changes in viscosity with temperature [12]. This is crucial for shock absorber components because they absorb repeated vibrations that result in increased temperatures [13]. This ability relies heavily on fluids to maintain viscosity. One type of coconut oil that performs well is the RBD (Refined, Bleached, Deodorized) type, as it has undergone a refining process that removes impurities, pigments, and volatile compounds. However, under prolonged thermal exposure, degradation still occurs, as indicated by increased free fatty acids and peroxide values, which can affect long-term performance [14]. Therefore, the refining process plays a crucial role in improving oil quality and delaying degradation.

Research on coconut oil as a biolubricant has been frequently developed due to its combination of good tribological and rheological properties. A study by Adou et al (2025) analyzed the characterization of coconut oil and used cooking oil for biolubricant applications. The results showed that coconut oil provides friction reduction as a liquid additive and has an effect on tribological performance [15]. Furthermore, a study by Nurulita et al (2024) analyzed the synthesis of biolubricants with infrared to produce a mixture of coconut oil and Calophyllum

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inophyllum (UCOCI) oil. The resulting friction coefficients were 0.1091 to 0.071, all lower than SAE 15W-40 [16]. A more specific study related to fluids used in damping applications, namely a study by Bongfa et al (2024), examined the tribological characteristics of native altili oil (AO). AO oil was combined with a synergistic binary of commercial polar additives. The results show that AO oil provides better friction reduction, better flow, and lower surface roughness compared to commonly used oil fluids [17]. Furthermore, research by Piri et al (2024) examined the addition of SiO2 nanoparticles to biolubricants, which resulted in improved physicochemical properties. The biolubricant was sonicated for 2.5 hours and proven to improve fluid viscosity stability and long-term performance. This could lead to improved performance in fluid dynamic applications such as engine lubrication systems and mechanical damping systems [18]. In addition to studies evaluating the tribological characteristics of vegetable oils as lubricants, other studies have also examined the effect of hydraulic fluids and their additives on the dynamic friction properties of shock absorbers. Kato and Sasaki (2019) showed that the concentration and type of additives in hydraulic oil significantly affect the friction characteristics of sliding surfaces, especially under reciprocating conditions similar to the actual operation of shock absorbers, where friction forces often play a significant role in the dynamic behavior of the system [19].

Previous research has focused on the friction and wear characteristics of conventional coconut oil biolubricants. Specific consideration of their direct application to shock absorbers as damping fluids is still very limited, as damping fluids require viscosity stability and good damping characteristics. Furthermore, research on the comfort of shock absorber biolubricant fluids has not been conducted. Therefore, this study will fill this gap by analyzing coconut oil biolubricants in motor vehicle shock absorbers for damping force and comfort evaluation.

2. Materials and Methods

This research was conducted through two stages: experimentation and simulation. The first stage involved experimental testing to obtain damping data, which was then used as input for suspension model simulations in MATLAB Simulink.

2.1. Material

The shock absorber used in this study is from the factory standard for the Honda Vario 125 cc motorcycle (Astraotoparts Manufacturing, Indonesia) which can be seen in Figure 1. This shock absorber is a single action type, which means it is effective in dampening especially in the rebound phase of the suspension movement.

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Fig. 1. Rear shock absorber Honda Vario 125 cc

The fluid used in this study was SAE 20W static oil (Aspira, Astraotoparts, Indonesia) mixed with RBD coconut oil biolubricant (Mezzaluna, Mega Surya Mas, Indonesia). The fluid properties are shown in Table 1. The percentages of coconut oil added to the original shock absorber oil were 15 wt%, 30 wt%, and 45 wt%. The volume of SAE 20 W synthetic oil is 32 ml.

Tab. 1. Fluid properties of SAE 20W and RBD coconut oil

Fluid Parameters	SAE 20W Oil	RBD Coconut Oil
Density, kg/m^3	860–880	910–920
Dynamic Viscosity, Pa·s (40°C)	0.065–0.085	0.025–0.035
Flash Point, °C	220–230	300–330
Thermal Conductivity, W/m·K	0.13–0.15	0.17–0.20

2.2. Damping Test

Damping force testing was conducted using a damper tester (EMA Series, MTS Systems Corporation (MTS), USA) as shown in Figure 2. The testing was conducted with the SAE J1490 test standard [20]. This damping test system records force and displacement data digitally, allowing for accurate analysis of the shock absorber's dynamic performance under various conditions. In damping force testing, the shock absorber was tested without the coil spring to isolate its damping characteristics. A fixed frequency of 2 Hz was used, with operating temperatures set at 27°C (normal conditions) and 31°C (warm-up conditions).

