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Analysis of Physical and Chemical Properties of Dammar Resin as an Alternative Fuel

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Abstract: Efforts to obtain alternative and renewable energy continue to be carried out sustainably. Various natural materials continue to be studied for their feasibility in using alternative and renewable fuels. One of the natural materials that have the potential as a source of renewable energy is dammar resin (Shorea Javanica k. et v.). Therefore, it is necessary to analyze dammar resin's physical and chemical properties to determine its potential as an alternative fuel. This study evaluates dammar resin's physical and chemical properties as a renewable energy source. In this research, the physical and chemical properties of dammar resin were investigated related to its function as an alternative fuel compared to other alternative fuels. This study also aims to determine the advantages and disadvantages of dammar resin's physical and chemical properties as an alternative fuel. The American Society for Testing and Materials standard (ASTM), International Organization for Standardization (ISO), and the American Oil Chemists Society standard (AOCS) methods have been adopted to analyze the physical and chemical properties of dammar resins. This study's physical and chemical properties were cloud point, pour point, flash point, density, energy content, ash content, sulfur content, iodine value, saponification value, and cetane number. The result indicates that based on the physical and chemical property analysis, dammar resin has potency as a renewable energy source and can be developed as an alternative fuel. Dammar resin has a low flash point, sulfur content, and iodine value but a high saponification value and cetane number; these values have met European requirements. Moreover, the energy content of dammar resin is lower, and the ash content is higher than other biodiesel materials. However, dammar resin still requires advanced processes to be converted as alternative energy because it still has a high density, cloud, and pour point.

Keywords: dammar resin, alternative fuel, physical properties, chemical properties.

达马尔树脂作为替代燃料的理化性质分析

摘要：继续以可持续的方式获取替代能源和可再生能源。继续研究各种天然材料在使用替代和可再生燃料方面的可行性。具有作为可再生能源来源的潜力的天然材料之一是达马尔树脂（爪哇海岸和）。因此，有必要分析达玛树脂的物理和化学性质，以确定其作为替代燃料的潜力。本研究评估了达玛树脂作为可再生能源的物理和化学特性。在这项研究中，与其他替代燃料相比，达马尔树脂的物理和化学性质与其作为替代燃料的功能有关。本研究还旨在确定达马尔树脂作为替代燃料的物理和化学特性的优缺点。已采用美国测试与材料协会标准、国际标准化组织和美国石油化学家协会标准方法来分析达马尔树脂的物理和化学性质。本研究的物理和化学性质为浊点、倾点、闪点、密度、能量含量、灰分含量、硫含量、碘值、皂化值和十六烷值。结果表明，基于物理和化学性质分析，达玛树脂具有作为可再生能源的潜力，可以开发为替代燃料。达马尔树脂的闪点、硫含量和碘值低，但皂化值和十六烷值高；这些值符合欧洲要求。而且，达玛树脂的能量含量较低，灰分含量高于其他生物柴油材料。然而，达马尔树脂仍然需要先进的工艺才能转化为替代能源，因为它仍然具有高密度、

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浊度和倾点。

关键词：达玛树脂, 替代燃料, 物理性质, 化学性质。

1. Introduction

Dammar tree is a tropical forest plant [1]. In Indonesia (i.e., Krui), tapping dammar resin is one of the farmer's livelihoods [2]. The tapped dammar is traded and exported. With well-managed supervision, the tapping process could be retained for up to 70 years without damaging or preserving the forest. The area of dammar forest in Indonesia that has not been explored yet is extensive.

The source of conventional fossil fuel energy is decreased gradually; meanwhile, the need for energy increases [3]. The utilization of alternative renewable energy sources to replace fossil fuels continues, including solar energy [4, 5], small-scale water energy [6], and other renewable alternative energy. Environment and eco-friendly energy sources are the pivotal factors for biodiesel fuel development [7-10]. Therefore, it is essential to intensify the efforts to explore other potential renewable energy sources [7-11]. With the vast area of Indonesian territory and the whole world's forest, it is necessary to ensure that the dammar resin is convincing to be a renewable energy source.

