THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 2 - 2023, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2023.2.02

RESEARCH ON THE RICE BRAN OIL – FLAMMABILITY TESTS ON A HIGH TEMPERATURE SURFACE

Liviu Cătălin ȘOLEA, Romică CREȚU
"Dunarea de Jos" University of Galati, Romania
e-mail: csolea@ugal.ro

ABSTRACT

In this work rice oil was tested when it is dripped onto a high temperature surface. The tests conducted determined the lowest temperature at which rice oil ignited and the highest temperature at which rice oil did not ignite in three tests conducted at the same temperature. The results of this study show that the values of the evaluated temperatures are of major importance regarding the use of rice oil as an eco-friendly lubricant. Thus, the highest temperature at which rice oil did not ignites is 465 °C, while the lowest temperature at which rice oil ignited is 470 °C. Moreover, at the end of the 8 tests performed, part of the oils collected in the tray of the installations used in the present study were subjected to spectrophotometric tests. Based on the obtained data, the transmittance spectra were plotted and the trichromatic components and coordinates were calculated, as well as the colour differences of the tested oils.

KEYWORDS: rice bran oil, flammability, CIELAB, chromatic coordinates, colour differences, eco-friendly lubricant

1. Introduction

Flammable liquids and gases, as well as concentrations of solid or liquid particles dispersed in a gaseous medium, can randomly interact with a high-temperature surface and ignite, causing major damage to the installations in which they operate. That is why it is necessary to know with as much probability as possible the maximum temperature at which flammability does not occur, as well as the lowest temperature at which flammability occurs for the sources listed above.

A number of researchers have studied the phenomena that determine the flammability of various liquids and gaseous media on surfaces with high temperatures [1-11]. In his studies, Babrauskas [12] listed and analysed methods for investigating the flammability of liquids, gases, and vapours on high-temperature surfaces. On the other hand, a series of scientific papers [13-15] analysed the flammability on hot surfaces of various types of vegetable oils. Also, in the last period of time, a series of tribological and rheological studies were carried out on rice bran oils, this being considered a potential ecological lubricant [16-21]. The use of bio-lubricants is increasingly recommended [20], especially in the context where recent research [22] shows that under the conditions of forestry strategies, for example, it is necessary to minimize the inevitable effects of anthropogenic climate changes in the future.

2. Experimental results

The flammability tests on a heated surface, for rice oil, were carried out on an installation belonging to the lubricant analysis laboratory of the Faculty of Engineering from "Dunarea de Jos" University of Galați.

The setup and working procedures have been extensively described in [9, 13, 14]. On the surface of the cylinder (Fig. 1), heated to various temperatures, a quantity of 10 ± 0.5 mL of rice oil is dripped, the draining time being 50 ± 5 sec. During the entire test period the temperature of the cylinder remains constant.

Analysing the flammability tests performed by various authors [9-15] for a series of vegetable, mineral and synthetic oils, it resulted that the first temperature test of rice oil should be performed at the temperature of 480 °C.

According to our studies, the test conducted showed that the rice oil ignited after 11 seconds after starting the test (Fig. 1.b). From the first drops that

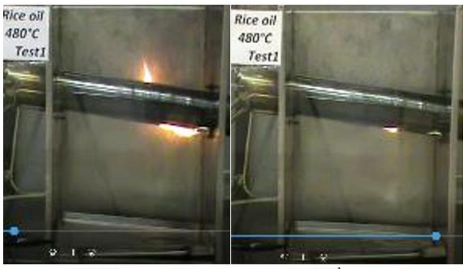
THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 2 - 2023, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2023.2.02

come into contact with the heated cylinder, a lot of smoke is released.

In Figure 1.c (second 21 of the test) the most intense burning of the oil during the test can be seen. It was also observed that the oil continued to burn on the cylinder surface for another 7 seconds after the test ended (Fig. 1.d).