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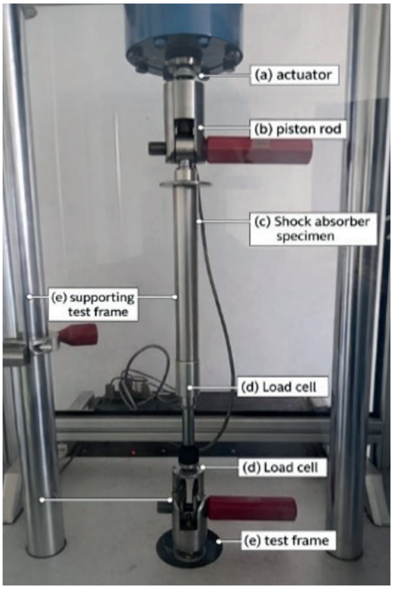

Fig. 2. Damping test

2.3. Ride Comfort

The damping force obtained from the experiment is then used to determine the damping coefficient (c_v). The damping coefficient value can be obtained by calculating the response of the damping force (F_d) to the velocity (v), which can be calculated in detail in equations 1 and 2.

$$F_d = c \cdot \dot{x} \tag{1}$$

So

$$c = \frac{F_d}{v} \tag{2}$$

The results of the best coconut oil biolubricant fluid percentage will be further analyzed to determine the dynamic response, especially the passenger vibration acceleration, which will be compared with the ISO 2631 standard. The comfort level categories based on ISO 2631 criteria are presented in Table 2.

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Tab. 2. Comfort reaction to acceleration [21]

Acceleration	Comfort Level
$a < 0.315$ m/s²	No complaints
0.315 m/s² $< a <$ 0.63 m/s²	Slightly uncomfortable
0.5 m/s² $< a <$ 1.0 m/s²	Somewhat uncomfortable
0.8 m/s² $< a <$ 1.6 m/s²	Uncomfortable
1.25 m/s² $< a <$ 2.5 m/s²	Very uncomfortable
$a > 2$ m/s²	Extremely uncomfortable

Therefore, a simulation was conducted using a free body diagram (Figure 3) of the half-motorcycle system. The passenger vibration acceleration was obtained by developing a block diagram model in Simulink that represents the dynamic behavior of the system based on the equations of motion used.

The simulation was performed with a sinusoidal wave excitation input with a fixed amplitude of 2 cm and a constant wavelength of 10 meters. The vehicle speed was varied at 10 km/h, 30 km/h, and 50 km/h to observe the system's response to different excitation frequencies. The initial parameters used in the half-vehicle simulation were obtained from experimental data and previous studies and are presented in Table 3.

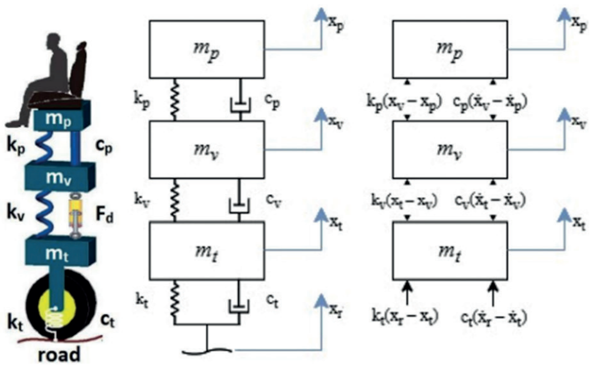

Fig 3. Half vehicle FBD for suspension motorcycles

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Tab. 3. Vehicle parameters

Parameters	Value
Rear motor mass (m_v), kg	58.5
Rear wheel mass (m_t), kg	6.5
Mass of 1 passenger and seat cushion (m_p), kg	60
Shock absorber spring constant (k_v), N/m	19739.2
Passenger seat spring constant (k_p), N/m	200 [22]
Passenger seat damping coefficient (c_p), Ns/m	1165 [22]
Radial tire spring constant 28 Psi (k_t), N/m	1143 [22]
Radial tire damping coefficient 28 Psi (c_t), Ns/m	3430 [22]

The equation of motion for the tire mass (m_t) can be described in equation 3–5.

$$\Sigma F_y = m_t \ddot{x}_t \tag{3}$$

$$k_t(x_r - x_t) + c_t(\dot{x}_r - \dot{x}_t) - k_v(x_t - x_v) - c_v(\dot{x}_t - \dot{x}_v) = m_t \ddot{x}_t \tag{4}$$

$$\dot{v}_t = \frac{1}{m_t}\left[k_t(x_r - x_t) + c_t(\dot{x}_r - \dot{x}_t) - k_v(x_t - x_v) - c_v(\dot{x}_t - \dot{x}_v)\right] \tag{5}$$

The equation of motion for the vehicle mass (m_v) can be described in equations 6–8.

$$\Sigma F_y = m_v \ddot{x}_v \tag{6}$$

$$k_v(x_t - x_v) + c_v(\dot{x}_t - \dot{x}_v) - k_p(x_v - x_p) - c_p(\dot{x}_v - \dot{x}_p) = m_v \ddot{x}_v \tag{7}$$

$$\dot{v}_v = \frac{1}{m_v}\left[k_v(x_t - x_v) + c_v(\dot{x}_t - \dot{x}_v) - k_p(x_v - x_p) - c_p(\dot{x}_v - \dot{x}_p)\right] \tag{8}$$

The equation of motion for the driver mass (m_p) can be described in equations 9–11.

$$\Sigma F_y = m_p \ddot{x}_p \tag{9}$$

$$k_p(x_v - x_p) + c_p(\dot{x}_v - \dot{x}_p) = m_p \ddot{x}_p \tag{10}$$

$$\dot{v}_p = \frac{1}{m_p}\left[k_p(x_v - x_p) + c_p(\dot{x}_v - \dot{x}_p)\right] \tag{11}$$