Various studies on the potential of dammar resin as an alternative fuel have been carried out. Dammar resin is a material that is easy to melt and turn into gas [12]. The easier for a material to melt and turn into gas, the material has potential as an alternative fuel. In the burning process, dammar resin is highly flammable. Testing dammar resins with a mass of 0.02 to 0.1 gram obtained a flame waiting time of 0.65 to 1.83 s with a combustion rate of 0.0055 to 0.011 gram/s in the burning process of the test material burned out [13]; this burning test reinforces that dammar resin has the potential as an alternative fuel. Other tests that have also been carried out on dammar resins are the Gas Chromatographic–Mass Spectrometric (GCMS) test. The GCMS test results on dammar resins also show that dammar resin has potential as an alternative fuel. The GCMS test results can be seen in Fig. 1, and the interpretation of Fig. 1 is presented in Table 1 [14].

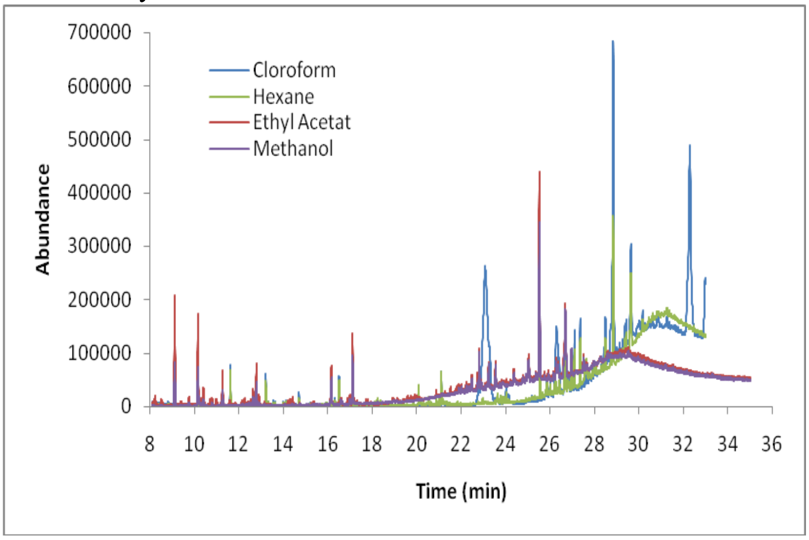

Fig. 1 Dammar resin GCMS test results

Table 1 Dammar resin chemical compounds from GCMS test results

Chemical compound	Carbons Number	Chemical structure	Weigh %
Cyclotrisiloxane, hexamethyl-	6	$C_6H_{18}O_3Si_3$	1.32
1,1,1,3,5,5,5-Heptamethyltrisiloxane	7	$C_7H_{22}O_2Si_3$	3.01
1R-α-Pinene	10	$C_{10}H_{16}$	1.72
3-Carene	10	$C_{10}H_{16}$	1.30
Limonene	10	$C_{10}H_{16}$	0.44
Cyclohexene, 1-methyl-4-(1-methylethylidene)-	10	$C_{10}H_{16}$	0.66

