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Analysis of the Physicochemical Properties of Some Selected Non-Edible Vegetable Oil-Based Cutting Fluids Using the Design of Experiment (DOE) Approach

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Abstract: The pursuit of environmentally friendly cutting fluids is ongoing as the problems of traditional cutting fluids become more apparent. The bulk of vegetable oils used in studies are consumable and, if marketed, may conflict with human utilization, making cutting fluids more costly. However, few investigations on the use of lesser-known vegetable oils as cutting fluids have been conducted. As a result, the goal of this research is to examine how effective some lesser-known vegetable oils will be if used as a cutting fluid. Based on some physicochemical properties such as acid value and viscosity, the developed vegetable oil-based cutting fluids (watermelon and jatropha) were statistically analyzed using 24 full factorial techniques. This paper aimed at determining the interaction of the physicochemical properties on the developed cutting fluids. Emulsifiers, antifoam agents, biocide, and anti-corrosive agents were considered as natural variables. The effect of the natural variables on the acidity index and viscosity of cutting fluids were fully analyzed with ANOVA, contour, and surface plots. From the responses obtained from the experiment as explained by the independent variables (emulsifying agent, anti-corrosion agent, biocide, and antifoam agent), the watermelon seed oil-based cutting fluid was 89% accurate, while the jatropha oil-based cutting fluid was 75% accurate.

Keywords: ANOVA; cutting fluids; physicochemical properties; vegetable oils; contour; surface plots

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1. Introduction

As oilseeds are predominantly produced for their oil and meal, there has been an increase in the global production of oilseeds over the last 30 years [1]. This would tend to be linked to an increased demand for oilseed products and by-products. The negative impacts of conventional cutting fluid on the environment and the health of the machinist are a major barrier to sustainable machining. Cutting fluids are primarily used in a machining operation to satisfy the cutting functions and non-cutting functions. The cutting functions are to reduce the heat generated during machining by cooling the machining interface; serve as a lubricant and protective film layer to the tool-workpiece interface to avoid the gumming of the cutting tool, and thereby enhance the tool life; and to enhance the surface quality of the machined product. The non-cutting functions take care of the environmental impacts and the health of the operator. According to various research reports, vegetable oil has the potential for fulfilling the cutting functions and non-cutting functions of cutting

fluids because of its lubricity properties. Therefore, vegetable oil will not only serve as an essential part of man's diet, but will also improve sustainable practices in machining operations. Vegetable oils have attracted growing interest due to growing environmental advantages and the fact that they are based on renewable resources [2].

Cutting fluid production can use a range of different oil sources. For the manufacturing of cutting fluid, non-edible vegetable oils, also known as second-generation fuel sources, can be regarded as potential substitutes for conventional edible food sources. Because of the high need for edible oils as a food source for humans, the utilization of non-edible plant oils is particularly important. Furthermore, the feedstock prices of culinary oils are simply too high to be employed as a cutting fluid. As a result, making cutting fluid from non-edible oils is an excellent technique to avoid all of the complications that come with using edible oils. The potential for transforming non-edible oil into cutting fluid, on the other hand, must be thoroughly investigated. This is because the physical and chemical qualities of cutting fluid formed from any feedstock must meet the limits of the cutting fluid standard of specifications [3]. The knowledge of the classification of vegetable oil as edible or non-edible is possible because of the physicochemical properties, and these will stimulate the potential of producing cutting fluids from non-edible vegetable oils.

Physicochemical properties are the intrinsic physical and chemical characteristics of a substance [4]. A chemical property is any property of a material that emerges throughout a chemical reaction; that is, any feature that could only be generated by altering a material's chemical characteristics. Chemical qualities cannot be established simply by looking at or touching a thing; the material's interior composition must be altered to explore its chemical properties. Physical qualities, on the other hand, are those that can be quantified or examined without affecting the material's chemical composition. A lot of chemical reactions take place when machining at elevated temperatures, and the heat generated causes mist that can be easily inhaled by the machinist. Knowledge of the physicochemical properties is needed to eliminate unsafe practices in machining [5].

The applicability of vegetable oils in the industry for the generation of biofuel, bio-lubricant, or polymer is dependent on their physicochemical properties because determining the best operating parameters and scaling-up of these processes require knowledge of several physicochemical parameters such as viscosity, acid value, density, refractive index, specific heat capacity, saponification value, iodine value, and peroxide value [6]. All of these physicochemical parameter values are intrinsic features of oils and also indicate an overall condition of the oils' unsaturation [7]. To evaluate the constituent composition of oils, many physical and chemical criteria of edible oil have been used [8,9]. Several researchers have investigated the effect of temperature on the oil stability, viscosity, peroxide value, and iodine value to determine the oil's quality and functioning [10,11]. The composition and physical and chemical properties of the oils suggest the applicability of the oil and will also help to monitor the individual structure of the vegetable oil. This study was designed to investigate the effect of two lesser-known vegetable oils as potential cutting fluids in machining, with emphasis on some of their physicochemical properties.