The test temperature was then decreased by 30 °C. The test performed at a temperature of 450 °C established that the oil does not ignite throughout the test (Fig. 2.a), the amount of smoke released when the oil comes into contact with the heated cylinder is insignificant compared to the tests that followed.

a) 1st second *b) 11th second*



c) 21st second *d) 62rd second*

***Fig. 1.** Rice oil tested at 480 °C*

Under these conditions, the next test was performed at a temperature located in the middle of the range between the temperatures of 450 °C and 480 °C, this temperature being 465 °C. The experimental results showed that even at this temperature the rice oil did not ignite, throughout the test (Fig. 2.b). This is the first test at a temperature of 465 °C at which the rice oil did not ignite.

a) 55th second *b)* 55th second

***Fig. 2.** Rice oil tested at 450 °C – test 1 (a) and 465 °C – test 1 (b)*

In order to achieve the proposed objective, the oil was tested at a temperature of 475 °C, a temperature located approximately in the middle of the range 465-480 °C. At this test temperature the oil ignited after 21 seconds from the start of the test (Fig. 3.b). Figure 3.c (second 29 of the test) showed the most intense oil burning during the test. And in this case the oil continues to burn, on the surface of the cylinder, after the test has ended (Fig. 3.d), the burning time being 5 seconds (a time shorter than that recorded in the case of the oil tested at a temperature of 480 °C).

The next test was performed at the next temperature at which the rice oil did not ignite, this temperature being 465 °C. At this temperature, two consecutive tests were performed in which the tested oil did not ignite (Fig. 4).

Thus, the highest temperature (465 °C) at which rice oil does not ignite was established (a total of 3 tests were performed at a temperature of 465 °C where the oil did not ignite) and the lowest temperature (475 °C) in which rice oil ignite.

a) 1st second *b) 21th second*

c) 29th second *d) 60nd second*

***Fig. 3.** Rice oil tested at 475 °C*

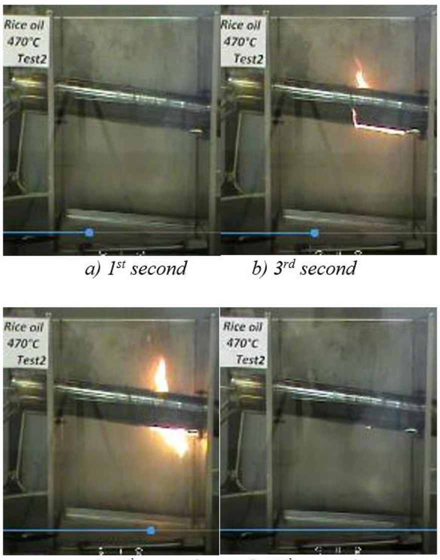
a) 55th second *b)* 55th second

***Fig. 4.** Rice oil tested at 465 °C, test 2 (a) and 465 °C, test 3 (b)*

N°. 2 - 2023, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2023.2.02

Fig. 5. *Rice oil tested at 470 °C, test 1-55th second*

In order to refine the range between the two temperatures, it was decided to carry out a maximum of three more tests halfway between the two temperatures specified above. Thus, tests were carried out at a temperature of 470 °C. The first test performed at the temperature mentioned above revealed that rice oil does not inflame (Fig. 5).



a) 1st second *b) 3rd second* *c) 19th second* *d) 57th second*

Fig. 6. *Rice oil tested at 470 °C, test 2*

In the case of the second test performed at a temperature of 470 °C, the oil ignites after only 3 seconds from the start of the test (Fig. 6.b). According to Figure 6.c (second 19 of the test) the most intense burning of the oil during the test was identified. And in this case the oil continues to burn, on the surface of the cylinder, after the test is over (Fig. 6.d). The burning time was only 2 seconds (a time shorter than that recorded in the case of the oil tested at a temperature of 475 °C).

The lowest temperature at which rice oil ignites is 470 °C, and the highest temperature at which rice oil does not ignite (after 3 tests) is 465 °C.

Figure 7 shows the order and results of the 8 tests performed.