Continuation of Table 1			
β Fenchyl alcohol	10	$C_{10}H_{18}O$	0.26
3-Cyclohexene-1-methanol, α, α4-trimethyl-	10	$C_{10}H_{18}O$	0.88
3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-	10	$C_{10}H_{18}O$	0.21
Tetrasiloxane, decamethyl-	10	$C_{10}H_{30}O_3Si_4$	0.64
2,3,4-Trimethoxyphenylacetonitrile	11	$C_{11}H_{13}NO_3$	0.80
Acetamide, N-[4-(trimethylsilyl)phenyl]-	11	$C_{11}H_{17}NOSi$	1.81
Silane, 1,4-phenylenebis [trimethyl-	12	$C_{12}H_{22}Si_2$	0.74
1,2-Bis(trimethylsilyl)benzene	12	$C_{12}H_{22}Si_2$	0.41
Benzene, 1,4-bis(trimethylsilyl)-cyclotrisiloxane, hexamethyl-	12	$C_{12}H_{22}Si_2$	0.69
3,4-Dimethyl-5-(3-methylphenyl)isoxazole	12	$C_{12}H_{13}NO$	6.13
2-acetyl-4-(2,5-dichlorophenyl)furan	12	$C_{12}H_8Cl_2O_2$	0.13
[1,1'-Biphenyl]-4-amine, 4'-fluoro-	12	$C_{12}H_{10}FN$	9.40
5-Methyl-2-trimethylsilyloxy-acetophenone	12	$C_{12}H_{18}O_2Si$	0.47
Trimethyl[4-(2-methyl-4-oxo-2-pentyl)phenoxy]silane	12	$C_{12}H_{18}O_2Si$	0.15
Propiophenone, 2'-(trimethylsiloxy)-	12	$C_{12}H_{18}O_2Si$	0.38
Acetic acid, [4-(1,1-dimethylethyl)phenoxy]-, methyl ester	13	$C_{13}H_{18}O_3$	5.18
Cis-3a,4,5,6,7,7a-hexahydro-5-(3-hydroxypropyl)-5-methyl-1H-inden-1-one	13	$C_{13}H_{20}O_2$	0.25
Lumiflavine	13	$C_{13}H_{12}N_4O_2$	0.23
Methyl 2-[1-(4-methylphenyl)hydrazine]-2-one	13	$C_{13}H_{21}NO$	0.62
N-Methyl-1-adamantaneacetamide	13	$C_{13}H_{21}NO$	2.75
Silane, trimethyl[5-methyl-2-(1-methylethyl)phenoxy]-	13	$C_{13}H_{22}OSi$	0.67
Trimethyl(4-tert.-butylphenoxy)silane	13	$C_{13}H_{22}OSi$	0.83
2,4,6-Cycloheptatrien-1-one, 3,5-bis-trimethylsilyl-	13	$C_{13}H_{22}OSi_2$	0.26
Methyl 3-bromo-1-adamantaneacetate	13	$C_{13}H_{19}BrO_2$	4.29
p-Trimethylsiloxybenzaldehyde oxime, trimethylsilyl-	13	$C_{13}H_{23}NO_2Si_2$	0.95
2,5-di-tert-Butyl-1,4-benzoquinone	14	$C_{14}H_{20}O_2$	0.97
Caryophyllene	15	$C_{15}H_{24}$	0.78
Trans-γ-bibabolene	15	$C_{15}H_{24}$	0.76
1H-Benzocycloheptene, 2,4a,5,6,7,8-hexahydro-3,5,5,9-tetramethyl-, (R)-	15	$C_{15}H_{24}$	1.32
2,6-Di (t-butyl)-4-hydroxybenzaldehyde	15	$C_{15}H_{22}O_2$	0.03
Benzo[h]quinoline, 2,4-dimethyl-	15	$C_{15}H_{13}N$	0.01
6 methyl-2 phenylindole	15	$C_{15}H_{13}N$	0.36
1H-Indole, 1-methyl-2-phenyl-	15	$C_{15}H_{13}N$	0.93
1,3-Dimethyl-4-azaphenanthrene	15	$C_{15}H_{13}N$	3.69
Trymethyl [4-(2-methyl-4-oxo-2-penthyl) phenoxy] silane	15	$C_{15}H_{24}O_2Si$	3.68