2. Methodology

Six liters of vegetable oils were extracted from each of the watermelon and jatropha seeds, which is due to the high percentage of oil recovery for solvent extraction. Viscous washing soap (8–12 mL), sodium molybdate (1–2 mL), triziane (0.5–1.0 mL), and silicones (0.5–1.0 mL) were added as additives to the vegetable oils using 2⁴ factorial designs to determine the best combinations [12,13]. Each assay was formulated by first mixing oil in water, followed by the four additives. Each assay contained a total volume of 100 mL. The aim was to study the best composition for these formulations and the efficiency of the additives. This mixture was carried out with the aid of a mechanical magnetic stirrer at 760 rpm for 10 min at a room temperature of 25 °C. Magnetic stirrers are silent and provide the possibility of stirring closed systems without the need for isolation, as in the case of mechanical agitation, and the mixture was uniformly mixed and no separation

after the mixture was observed. The 16 samples were characterized to identify the acid values and viscosity. The acid values of the extracted oils were carried out in triplicate with the procedure adopted from [14,15] and were evaluated using Equation (1). On the other hand, the viscosities of the samples were evaluated using an Oswald kinematic viscometer [16,17] at a temperature of 80 °C and were evaluated using the relationship in Equation (2). The oils' viscosities were evaluated at a temperature of 80 °C to further check the conformation to viscosity limit at an elevated temperature, as machining is done at an elevated temperature. The photographic view of the viscosity measurement is shown in Figure 1. Minitab software 16 was adopted for the full factorial technique, contour plot, and surface plot analyses. Response surface methodology (RSM) is a sequential procedure and is used to optimize the process parameters and to find the sweet spot for multi-response parameters. The response variables can be influenced by several independent variables, and four phases of RSM were employed in the research, namely, discovery, breakthrough, optimization, and validation. The optimum point is where the sources are minimum, and the output is maximum and we move rapidly sequentially toward the optimum point with a method of steepest ascent. Central composite design (CCD) was used to spot the curvature in the design model. Analysis of variance (ANOVA) was used to determine the parameters that greatly affect the response variable.

$$\text{Acid Value} = \frac{56.1 \times M_o \times V_o}{W_s} \quad (1)$$

where M_o is the molarity of KOH (M), V_o = vol. of KOH (mL), and W_s is the weight of the sample (kg)

$$\text{Viscosity} = P\rho t - \frac{Q\rho}{t} \quad (2)$$

where ρ is the density in g/mL, t is time in seconds, and P and Q are the constants.

Figure 1. Determination of the kinematic viscosity.

3. Results and Discussion

The analysis of the physicochemical properties of watermelon seed oil-based cutting fluid was carried out using the four natural variables (emulsifier, antifoam, anti-corrosive agent, and biocide), as presented in Table 1. All of the measurements were taken in triplicates and the average values are recorded in the entire tables.

Table 1. Analysis of the physicochemical properties of the prepared watermelon seed oil-based cutting fluids.

Natural Variables				Coded Values				Responses	
Emulsifying Agent (EA)	Anti-Corrosion Agent (ACA)	Biocide (BI)	Antifoam Agent (AFA)	A	B	C	D	Acid Value (mg)	Viscosity (cSt)
8	1	0.5	0.5	−1	−1	−1	−1	44.46	47.4
12	2	1	1	1	−1	−1	−1	45.02	50.1
8	1	0.5	0.5	−1	1	−1	−1	44.32	43.2
12	2	1	1	1	1	−1	−1	44.46	51.6
8	1	0.5	0.5	−1	−1	1	−1	44.32	39.7
12	2	1	1	1	−1	1	−1	43.61	45.1
8	1	0.5	0.5	−1	1	1	−1	42.78	46.4
12	2	1	1	1	1	1	−1	42.64	49.9
8	1	0.5	0.5	−1	−1	−1	1	43.34	54.6
12	2	1	1	1	−1	−1	1	43.62	57.7
8	1	0.5	0.5	−1	1	−1	1	43.90	53.1
12	2	1	1	1	1	−1	1	42.92	48.4
8	1	0.5	0.5	−1	−1	1	1	43.62	49.4
12	2	1	1	1	−1	1	1	41.65	51.7
8	1	0.5	0.5	−1	1	1	1	42.92	53.7
12	2	1	1	1	1	1	1	42.36	50.7

Given that the natural variables are the emulsifying agent, anti-corrosion agent, biocide, and antifoam agent, their transformations to coded values are given by Equations (3)–(6):

$$A = \frac{(EA - 10)}{2} \quad (3)$$

$$B = \frac{(ACA - 1.5)}{0.5} \quad (4)$$

$$C = \frac{(BI - 0.75)}{0.25} \quad (5)$$

$$D = \frac{(AFA - 0.75)}{0.25} \quad (6)$$

3.1. Response Surface Regression: Acid Value vs. A, B, C, and D

Tables 2 and 3 show the responses from the surface regression for acid values in watermelon seed oil-based for the estimated regression coefficient and analysis of variance, respectively.

Table 2. Estimated regression coefficients for acid value of watermelon seed oil-based.

Term	Coefficient	SE Coefficient	T	p
Constant	43.4963	0.1254	346.776	0.000
A	−0.2113	0.1254	−1.684	0.153
B	−0.2087	0.1254	−1.664	0.157
C	−0.5088	0.1254	−4.056	0.010
D	−0.4550	0.1254	−3.628	0.015
A*B	0.0188	0.1254	0.149	0.887
A*C	−0.2113	0.1254	−1.684	0.153
A*D	−0.1925	0.1254	−1.535	0.185
B*C	−0.1037	0.1254	−0.827	0.446
B*D	0.1925	0.1254	1.535	0.185
C*D	0.1050	0.1254	0.837	0.441

Table 3. Analysis of variance for acid value of watermelon seed oil-based.