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3. Results and Discussion

The results of the Damping Force (Fd) test for both the compression and rebound phases on the shock absorber at normal temperature (27°C) are presented in Figures 4 and 5:

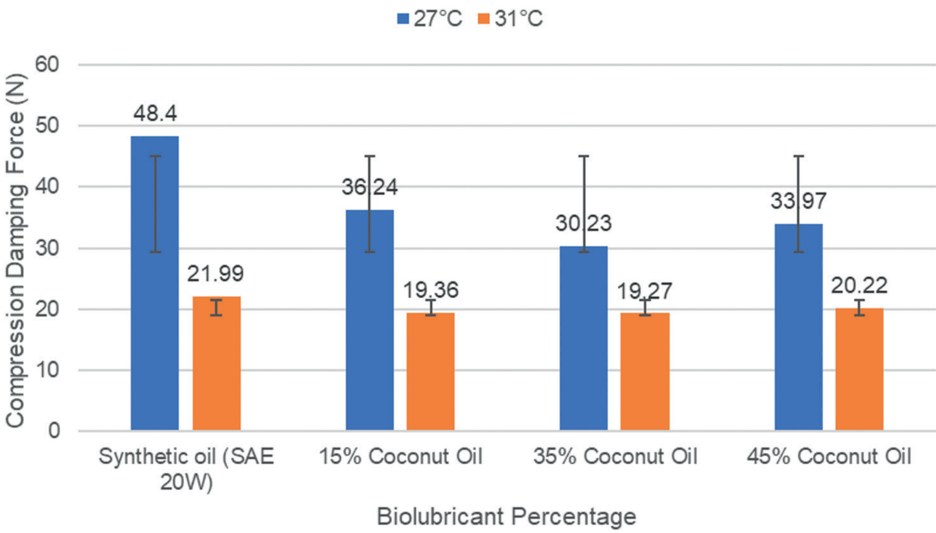

Fig. 4. Comparison graph of compression damping force at temperatures of 27°C and 31°C

At a temperature of 27°C, the compression damping force for all variations is relatively low, ranging from 19.27 N to 21.99 N. The original synthetic oil produces the highest force (21.99 N), while the 15% coconut percentage has the lowest value (19.27 N). The low value of the damping force during compression is caused by the type of shock absorber used, namely the single action type. This type only works actively in the rebound direction, while in the compression direction it produces minimal damping force. This is in accordance with the characteristics of its design which is focused on damping vibrations when the suspension returns from a compressed condition, not when it receives pressure. At a temperature of 31°C, the compression damping force value also remains at a low level, in line with the characteristics of the single action type shock absorber which is designed to work predominantly during expansion. In addition to being influenced by the shock absorber type, variations in lubricant viscosity and orifice geometry also significantly affect the damping force and shock absorber performance during dynamic loads in the compression and rebound phases [23]. This shows that in addition to mechanical design, the properties of the lubricating fluid play an important role in determining damping characteristics, especially in single-action shock absorbers that predominantly work in the rebound direction.

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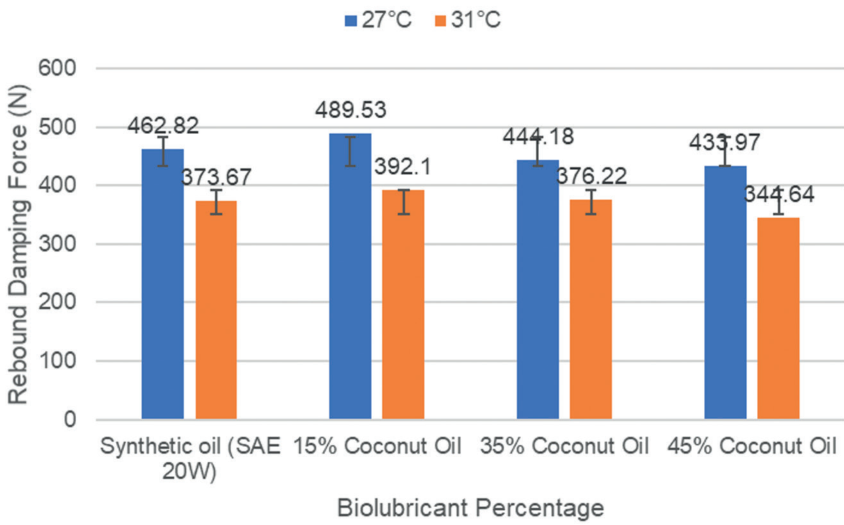

Fig. 5. Comparison graph of rebound damping force at temperatures of 27°C and 31°C