Continuation of Table 1			
Isomaturnin	16	$C_{16}H_{14}O_3$	0.59
Dehydrocacalohastin-14-ol	16	$C_{16}H_{16}O_3$	0.25
3-Methyl-5-diphenyldihydrafuran	17	$C_{17}H_{16}O$	0.32
2,2-Dimethyl-6-acethyl-3,4-dihydronaphtho[1,2-b]pyrane	17	$C_{17}H_{18}O_2$	0.54
12-methoxy-19-norpodocarpa-3,5,8,11,13-pentaen-7-one	17	$C_{17}H_{18}O_2$	1.06
2-(4'-Methoxyphenyl)-2-(2'-methoxyphenyl)propane	17	$C_{17}H_{20}O_2$	0.24
2-Hydroxy-12-methosy-19-norpodokarpa-1,8,11,13-tetraen-3-one	17	$C_{17}H_{20}O_3$	0.78
7,9-Di-tert-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione	17	$C_{17}H_{24}O_3$	0.57
Trimethyl[4-(1,1,3,3,-tetramethylbutyl)phenoxy]silane	17	$C_{17}H_{30}OSi$	0.39
1-Methyl-oestra-1,3,5(10)-trien-18-nor-17-ketone	18	$C_{18}H_{22}O$	1.31
Methyl 1-methyl-3-propyl-9H-carbazole-2-carboxylate	18	$C_{18}H_{19}NO_2$	0.13
Phenanthrene, 7-ethenyl-1,2,3,4,4a,4b,5,6,7,8,10,10a-dodecahydro-4a,7-dimethyl-1-methylene-,[4aS-(4aα,4aβ,7β,10aβ)]-	18	$C_{19}H_{28}$	0.17
Androst-16-en-3-one, (5α)-	19	$C_{19}H_{28}O$	0.40
10,11-Dihydrobenzo[k]fluoranthene	20	$C_{20}H_{14}$	1.43
Phenanthrene, 7-ethenyl-1,2,3,4,4a,4b,5,6,7,8,10,10a-dodecahydro-1,1,4a,7-tetramethyl-, [4aS-(4aα,4bβ,7β,10aβ)]-	20	$C_{20}H_{32}$	1.00
Ent-pimara-8(14),15-diene	20	$C_{20}H_{32}$	0.43
Retinol	20	$C_{20}H_{30}O$	6.23
Cholesterol	27	$C_{27}H_{46}O$	9.22
Epicodisterol	28	$C_{28}H_{46}O$	3.32
γ-Sitosterol	29	$C_{29}H_{50}O$	11.48

In Table 1, it can be seen that there are 61 types of chemical compounds containing carbon amounts varying from 6 to 29; the weight of chemical compounds is between 0.01 to 11.48% of the total weight of dammar resin material. Various hydrocarbon compounds show that this dammar resin is suitable alternative fuel.

The feasibility of dammar resins as alternative fuels still needs to be tested by knowing the physical and chemical properties of dammar resins and comparing them with other materials that have been previously studied.

Therefore, this research is aimed to investigate and analyze the potency of dammar resin as a source of renewable energy.

2. Methods and Materials

2.1. Materials

The material used in this study is dammar resin (Fig. 2). Dammar resin is a product that is yielded from the tapping process. The tapped dammar resin is categorized into three levels of quality. The best quality level is used in this research: the yellowish color and size larger than 3 cm^3.

Fig. 2 Dammar resin

2.2. Physical and Chemical Properties Methods

The physical and chemical properties of dammar resin are analyzed using standard methods of the American Society for Testing and Materials (ASTM), International Organization for Standardization (ISO), and the American Oil Chemists Society standard (AOCS). These methods are shown in Table 2. The higher cetane number is determined by the Krisnangkura method [16].

Table 2 Standard methods in determining the physical and chemical properties of fuel

Physical and chemical properties	Standard method	Unit
Cloud point	ASTM D2500 [15]	ºC
Pour point	ASTM D97 [15]	ºC
Flashpoint	EN ISO 3679 [15]	ºC
Density at 15 ^{0}C	EN ISO 3675 [15]	g/ml
Energy content	ASTM D2015 [8]	MJ/kg
Ash content	ASTM D482 [15]	wt. %
Sulfur content	EN ISO 3987 [15]	wt. %
Iodine value	AOAC CD1-25 [8]	Centigram I/g oil
Saponification value	AOAC CD3-25 [8]	mg KOH/g oil

3. Results and Discussion

The laboratory testing results for dammar resin's physical and chemical properties can be seen in Table 3. The physical and chemical properties of other biodiesel materials [7-10] are also included in table 3 as a comparison.

At room temperature, shown in table 3, dammar resin will be in solid form, where the cloud point and the pour point are 53 ºC and 68 ºC. These values are higher than tobacco seed oil [7], tomato seed oil [8], and other biodiesel materials [9] shown in table 3. The high of the clouds point and the pour point indicates that the material easily crystallizes at low temperatures so that it can block the flow of biodiesel. That is an obstacle to biodiesel in general [17, 18]. However, it can be overcome by preheating biodiesel before use which can be done by utilizing exhaust gas using a heat exchanger [19, 20]. Another solution is to use an appropriate additive [21-25] so that biodiesel remains liquid even at low temperatures. Improvements to flow and ignition in the combustion chamber can also be made by improving the injection system that can increase the pressure and temperature of biodiesel when entering the combustion chamber [26].