Source	DF	SEQ SS	ADJ SS	ADJ MS	F	p
Regression	10	11.1190	11.1190	1.11190	4.42	0.057
Linear	4	8.8649	8.8649	2.21622	8.80	0.017
A	1	0.7140	0.7140	0.71403	2.84	0.153
B	1	0.6972	0.6972	0.69722	2.77	0.157
C	1	4.1412	4.1412	4.14123	16.45	0.010
D	1	3.3124	3.3124	3.31240	13.16	0.015
Interaction	6	2.2541	2.2541	0.37568	1.49	0.339
A*B	1	0.0056	0.0056	0.00563	0.02	0.887
A*C	1	0.7140	0.7140	0.71403	2.84	0.153
A*D	1	0.5929	0.5929	0.59290	2.36	0.185
B*C	1	0.1722	0.1722	0.17222	0.68	0.446
B*D	1	0.5929	0.5929	0.59290	2.36	0.185
C*D	1	0.1764	0.1764	0.17640	0.70	0.441
Residual	5	1.2586	1.2586	0.25172		
Error						
Total	15	12.3776				

From Table 4, the acid value of watermelon vs. A, B, C, and D, it was observed that only biocide and antifoam agents were significant using the response surface technique. The optimized model for the response surface is given by Equation (7):

$$\text{Acid Value} = 43.4963 + 0.5088C - 0.4550D \quad (7)$$

Table 4. Table of coefficients for the acid values.

Term	Coefficient	p-Value
Constant	43.4963	0.000 *
A	−0.2113	0.153
B	−0.2087	0.157
C	−0.5088	0.010 *
D	−0.4550	0.015 *
AB	0.0188	0.887
AC	−0.2113	0.153
AD	−0.1925	0.185
BC	−0.1037	0.446
BD	0.1925	0.185
CD	0.1050	0.445

Coefficients significant at 5%. * represents 95% confidence interval, ** represents 90% confidence interval. Same in the tables below.

Only the significant coefficients at 5% were selected in the equation. The R-squared indicating the “validity of the model” indicates that the independent variables predicted roughly 89% of the responses obtained from the acidity test (emulsifying agent, anti-corrosion agent, biocide, and antifoam agent). As a result, the developed model is 89% suitable. The aggregate of all linear effects and interaction effects (which compensate for the regression effect) is significant at 10%, but not at 5%, according to Table 5. Figures 2 and 3 show how the addition of a biocide and an antifoam agent alters the acidity of watermelon seed oil-based when used as a cutting fluid. Values greater than 44.5 were discovered to be the acidity peak; this was reached strictly around −1 biocide and −1 antifoam agent (using coded values). This means that when the biocide and antifoam agents contribute 0.525% each, the acidity of watermelon seed oil-based used as a cutting fluid will be larger than 44.5. Around the region where the biocide is 0.7 and the antifoam agent is 0.5, the acid value was found to be less than 43. Biocide and antifoam agents provide 0.925% and 0.875%, respectively, in this region.

Table 5. Analysis of variance for the acid value.

Source		SS	DF	MS	F	p-Value
Regression	A	0.714	1	0.714	2.84	0.153
	B	0.6972	1	0.6972	2.77	0.157
	C	4.1412	1	4.1412	16.45	0.010 *
	D	3.3124	1	3.3124	13.16	0.015 *
	AB	0.0056	1	0.0056	0.02	0.887
	AC	0.714	1	0.714	2.84	0.153
	AD	0.5929	1	0.5929	2.36	0.185
	BC	0.1722	1	0.1722	0.68	0.446
	BD	0.5929	1	0.5929	2.36	0.185
	CD	0.1764	1	0.1764	0.7	0.441
Residual						
Error		1.2586	5	0.2517		
Total		12.3776	15

Figure 2. Contour plot of acid values vs. biocide (C) and antifoam agent (D). **Figure 3.** Surface plot of acid values vs. biocide (C) and antifoam agent (D).

3.2. Response Surface Regression: Viscosity vs. A, B, C, and D

Tables 6 and 7 show the responses from surface regression for the viscosity of watermelon seeds oil-based for estimated regression coefficient and analysis of variance respectively.

Table 6. Estimated regression coefficients for viscosity of watermelon seed oil-based.

Term	COEF	SE COEF	T	p
Constant	49.5438	0.5750	86.158	0.000
A	1.1063	0.5750	1.924	0.112
B	0.0813	0.5750	0.141	0.893
C	−1.2188	0.5750	−2.119	0.088
D	2.8688	0.5750	4.989	0.004
A*B	−0.5813	0.5750	−1.011	0.358
A*C	−0.0812	0.5750	−0.141	0.893
A*D	−1.3937	0.5750	−2.424	0.060
B*C	1.7687	0.5750	3.076	0.028
B*D	−1.0188	0.5750	−1.772	0.137
C*D	0.1813	0.5750	0.315	0.765

Table 7. Responses from surface regression for the viscosity of watermelon seed oil-based.