Meanwhile, the rebound damping force at 27°C was much higher. A mixture of 15% coconut oil produced the highest rebound force of 489.53 N. This was greater than synthetic oil at 462.82 N, indicating an increase in rebound resistance due to higher viscosity. Meanwhile, 45% coconut oil showed the lowest rebound force of 433.97 N. These results indicate that increasing the proportion of coconut oil, which decreases the overall viscosity of the mixture, results in a lower damping force. Meanwhile, the rebound damping force at 31°C decreased for both the synthetic oil and all coconut oil biolubricant presentations. These results indicate that higher temperatures reduce the oil viscosity, thereby decreasing resistance during the rebound phase [24]. The 15% coconut oil variation achieved the highest damping force of 392.10 N, indicating that small amounts of coconut oil maintain damping performance despite temperature changes. In contrast, the 45% variation, which has the highest coconut oil content, recorded the lowest damping force (344.64 N), indicating that excessive coconut oil content can reduce damping effectiveness. Fluid experiences a decrease in compression force when the temperature is increased because under these conditions the viscosity decreases so that the drag and damping force on the shock movement are reduced [25]. The decrease in viscosity occurs due to the partial substitution of synthetic base oil with coconut oil, which generally has a lower dynamic viscosity, especially at higher temperatures. In hydraulic damping systems, damping force is strongly influenced by fluid viscosity, so changes in viscosity directly affect the damping force characteristics and dynamic response of the system [26]. Therefore, decreasing viscosity tends to result in lower damping force, potentially improving comfort. At higher temperatures, the viscosity difference between formulations becomes smaller, resulting in less significant differences in damping performance and relatively better thermal stability [27].

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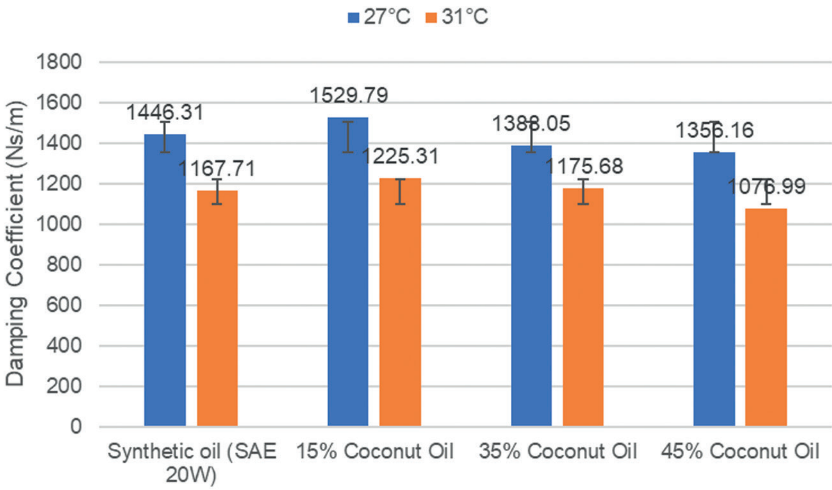

Fig. 6. Comparison graph of rebound damping force at temperatures of 27°C and 31°C

The results of the damping coefficient calculations can be seen in Figure 6. These results indicate a linear relationship with the damping force. This trend is clearly visible in the data, where higher damping forces result in higher CV values. At 27°C, the rebound direction produces a significantly higher CV value than compression, consistent with the characteristics of a single-action shock absorber, which primarily functions during rebound. The 15% coconut oil variation demonstrated the highest performance, with a rebound CV value of 1529.79 Ns/m, slightly exceeding that of the original oil (1446.31 Ns/m). This result indicates that at this percentage, it provides better fluid resistance to piston movement. When the temperature was increased to 31°C, CV values decreased across all rebound direction variations. This reflects the decrease in oil viscosity at higher temperatures, which reduces fluid resistance and damping force. Despite this decrease, the 15% coconut oil maintained the highest CV value of 1225.31 Ns/m. In contrast, the 45% variation recorded the lowest CV value of 1076.99 Ns/m at 31°C, reinforcing the indication that higher coconut oil content with lower viscosity reduces damping effectiveness. These results indicate that at this percentage, coconut oil provides better fluid resistance to piston movement. Furthermore, coconut oil is predominantly composed of saturated medium-chain fatty acids, particularly lauric acid, which contributes to improved oxidative stability and relatively consistent rheological behavior at room temperature [28]. At this point, a higher viscosity decrease (35–45%) occurs due to an imbalance in the molecular chain structure relative to the base viscosity of synthetic oil. Variations in fluid properties, especially viscosity, have been reported to significantly affect the damping characteristics and dynamic behavior of hydraulic shock absorbers [23].

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The results above indicate that 15% coconut oil was identified as the best formulation, providing the highest damping. Therefore, this variation was selected for further simulations on a vehicle model simulated using Simulink to analyze the dynamic response of passengers. The simulation results of the semi-suspended vehicle system, presented in the form of graphs of acceleration amplitude and RMS acceleration of passenger vibrations at sinusoidal excitation input with a shock absorber temperature of 27°C, can be seen in Figure 7.