Table 3 Laboratory testing results and its comparison to biodiesel/vegetable oil literature

Biodiesel/vegetable oil	Cloud point (ºC)	Pour point (ºC)	Flashpoint (ºC)	Density (g/ml)	Energy content (MJ/kg)	Ash content (wt. %)	Sulfur content (wt. %)	Iodine value (cgI/g)	Sap. value (mg KOH/g)	Cetane number
Corn	-1.1	-40.0	277	0.9095	39.5	0.01	0.010	122.6	187 – 195	37.6
Cottonseed	1.7	-15.0	234	0.9148	39.5	0.01	0.010	105.7	189 – 198	41.8
Peanut	12.8	-6.7	271	0.9026	39.8	0.005	0.010	-	187 – 196	41.8
Rapeseed	-3.9	-31.7	246	0.9115	39.7	0.054	0.010	130.0	168 – 181	37.6
Sesame	-3.9	-9.4	260	0.9133	39.3	< 0.01	0.010	106.6	187 – 195	40.2
Soya bean	-3.9	-12.2	254	0.9138	39.6	< 0.01	0.010	112.5	189 – 195	37.9
Sunflower	7.2	-15.0	274	0.9161	39.6	< 0.01	0.010	125.5	188 – 194	37.1
Tobacco	-7.8	-14.0	220	0.9175	39.4	0.008	0.006	135.0	193	38.7
Tomato	-8.9	-16.1	189	0.9151	35.9	0.034	0.004	124.0	195	41.0
Dammar	53	68	155	1.0821	33.1	0.037	0.004	50.7	217.8	59.9

Compared to other biodiesel materials [7-9] shown in table 3, dammar resin has the lowest flashpoint of 155 °C, which shows that the dammar resin is the most flammable compared to other biodiesel fuels in table 3. On the other hand, the flashpoint of dammar resins is larger than the minimum European requirement for biodiesel is 101 °C [15], so dammar resin meets European requirements. The advantage is that it is safe when stored at room temperature.

Dammar resin density is 1.0821 g/ml, higher than other materials [7-9] shown in table 3. Dammar resin density is also higher than European requirements for biodiesel fuel, which is 0.820-0.845 g/ml [15]. Preheating can be done so that the density of dammar resins or other biodiesel can decrease with increasing temperature; preheating can be done by utilizing the exhaust gas using a heat exchanger [19, 20]. Mixing with suitable additives can also reduce the density of biodiesel, including Dammar resin [21-25].

Dammar resin has an energy content of 33.1 MJ/kg, and this value is lower when compared to other biodiesel materials [7-9] shown in table 3. Therefore, based on mass, the ability of dammar resin to produce energy is lower than other biodiesel materials, shown in table 3. However, because fuel enters the combustion chamber through pump injection, the flow is different based on volume and density. Therefore, based on volume, dammar resin has an energy content of 35.83 MJ/l, higher than the energy content of tomato seed oil [8], which is 32.85 MJ/l, and smaller than tobacco seed oil [7] which is 36.15 MJ/l, as for the content energy from other biodiesel materials [9] shown in table 3 is around 35.89-36.28 MJ/l.

The ash content of dammar resin is 0.037 wt.%; this value is almost the same as the ash content value of other biodiesel materials [7-9], as shown in table 3. However, the ash content of dammar resin is still higher than the minimum European requirements for automotive diesel fuel is 0.01 wt.% [15]. Improving the quality of biodiesel, including reducing ash content, can be done by purification or cleaning [27-29]. Although the ash content of dammar resin is higher than European requirements, it is relatively low to use as fuel and safe for the environment [8].

The sulfur content of dammar resin is 0.004 wt.%, this value is the same as the sulfur content of tomato seed oil [8] but is lower than other biodiesel materials [7, 9] shown in table 3. The sulfur content of all the biodiesel materials in table 3 is lower than the maximum European requirement for biodiesel fuel is 0.02 wt.% [15]. Sulfur compounds harm the combustion chamber, and the resulting combustion causes environmental pollution [30], so it is sought that the fuel does not have sulfur content. With a sulfur content value of 0.004 wt.%, dammar resin can be said to be sulfur-free, meaning dammar resin is a non-corrosive and non-pollutant fuel [30-31].