Source	DF	SEQ SS	ADJ SS	ADJ MS	F	p
Regression	10	278.906	278.906	27.891	5.27	0.040
Linear	4	175.128	175.128	43.782	8.28	0.020
A	1	19.581	19.581	19.581	3.70	0.112
B	1	0.106	0.106	0.106	0.02	0.893
C	1	23.766	23.766	23.766	4.49	0.088
D	1	131.676	131.676	131.676	24.89	0.004
Interaction	6	103.779	103.779	17.296	3.27	0.107
A*B	1	5.406	5.406	5.406	1.02	0.358
A*C	1	0.106	0.106	0.106	0.02	0.893
A*D	1	31.081	31.081	31.081	5.87	0.060
B*C	1	50.056	50.056	50.081	9.46	0.028
B*D	1	16.606	16.606	16.606	3.14	0.137
C*D	1	0.526	0.526	0.526	0.10	0.765
Residual	5	26.453	26.453	5.291		
Error						
Total	15	305.359				

From Table 8 for viscosity vs. A, B, C, and D, it was observed that only the antifoam agent and the interaction effect between “anti-corrosion agent and biocide” were significant at 5%, meanwhile biocide and the interaction effect between “emulsifying agent” were significant at 10%, using the response surface technique. Equations (8) and (9) give the optimal model for the response surface at 5% and 10% significant levels, respectively:

$$\text{Viscosity} = 49.5483 + 2.8688D + 1.7687BC \quad (8)$$

$$\text{Viscosity} = 49.5483 - 1.2188C + 2.8688D - 1.3937AD + 1.7687BC \quad (9)$$

Table 8. Table of coefficients for viscosity of watermelon seed oil-based.

Term	Coefficient	p-Value
Constant	49.5483	0.000 *
A	1.1063	0.112
B	0.0813	0.893
C	−1.2188	0.088 **
D	2.8688	0.004 *
AB	−0.5813	0.358
AC	−0.0812	0.893
AD	−1.3937	0.060 **
BC	1.7687	0.028 *
BD	−1.0188	0.137
CD	0.1813	0.765

The “adequacy of the model” R-squared shows that the independent variables explained roughly 91% of the responses obtained from the acidity experiment (emulsifying agent, anti-corrosion agent, biocide, and antifoam agent). This signifies that the designed model is 91% acceptable. Table 9 also demonstrates that the sum of all linear and interaction effects (which account for the regression effect) is statistically significant at 5%.

Table 9. Regression effect for the viscosity of watermelon seed oil-based.

Source		SS	DF	MS	F	p-Value
Regression	A	19.581	1	19.581	3.7	0.112
	B	0.106	1	0.106	0.02	0.893
	C	23.766	1	23.766	4.49	0.088 **
	D	131.676	1	131.676	24.89	0.004 *
	AB	5.406	1	5.406	1.02	0.358
	AC	0.106	1	0.106	0.02	0.893
	AD	31.081	1	31.081	5.87	0.060 **
	BC	50.056	1	50.056	9.46	0.028 *
	BD	16.606	1	16.606	3.14	0.137
	CD	0.526	1	0.526	0.1	0.765
Residual						
Error		26.45	5	5.291		
Total		305.4	15			

The contour and surface plots in Figures 4 and 5 illustrate how biocide and antifoam agents impact the viscosity of watermelon seed oil-based when used as a cutting fluid. The viscosity peak was found to be more than 52.5 in a region where the viscosity was fairly eased around −0.5 biocide and 0.6 antifoam (using the coded values). This denotes that when watermelon seed oil-based is used as a cutting fluid, the viscosity will exceed 52.5, with biocide and antifoam agent contributions of 0.625% and 0.9%, respectively. The minimum viscosity was found to be less than 46.5 when biocide was loosely around the region of 0.7 and the antifoam agent was also loosely around −0.9 (using coded values). This implies that, to obtain minimum viscosity of values less than 46.5, the contribution from the biocide should be in the region (or slightly deviating from) of 0.925%, and the contribution from the antifoam agent should be in the region (or slightly deviating from) of 0.525%. Figures 6 and 7 show how anti-corrosion and antifoam additives affect the viscosity of watermelon seed oil-based when used as a cutting fluid, respectively. The peak of viscosity was attained in the region of 0.7 for antifoam agents and −0.6 for anti-corrosion agents with values greater than 52 (using coded values). It was also observed that the region around these peak values of viscosity was fairly loose; hence, a little deviation in the contribution of these substances is not expected to disrupt the peakedness of the viscosity of the watermelon seed oil-based cutting fluid [17]. This indicates that when watermelon seed oil-based is used as a cutting fluid, the viscosity will surpass 52 when the antifoam

agent contribution is at (or slightly diverging from) 0.925%, and the anti-corrosion agent contribution is at (or slightly deviating from) 1.2%. The viscosity was determined to be at its lowest with values less than 46 in a zone where the antifoam agent and anti-corrosion agent were both strictly -1 . Thus, to achieve a minimum viscosity value of less than 46, the contribution of the antifoam agent must not deviate from 0.5%, and the contribution of the anti-corrosion agent must not stray from 1%.

Figure 4. Contour plot of viscosity vs. biocide (C) and antifoam agents (D).