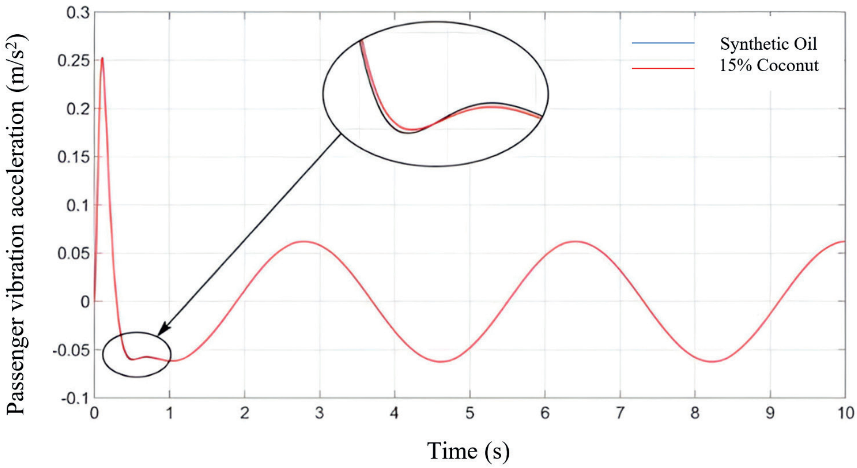

Fig. 7. Amplitude of passenger vibration acceleration against time with a vehicle speed of 10 km/h on a shock absorber at a temperature of 27°C

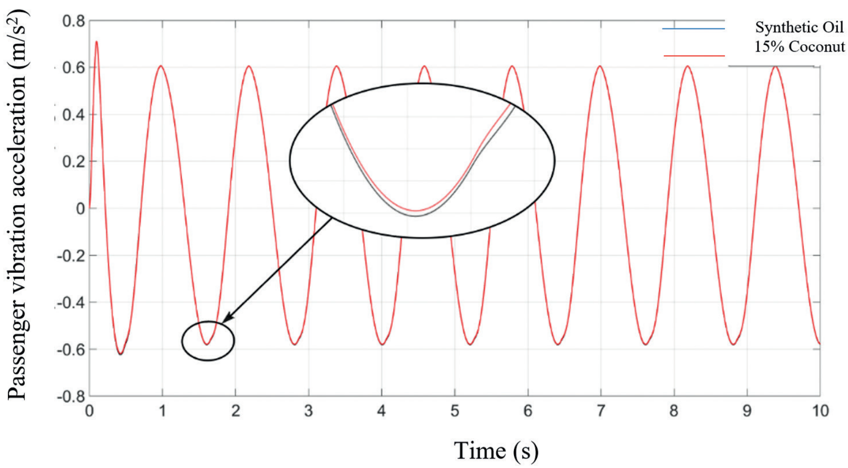

Fig. 8. Amplitude of passenger vibration acceleration against time with a vehicle speed of 30 km/h on a shock absorber at a temperature of 27°C

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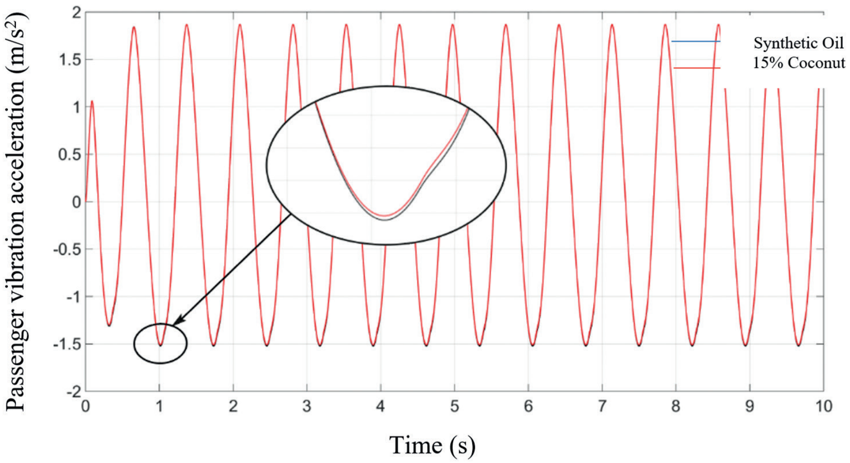

Fig. 9. Passenger vibration acceleration amplitude versus time at a vehicle speed of 50 km/h for a shock absorber at 27°C

Based on Figures 7–9, several graphs of passenger vibration acceleration amplitude versus time for a shock absorber at 27°C at various vehicle speeds, it can be seen that at all speeds, the graphs show similar, even overlapping, trends between the use of pure oil and the 15% coconut oil. Previous studies have shown that variations in hydraulic fluid properties, particularly viscosity, influence the damping characteristics of shock absorbers while producing only limited changes in overall suspension dynamic response [27]. However, a more in-depth analysis reveals differences at certain phases of suspension movement. At a speed of 10 km/h, the difference in vibration acceleration amplitude is observed in the peak deceleration phase (peak rebound phase) at the beginning of the iteration, with the 15% coconut oil application having a lower value. Meanwhile, at speeds of 30 km/h and 50 km/h, the difference in vibration acceleration amplitude is observed in the deceleration phase (peak rebound phase) across all iterations, with the 15% coconut oil application having a lower value. This study shows that the mixture is able to increase energy dissipation more effectively at medium to high speeds, possibly due to better viscosity stability and more optimal fluid shear response. Figure 10 below shows the RMS results for passenger vibration acceleration at a shock absorber temperature of 27°C for each fluid at various speeds:

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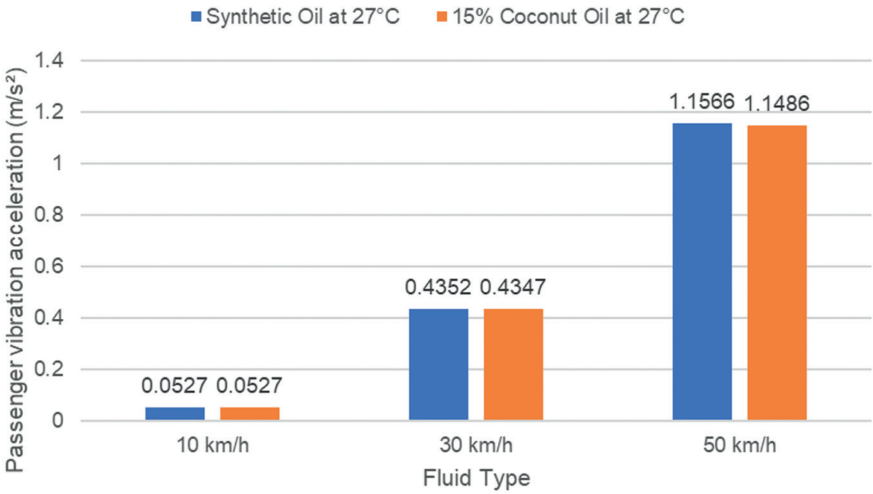

Fig. 10. RMS passenger vibration acceleration at a shock absorber temperature of 27°C

As shown in Figure 10, at a low speed of 10 km/h, the RMS value remains unchanged between the use of original oil and 15%, which is 0.0527 m/s². However, at speeds of 30 km/h and 50 km/h, 15% shows a slight decrease in the RMS value from the use of original oil, namely from 0.4352 m/s² to 0.4347 m/s² and from 1.1566 m/s² to 1.1486 m/s² respectively. At low speed conditions, there has been no change in viscosity because the addition of 15% coconut oil has not significantly changed the vibration acceleration. At higher speeds, the suspension begins to enter the non-linear damping zone [29, 30]. Coconut oil has a high viscosity index, a more stable friction coefficient, and the ability to reduce stick slippage in the damper valve. This combined effect reduces vibration acceleration, albeit by a small margin. At high velocity damping, the fluid's viscosity is crucial: coconut oil has a molecular structure of saturated medium-chain triglycerides, providing a mild shear-thinning effect, making it slightly easier for the fluid to flow through the damper orifice. This reduces peak rebound force, thus reducing vibration [23].

Meanwhile, the results of the simulation of the half-suspended vehicle system, which are presented in the form of graphs of acceleration amplitude and RMS acceleration of passenger vibrations at sinusoidal excitation input of 31°C shock absorber temperature, are presented in Figures 11, 12 and 13.

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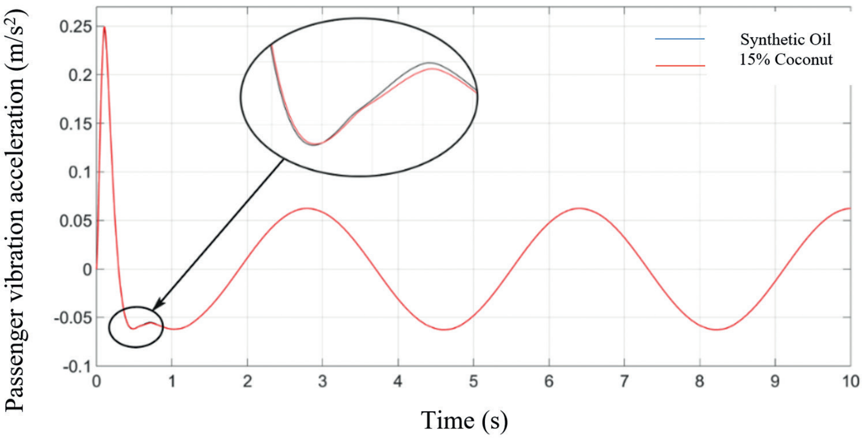

Fig. 11. Amplitude of passenger vibration acceleration against time with a vehicle speed of 10 km/h on a shock absorber at a temperature of 31°C

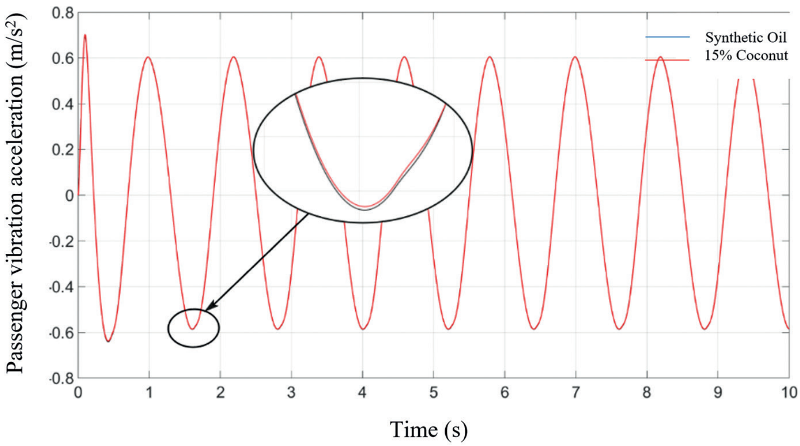

Fig. 12. Amplitude of passenger vibration acceleration against time with a vehicle speed of 30 km/h on a shock absorber at a temperature of 31°C