Dammar resin has an iodine value lower than other biodiesel materials [7-9] shown in table 3. European requirements for biodiesel fuel require a maximum iodine value of 120 cgI/g [15]; table 3 shows that the dammar resin iodine value is lower than European requirements. The iodine value has an impact on the formation of carbon deposits in the combustion chamber, where the greater the iodine value, the carbon deposits will be even greater [32]; the use of dammar resin as fuel will reduce carbon deposits formed in the combustion chamber. Low iodine value has an impact on the high value of cloud point and pours point [33], so it is necessary to preheat or additive so that dammar resin is suitable for use [19-25]; purification and cleaning processes can also improve the quality of biodiesel [27-29].

Dammar resin saponification value is 217.8 mgKOH/g. This value is highest than other biodiesel materials [7, 8, 10] shown in table 3. The saponification value is lower than the maximum European requirement for biodiesel fuel is 370 mgKOH/g [15]. With this value, dammar resin has the longest average length of chain fatty acid compared to other materials. High saponification value has a negative impact, corrosion on diesel engine components.

The cetane number is calculated using the Krisnangkura method [16]. The cetane number of dammar resin is 59.9, and this value is the highest compared to other biodiesel materials [7-9] shown in table 3. The cetane number of dammar resin can exceed the European requirements for biodiesel fuel; a minimum is 51 [15] - the higher of cetane number, the faster the ignition of fuel in the combustion chamber. Dammar resin has a high cetane number, the faster the ignition in the combustion chamber, which is supported by the low flash point of dammar resin.

Overall, dammar resins' physical and chemical properties have potency as a renewable energy source and can be developed as an alternative fuel. However, some physical and chemical properties improvements are still needed to meet the minimum requirements. Nevertheless, by applying specific treatments to improve its physical and chemical properties, dammar resin can be developed as an alternative fuel for automotive diesel fuel.

4. Conclusion

This study's comparison material is vegetable oil or biodiesel derived from corn, cottonseed, peanut, rapeseed, sesame, soybean, sunflower, tobacco, and tomato. The results showed that the dammar resin has a flashpoint of 155°C, is lower than other biodiesel materials by 189-277°C, and has met the minimum European requirement of 101°C. The dammar resin has a sulfur content of 0.004 wt.%, lower than other biodiesel materials by 0.004-0.01 wt.%, and has met the maximum European requirement of 0.02 wt.%. The dammar resin has an iodine value of 50.7 cgI/g, lower than other biodiesel materials by 105.7-124 cgI/g, and has met the maximum European requirement of 120 cgI/g. The dammar resin has a saponification value of 217.8 mgKOH/g, higher than other biodiesel materials by 169-198 mgKOH/g, but has met the minimum European requirement of 370 mgKOH/g. The dammar resin has a cetane number of 59.9, higher than other biodiesel materials by 37.1-41.8, and has met the minimum European requirement of 51.

The dammar resin has an energy content of 33.1 MJ/kg, lower than other biodiesel materials by 35.9-39.8 MJ/kg, but based on the volume; the dammar resin has an energy content of 35.83 MJ/l, equivalent to other biodiesel materials by 32.85-36.28 MJ/l.

The dammar resin density is 1.0821 g/ml, higher than other biodiesel materials by 0.9026-0.9175 g/ml, and does not meet the European requirement by 0.820-0.845 g/ml. The dammar resin has an ash content of 0.037 wt.%, equivalent to other biodiesel materials by 0.008-0.054 wt.%, but does not meet the maximum European requirement of 0.01 wt.%. The Damar resin has a cloud point and pours points of 53 ºC and 68 ºC, much higher than other biodiesel materials.

Dammar resin has potency as a renewable energy source and can be developed as an alternative fuel. However, dammar resin still requires advanced processes to be converted as alternative energy into oil form at room temperature. In addition, it still has a high-density level, cloud, and pour point compared to other biodiesel materials.

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