Figure 5. Surface plot of viscosity vs. biocide (C) and antifoam agents (D).

Figure 6. Contour plot of viscosity vs. anti-corrosive (B) and antifoam agents (D).

Figure 7. Surface plot of viscosity vs. anti-corrosive (B) and antifoam agents (D).

The four natural variables (emulsifier, antifoam, anti-corrosive agent, and biocide) were used to analyze the physicochemical parameters of jatropha oil-based cutting fluid, as shown in Table 10.

Table 10. Analysis of the physicochemical properties of the prepared jatropha oil-based cutting fluids.

Natural Variables				Coded Values				Responses	
Emulsifying Agent (EA)	Anti-Corrosion Agent (ACA)	Biocide (BI)	Antifoam Agent (AFA)	A	B	C	D	Acid Value (mg)	Viscosity (cSt)
8	1	0.5	0.5	−1	−1	−1	−1	40.39	49.4
12	2	1	1	1	−1	−1	−1	40.11	48.1
8	1	0.5	0.5	−1	1	−1	−1	40.67	66.4
12	2	1	1	1	1	−1	−1	40.95	56.6
8	1	0.5	0.5	−1	−1	1	−1	39.97	47.3
12	2	1	1	1	−1	1	−1	39.83	65.5
8	1	0.5	0.5	−1	1	1	−1	40.53	47.8
12	2	1	1	1	1	1	−1	40.25	54.2
8	1	0.5	0.5	−1	−1	−1	1	40.39	56.3
12	2	1	1	1	−1	−1	1	38.57	44.8
8	1	0.5	0.5	−1	1	−1	1	39.97	58.6
12	2	1	1	1	1	−1	1	40.11	58.4
8	1	0.5	0.5	−1	−1	1	1	38.42	72.5
12	2	1	1	1	−1	1	1	39.27	65.3
8	1	0.5	0.5	−1	1	1	1	40.11	73.0
12	2	1	1	1	1	1	1	40.12	64.5

3.3. Response Surface Regression: Acid Value vs. A, B, C, and D

Tables 11 and 12 show the responses from the surface regression for the acid value of jatropha oil-based cutting fluid for the estimated regression coefficient and analysis of variance, respectively.

Table 11. Estimated regression coefficients for the acid value of jatropha oil-based cutting fluid.

Term	COEF	SE COEF	T	p
Constant	39.9787	0.1488	268.655	0.000
A	−0.0775	0.1488	−0.521	0.625
B	0.3600	0.1488	2.419	0.060
C	−0.1663	0.1488	−1.117	0.315
D	−0.3588	0.1488	−2.411	0.061
A*B	0.0962	0.1488	0.647	0.546
A*C	0.1325	0.1488	0.890	0.414
A*D	−0.0250	0.1488	−0.168	0.873
B*C	0.0800	0.1488	0.538	0.614
B*D	0.0975	0.1488	0.655	0.541
C*D	0.0263	0.1488	0.176	0.867

According to Table 13 (table of coefficients) for the acid value (of jatropha) vs. A, B, C, and D, none of the qualities were significant at 5% by using the response surface technique; however, at 10% level of significance, the anti-corrosion and antifoam agents were noteworthy. The prediction fit for the response surface is given by Equation (10):

$$\text{Acid Value} = 39.9787 + 0.3600B - 0.3588D \quad (10)$$

Table 12. Analysis of variance for the acid value of jatropha oil-based cutting fluid.

Source	DF	SEQ SS	ADJ SS	ADJ MS	F	S
Regression	10	5.37580	5.37580	0.53758	1.52	0.338
Linear	4	4.67115	4.67115	1.16779	3.30	0.112
A	1	0.09610	0.09610	0.09610	0.27	0.625
B	1	2.07360	2.07360	2.07360	5.85	0.060
C	1	0.44223	0.44223	0.44223	1.25	0.315
D	1	2.05923	2.05923	2.05923	5.81	0.061
Interaction	6	0.70465	0.70465	0.11744	0.33	0.894
A*B	1	0.14822	0.14822	0.14822	0.42	0.546
A*C	1	0.28090	0.28090	0.28090	0.79	0.414
A*D	1	0.01000	0.01000	0.01000	0.03	0.873
B*C	1	0.10240	0.10240	0.10240	0.29	0.614
B*D	1	0.15210	0.15210	0.15210	0.43	0.541
C*D	1	0.01103	0.01103	0.01103	0.03	0.867
Residual	5	1.77158	1.77158	0.35432		
Error						
Total	15	7.14738				

Table 13. Table of coefficient for acid values.

Term	Coefficient	p-Value
Constant	39.9787	0.000 *
A	−0.0775	0.625
B	0.3600	0.060 **
C	−0.1663	0.315
D	−0.3588	0.061 **
AB	0.0962	0.546
AC	0.1325	0.414
AD	−0.0250	0.873
BC	0.0800	0.614
BD	0.0975	0.541
CD	0.0263	0.867

Coefficients significant at 5%.

Only the significant coefficients at 10% were selected in the equation. The R-squared indicating the “accuracy of the model” indicates that the independent variables explained approximately 75% of the responses obtained from the acidity experiment (emulsifying agent, anti-corrosion agent, biocide, and antifoam agent). This implies that the planned model is 75% adequate in agreement with the work reported in [18]. The ANOVA table (see Table 14) also demonstrates that the sum of all linear effects and interaction effects (which compensate for the regression effect) is not significant at 5% or 10%.