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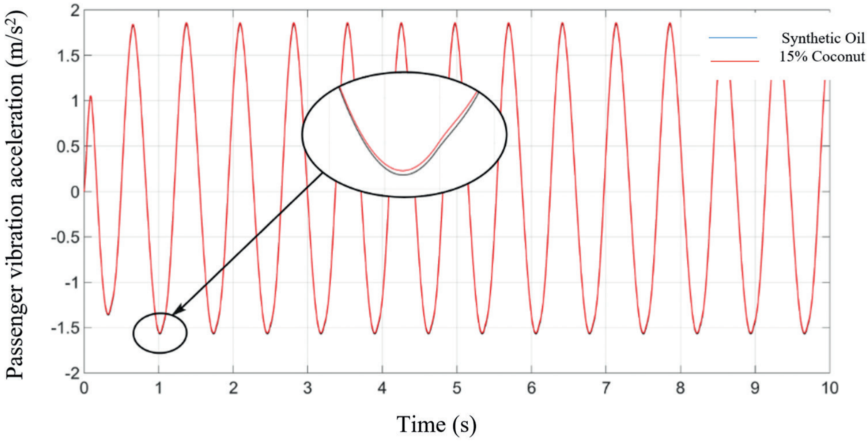

Fig. 13. Amplitude of passenger vibration acceleration against time with a vehicle speed of 30 km/h on a shock absorber at a temperature of 31°C

At higher temperatures, the viscosity of the shock absorber fluid decreases. This decrease in viscosity causes the damping coefficient to decrease, making the shock absorber less effective in damping and dissipating vibration energy, especially at medium to high speed excitations [27]. As a result, the RMS value of vibration acceleration at 31°C increases slightly compared to 27°C. Although the increase is not significant, this pattern is consistent with the rheological characteristics of synthetic fluids and coconut oil-based biolubricants, where increasing temperature is always followed by a decrease in fluid resistance to flow during compression and rebound processes [12, 31, 32].

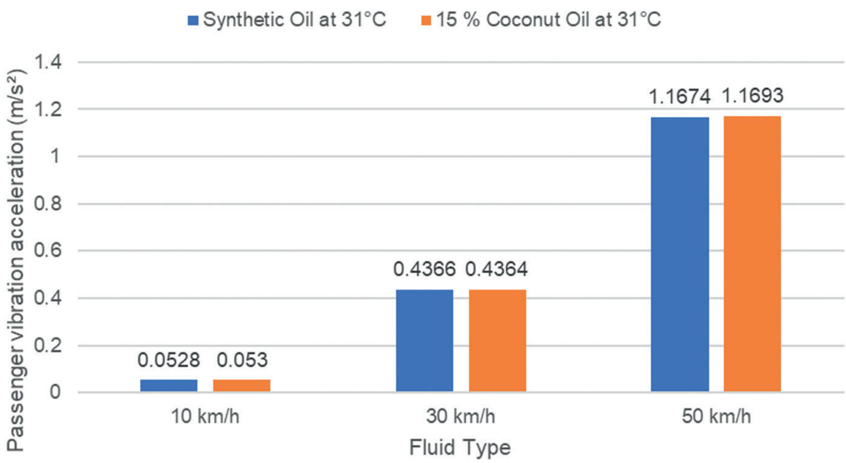

Fig. 14. RMS acceleration of passenger vibration at shock absorber temperature of 31°C

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Figure 14 shows that at speeds of 10 km/h and 50 km/h, the RMS vibration acceleration value for the 15% coconut oil was higher than for the synthetic oil. However, at a speed of 30 km/h, the value decreased and was lower than the synthetic oil, at 0.4366 m/s² compared to 0.4364 m/s². This indicates that synthetic lubricants generally have more consistent viscosity stability and performance across various operating conditions [33].

Furthermore, to evaluate passenger comfort, the ISO 2631 comfort standard was used to determine comfort levels based on the RMS of passenger vibration acceleration. The results of the comfort analysis for the shock absorber at temperatures of 27°C and 31°C are presented in Tables 4 and 5.

Tab. 4. Comfort level at shock absorber temperature of 27°C

v [km/h]	Synthetic oil		15% Coconut oil	
	a_p RMS [m/s²]	Comfort level	a_p RMS [m/s2]	Comfort level
10	0.0527	No complaints	0.0527	No complaints
30	0.4352	A little uncomfortable	0.4347	A little uncomfortable
50	1.1566	Uncomfortable	1.1486	Uncomfortable

Table 4 shows that at 27°C, both synthetic and 15% coconut oil remained well below the ISO 2631 discomfort threshold, thus categorizing them as "no complaints." This means that at this low speed, the suspension still effectively dampens vibrations, maintaining passenger comfort.