Figures 8 and 9 demonstrate the contour and surface plots of how anti-corrosion and antifoam chemicals alter the acidity of jatropha oil when used as a cutting fluid. The greatest achievable acid values were over 40.5; at this point of acidity, antifoam and anti-corrosion agents are anticipated to strictly lie in the region of −0.9 and 0.9, respectively (using coded values). This explains that the maximal acid value of jatropha oil can be obtained only with 0.525% antifoam agent and 1.95% anti-corrosion agent. The contribution deviation is fairly stringent, thus any noticeable effect will cause the acidity to deviate from its peak [19]. The minimal acidity was found to be less than 39.3 in an area where the antifoam and anti-corrosion agents are both strictly 0.9 (using coded values). This means that for jatropha oil to have the lowest acidity value, the simultaneous contributions of the antifoam and anti-corrosion agents must be 0.975% and 1.05%, respectively, with no fluctuation tolerated.

Table 14. Analysis of variance for acid values.

Source		SS	DF	MS	F	<i>p</i> -Value
A		0.0961	1	0.5376	0.27	0.625
B		2.0736	1	0.0961	5.85	0.06
C		0.4422	1	2.0736	1.25	0.315
D		2.0592	1	0.4422	5.81	0.061
AB		0.1482	1	2.0592	0.42	0.546
AC		0.2809	1	0.1482	0.79	0.414
AD		0.01	1	0.2809	0.03	0.873
BC		0.1024	1	0.01	0.29	0.614
BD		0.1521	1	0.1024	0.43	0.541
CD		0.011	1	0.1521	0.03	0.867
Residual						
Error		1.7716	5	0.3543		
Total		7.1474	15

Figure 8. Contour plot of acid value vs. anti-corrosion agent (B) and antifoam agent (D). **Figure 9.** Surface plot of acid value vs. anti-corrosion agent (B) and antifoam agent (D).

3.4. Response Surface Regression: Viscosity vs. A, B, C, and D

Tables 15 and 16 show the responses from the surface regression for the viscosity of jatropha oil-based cutting fluid for the estimated regression coefficient and analysis of variance, respectively.

Table 15. Estimated surface regression coefficients for the viscosity of jatropha oil-based cutting fluid.

Term	COEF	SE COEF	T	p
Constant	58.0438	1.590	36.497	0.000
A	−0.8687	1.590	−0.546	0.608
B	1.8938	1.590	1.191	0.287
C	3.2188	1.590	2.024	0.099
D	3.6312	1.590	2.283	0.071
A*B	3.6312	1.590	−0.405	0.702
A*C	1.9813	1.590	1.246	0.268
A*D	−2.5563	1.590	−1.607	0.169
B*C	−3.2813	1.590	−2.063	0.094
B*D	0.0562	1.590	0.035	0.973
C*D	3.9313	1.590	2.472	0.056

Table 16. Analysis of variance for viscosity of jatropha oil-based cutting fluid.

Source	DF	SEQ SS	ADJ SS	ADJ MS	F	p
Regression	10	1039.78	1039.78	103.978	2.57	0.155
Linear	4	446.20	446.20	111.549	2.76	0.148
A	1	12.08	12.08	12.076	0.30	0.608
B	1	57.38	57.38	57.381	1.42	0.287
C	1	165.77	165.77	165.766	4.10	0.099
D	1	210.98	210.98	210.976	5.21	0.071
Interaction	6	593.58	593.58	98.930	2.44	0.173
A*B	1	6.63	6.63	6.631	0.16	0.702
A*C	1	62.81	62.81	62.806	1.55	0.268
A*D	1	104.55	104.55	104.551	2.58	0.169
B*C	1	172.27	172.27	172.266	4.26	0.094
B*D	1	0.05	0.05	0.051	0.00	0.973
C*D	1	247.28	247.28	247.276	6.11	0.056
Residual	5	202.34	202.34	40.469		
Error						
Total	15	1242.12				

Table 17 (table of coefficients) for viscosity (of jatropha) vs. A, B, C, and D reveals that neither of the properties were significant at 5% using the response surface technique, but biocide, antifoam agents, the interaction effect of “anti-corrosion agents and biocide”, and the interaction effect of “biocide and antifoam agents” were significant at 10% statistical significance. Equation (11) gives the predictive fit for the response surface:

$$\text{Viscosity} = 58.0438 + 3.2188C + 3.6312D - 3.2813BC + 3.9313CD \quad (11)$$

Table 17. Table of coefficient for viscosity of jatropha.

Term	Coefficient	p-Value
Constant	58.0438	0.000 *
A	−0.8687	0.608
B	1.8938	0.287
C	3.2188	0.099 **
D	3.6312	0.071 **
AB	−0.6438	0.702
AC	1.9813	0.268
AD	−2.5563	0.169
BC	−3.2813	0.094 **
BD	0.0562	0.973
CD	3.9313	0.056 **

Coefficients significant at 5%.

In the equation, only significant coefficients at 10% were chosen. The R-squared indicating “model adequacy” demonstrates that the independent variables explained roughly 83% of the responses obtained from the acidity experiment (emulsifying agent, anti-corrosion agent, biocide, and antifoam agent). As a result, the developed model is 83% acceptable. Table 18 also demonstrates that the sum of all linear and interaction effects (which account for the regression effect) is not statically important at 5% or 10%.

Table 18. Regression effect for the viscosity of jatropha oil.

Source	SS	DF	MS	F	p-Value
Regression					
A	12.08	1	12.08	0.3	0.608
B	57.38	1	57.38	1.42	0.287
C	165.77	1	165.77	4.1	0.099
D	210.98	1	210.98	5.21	0.071
AB	6.63	1	6.63	0.16	0.702
AC	62.81	1	62.81	1.55	0.268
AD	104.55	1	104.55	2.58	0.169
BC	172.27	1	172.27	4.26	0.094
BD	0.05	1	0.05	0	0.973
CD	247.34	1	247.34	6.11	0.056
Residual					
Error	202.34	5			
Total	1242.12	15			

The contour and surface plots of how biocide and antifoam agents alter the viscosity of jatropha oil when used as a cutting fluid are shown in Figures 10 and 11. The optimum viscosity was found to be in the range of 1.0 for the antifoam agent and 1.0 for the biocide (applying coded values); the viscosity of jatropha oil was estimated to be more than 67.5 in this range. This means that to achieve a viscosity peak of more than 67.5, the antifoam agent and biocide should both be kept at a minimum of 1%, and this is inconsonant with the research carried out in [20]. Because the proportion of these compounds is so rigorous, anything less than 1% of biocide and antifoam agents will prevent the viscosity from reaching its peak. At a location where the antifoam is slightly strict on −1 and the biocide is quite free on 0.5, the least viscosity available was found to be below 55 (using coded values). This means that when antifoam is exactly 0.5% and biocide is loosely about 0.875%, the viscosity can be reduced to its bare minimum.

Figure 10. Contour plot of acid value vs. biocide (C) and antifoam agent (D).

Figure 11. Surface plot of viscosity vs. biocide (C) and antifoam agent (D).

The summary of the physicochemical properties of watermelon and jatropha oil-based cutting fluids are presented in Tables 19 and 20 for acid values and viscosities, respectively.

Table 19. Comparison of the physicochemical properties regarding acidity of fluids.

Cutting Fluid	Contributing Value	Minimum	Value	Maximum	Value
Jatropha oil	Emulsifying agent	0		0	
	Anti-corrosive agent	0		0	
	Biocide	0.93%	<43	0.53%	>44.5
	Antifoam agent	0.88%		0.53%	
Watermelon seeds oil-based	Emulsifying agent	0		0	
	Anti-corrosive agent	1.05%		1.95%	
	Biocide	0	<39.3	0	>40.5
	Antifoam agent	0.98%		0.53%	

Table 20. Comparison of the physicochemical properties regarding viscosity of fluids.

Cutting Fluid	Contributing Value	Minimum	Value	Maximum	Value
Jatropha oil	Emulsifying agent	0		0	
	Anti-corrosive agent	0		0	
	Biocide	0.93%	46.5	0.625	>52.5
	Antifoam agent	0.53%		0.9	
Jatropha oil	Emulsifying agent	0		0	
	Anti-corrosive agent	0.50%		1.20%	
	Biocide	0	<46.5	0	>52.0
	Antifoam agent	1.00%		0.93%	
Watermelon seed oil-based	Emulsifying agent	0		0	
	Anti-corrosive agent	0		0	
	Biocide	0.88%	<55	1%	>67.5
	Antifoam agent	0.50%		1%	

4. Conclusions

The analyses of the physicochemical properties of the watermelon seeds and jatropha oil-based cutting fluids prepared were carried out. The natural variables are an emulsifying agent, anti-corrosion agent, biocide, and antifoam agent. The R-squared showing the “adequacy of the model” for the two prepared cutting fluids was adequate from the responses obtained from the acidity experiment, as explained by the independent variables (emulsifying agent, anti-corrosion agent, biocide, and antifoam agent). The watermelon seed oil-based cutting fluid was 89% accurate, while the jatropha cutting fluid was 75% accurate. ANOVA revealed that the combination of all linear and interaction effects (which make up for the regression effect) was not significant at 5% watermelon seed oil-based and jatropha cutting fluids. In addition, none of the linear or interaction effects were found to be significant. The peaks of acidity and viscosity were also determined. The process parameters were carefully selected and optimized in this study, and can be adopted by future researchers either working on the optimization of the physicochemical properties of watermelon seed and/or jatropha oil-based cutting fluids.