When the speed was increased to 30 km/h, the RMS value of passenger vibration acceleration increased to approximately 0.467 m/s². This increase is quite significant compared to the previous condition. However, this condition is still tolerable for most people and does not cause serious disruption to driving comfort.

At the highest speed of 50 km/h, the vibration acceleration value reached more than 1 m/s² for both fluid types. This indicates that at high speeds, suspension damping performance decreases, and vibrations transmitted to the passenger's body exceed the comfort threshold. Therefore, this condition has the potential to cause fatigue or discomfort if prolonged. The same thing applies to the comfort criteria for using shock absorbers at a temperature of 31°C as written in Table 5.

The advantage of this research formulation is a significant increase in damping force, especially during the rebound phase, thus reducing vibrations experienced by passengers and increasing ride comfort. However, there are several limitations that need to be considered. The effect of the formulation on the compression phase is relatively small, and this

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study only evaluated one range of coconut oil percentages, without direct measurements of fluid physical parameters such as viscosity, density, and viscosity index, which are important for understanding the quantitative relationship between fluid properties and damping characteristics.

Tab. 5. Comfort level at shock absorber temperature of 31°C

v [km/h]	Synthetic oil		15% Coconut oil	
	a_p RMS [m/s²]	Comfort level	a_p RMS [m/s²]	Comfort level
10	0.0528	No complaints	0.053	No complaints
30	0.4366	A little uncomfortable	0.4364	A little uncomfortable
50	1.1674	Uncomfortable	1.1693	Uncomfortable

4. Conclusions

Based on the results of experimental testing and simulations, it can be concluded that the addition of coconut oil to synthetic shock absorber oil affects the damping characteristics. Pure synthetic oil produced the highest compression damping force values, namely 48.4 N at 27°C and 21.99 N at 31°C. Among the coconut oil blend variations, the 15% blend provided higher compression damping values at 27°C (36.24 N) compared to 30% and 45%, indicating that moderate levels are more optimal at low temperatures. At 31°C, the 45% coconut oil blend produced the highest compression damping (20.22 N), indicating that temperature influences damping performance at higher blend levels. The highest rebound damping force values for both temperatures (27°C and 31°C) were achieved by the 15% coconut oil blend, which were 489.53 N at 27°C and 392.1 N at 31°C. These values were approximately 5.7% higher than those of pure synthetic oil, indicating that the addition of coconut oil at moderate levels can improve shock rebound response and potentially enhance ride comfort. These results indicate that at certain concentrations, coconut oil can enhance the shock absorber's ability to absorb oscillatory energy and improve damping characteristics. However, adding excessive concentrations (>30%) can reduce damping performance, likely due to changes in the viscosity and flow characteristics of the oil mixture. Based on these findings, the 15% mixture was selected for further analysis through dynamic response simulations with sinusoidal excitation input.

The simulation results show that the RMS value of passenger vibration acceleration increases with increasing vehicle speed. Although the difference in RMS values between the original oil and 15% is relatively small, with 15% being superior at 27°C at 30 km/h and 50 km/h, and at 31°C at 30 km/h, both remain within the same comfort level category based on the ISO 2631 standard.

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The main advantage of using coconut oil as a biolubricant is its ability to improve damping performance while offering a more environmentally friendly and sustainable alternative to conventional synthetic oils. Its high viscosity and good thermal stability allow coconut oil to absorb repeated oscillatory energy without significant degradation, which is essential for maintaining the comfort and performance of a motorcycle suspension system.

However, this study has several limitations. The improvement in damping performance occurs primarily in the rebound phase, while the effect is minimal in the compression phase due to the use of a single-action shock absorber. Furthermore, this study only evaluated a limited range of coconut oil percentages and did not directly measure fluid physical parameters, such as viscosity, density, and viscosity index, which are crucial for understanding the quantitative relationship between fluid properties and damping characteristics.

In light of these findings, further research is recommended to expand the range of coconut oil blend percentage variations to a wider range to produce significant differences in damping characteristics. Future research should also involve direct measurements of fluid physical parameters, such as viscosity, density, and viscosity index, to quantitatively correlate fluid properties with damping performance. Furthermore, to enhance the validity of the simulation results, further experimental testing is needed to verify the accuracy of the half-vehicle suspension system modeling developed using MATLAB Simulink.

5. Nomenclature

F_d Damping force (N)
c Damping coefficient (Ns/m)
v Velocity (m/s)
x Displacement (m)
$\dot{x}$ Velocity (first derivative of displacement) (m/s)
$\ddot{x}$ Acceleration (second derivative) (m/s2)
m_t Tire mass (kg)
m_v Vehicle (rear body) mass (kg)
m_p Passenger mass (kg)
k_t Tire spring stiffness (N/m)
k_v Suspension spring stiffness (N/m)
k_p Seat spring stiffness (N/m)
c_t Tire damping coefficient (Ns/m)
c_v Suspension damping coefficient (Ns/m)
c_p Seat damping coefficient (Ns/m)
x_r Road displacement input (m)
x_t Tire displacement (m)
x_v Vehicle body displacement (m)

x_p Passenger displacement (m)
a_p Passenger acceleration (m/s2)
RMS Root Mean Square acceleration (m/s2)
T Temperature (°C)

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