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References

- Wang, H.J.; Murphy, P.A. Isoflavone composition of American and Japanese soybeans in Iowa: Effects of variety, crop year, and location. *J. Agric. Food Chem.* **1994**, *42*, 1674–1677. [\[CrossRef\]](#)
- Demirbas, A. Relationships derived from physical properties of vegetable oil and biodiesel fuels. *Fuel* **2008**, *87*, 1743–1748. [\[CrossRef\]](#)
- Atabani, A.E.; Silitonga, A.S.; Ong, H.C.; Mahlia, T.M.I.; Masjuki, H.H.; Badruddin, I.A.; Fayaz, H. Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production. *Renew. Sustain. Energy Rev.* **2013**, *18*, 211–245. [\[CrossRef\]](#)
- Bartolomei, M.; Bertocchi, P.; Antoniella, E.; Rodomonte, A. Physico-chemical characterisation and intrinsic dissolution studies of a new hydrate form of diclofenac sodium: Comparison with anhydrous form. *J. Pharm. Biomed. Anal.* **2006**, *40*, 1105–1113. [\[CrossRef\]](#) [\[PubMed\]](#)
- Kazeem, R.A.; Fadare, D.A.; Abutu, J.; Lawal, S.A.; Adesina, O.S. Performance evaluation of jatropha oil-based cutting fluid in turning AISI 1525 steel alloy. *CIRP J. Manuf. Sci. Technol.* **2020**, *31*, 418–430. [\[CrossRef\]](#)
- Mengyue, C.; Hui, H.; Xiaoshuang, S.; Xiuyang, J.; Binggui, C. The gradual change characteristics at the end of the Younger Dryas event inferred from a speleothem record from Xianyun Cave, Fujian Province. *Quat. Sci.* **2018**, *38*, 711–719.
- Knothe, G.; Dunn, R.O. Dependence of oil stability index of fatty compounds on their structure and concentration and presence of metals. *J. Am. Oil Chem. Soc.* **2003**, *80*, 1021–1026. [\[CrossRef\]](#)
- Ceriani, R.; Paiva, F.R.; Gonçalves, C.B.; Batista, E.A.C.; Meirelles, A.J.A. Densities and viscosities of vegetable oils of nutritional value. *J. Chem. Eng. Data* **2008**, *53*, 1846–1853. [\[CrossRef\]](#)
- Mousavi, K.; Shoeibi, S.; Ameri, M. Effects of storage conditions and PET packaging on quality of edible oils in Iran. *Adv. Environ. Biol.* **2012**, *6*, 694–701.
- Farhoosh, R.; Moosai, S.M.R.; Sharif, A. Investigation on frying oils quality in terms of color index, refractive index and viscosity during frying process. *J. Food Sci. Technol.* **2008**, *5*, 13–19.
- Pan, J.F.; Shen, H.X.; You, J.; Luo, Y.K. Changes in physiochemical properties of Myofibrillar protein from Silver Carp (*Hypophthalmichthys molitrix*) during heat treatment. *J. Food Biochem.* **2011**, *35*, 939–952. [\[CrossRef\]](#)
- Kazeem, R.A.; Fadare, D.A.; Ikumapayi, O.M.; Azeez, T.M.; Adediran, A.A. Development of Bio-Cutting Fluid (*Cirtullus lanatus*) and its Performance Assessment on the Machining of AISI 1525 Steel Using Taguchi Technique and Grey Relational Analysis. *Biointerface Res. Appl. Chem.* **2022**, *12*, 5324–5346.
- Sidney, W.; AOAC. *Official Methods of Analysis*, 14th ed.; Association of Official Analytical Chemists: Arlington, VA, USA, 1984.
- Oyinbo, S.T.; Ikumapayi, O.M.; Jen, T.C.; Ismail, S.O. Experimental and Numerical prediction of extrusion load at different lubricating conditions of aluminium 6063 alloy in backward cup extrusion. *Eng. Solid Mech.* **2020**, *8*, 119–130. [\[CrossRef\]](#)
- Margheritini, L.; Colaleo, G.; Contestabile, P.; Bjørgård, T.L.; Simonsen, M.E.; Lanfredi, C.; Dell’Anno, A.; Vicinanza, D. Development of an Eco-Sustainable Solution for the Second Life of Decommissioned Oil and Gas Platforms: The Mineral Accretion Technology. *Sustainability* **2020**, *12*, 3742. [\[CrossRef\]](#)
- Singh, H.; Sharma, V.S.; Dogra, M. Exploration of graphene assisted vegetables oil based minimum quantity lubrication for surface grinding of TI-6AL-4V-ELI. *Tribol. Int.* **2020**, *144*, 106113. [\[CrossRef\]](#)
- Kumar, M.S.; Krishna, V.M.; Varun, A. Investigation on influence of Hybrid Biodegradable Nanofluids (CuO-ZnO) on Surface Roughness in Turning AISI 1018 Steel. *Mater. Today Proc.* **2020**, *24*, 1570–1576. [\[CrossRef\]](#)
- Pal, A.; Chatha, S.S.; Sidhu, H.S. Experimental investigation on the performance of MQL drilling of AISI 321 stainless steel using nano-graphene enhanced vegetable-oil-based cutting fluid. *Tribol. Int.* **2020**, *151*, 106508. [\[CrossRef\]](#)
- Singh, Y.; Sharma, A.; Singh, N.K.; Singla, A.; Kumar, R. Moringa Oleifera: Bio based lubricant development from a novel feedstock for tribological characterization. *Adv. Mater. Process. Technol.* **2020**, 1–13. [\[CrossRef\]](#)
- Majak, D.; Olugu, E.U.; Lawal, S.A. Analysis of the effect of sustainable lubricants in the turning of AISI 304 stainless steel. *Procedia Manuf.* **2020**, *43*, 495–502. [\[CrossRef\]](#)