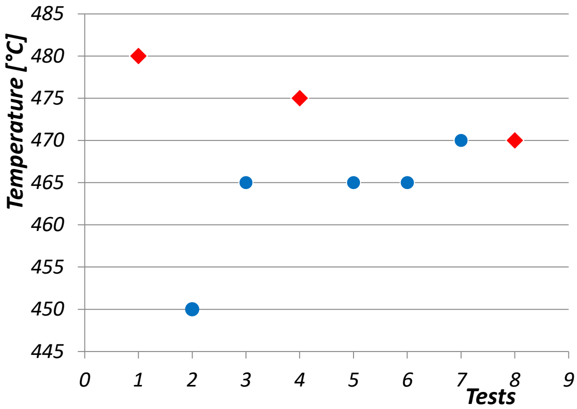


Fig. 7. *Flammability tests for rice oil (the red rhombus – it ignites; the blue circles – it does not ignite)*

At the end of the 8 tests carried out, part of the oils collected in the tray of the installation were subjected to spectrophotometric tests. Thus, the transmittance curves of the untested rice oil, as well as of the samples where the rice oil was tested at the temperature of 470 °C (test 1 – the oil does not burn and test 2 – the oil burns) and for the tested oil were determined at a temperature of 465 °C (test 1 – the oil does not burn).

Transmittance values were determined in the wavelength range of 380-780 nm, using a measurement step of 0.2 nm. A 10 mm glass cuvette was used.

Figure 8 shows the transmittance curves of the oils tested at temperatures of 465 °C (test 1 - the oil did not burn), 470 °C (test 1 - the oil did not burn), 470 °C (test 2 - the oil burned) as well as for untested rice oil.

Based on the experimental values of the transmittances determined at the wavelengths of 445, 495, 550 and 625 nm, the trichromatic components and coordinates were calculated (Table 1), these being the calculation support for determining the chromatic coordinates (Table 2) and the colour differences (Table 3) for the oil samples tested at the above-mentioned temperatures as well as for the untested rice oil.

From the analysis of the transmittance curves (Fig. 8), very small differences can be observed between the oil that was not tested for flammability and the oils that did not ignite at the temperatures of 465 °C and 470 °C, respectively test 1.

On the other hand, a major difference is observed between the case of the oil that ignited at the temperature of 470 °C (test 2) and the untested oil. This is due to the radical chemical transformations through which the lipids and other organic molecules in the oil composition undergo as the working temperature increases, also studied in our recent research [23].

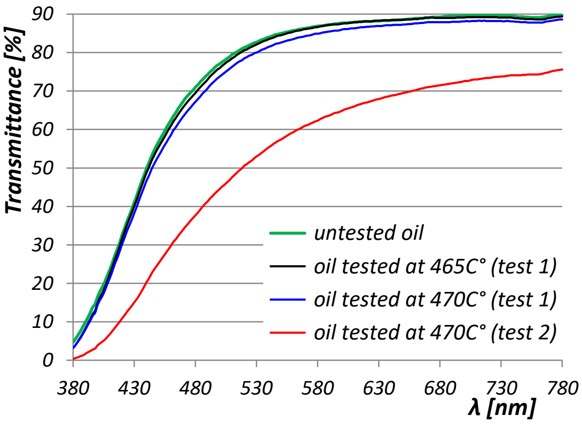


Fig. 8. *Spectral transmittance curves of rice oils*

Moreover, as can be seen from table 1, these chemical transformations that occur with the change in temperature induce, at the same time, chromatic variations in accordance with the conditions of the tests carried out. Thus, both in the case of the trichromatic components and that of the trichromatic coordinates, the variations of these parameters are noted depending on the temperature at which the flammability tests were performed.

These results are highlighted in the case of the oil tested at the temperature of 470 °C (the oil burns) when the location of the colour of the oil in the chromatic circle is totally different from that of the untested oil.

This shows that, at this temperature, the behavior of the oil is different when performing the two tests, consistent with the fact that the chromophore and auxochrome groups undergo transformations in turn. This aspect is much more relevant in the case of expressing the colour variation of oil subjected to flammability tests by means of the chromatic coordinates L^*, a^*, b^*, respectively C^*_{ab} and h_{ab} (Table 2).

Table 1*. Experimental results for rice oils tested at various temperatures, obtained according to the color system (x, y) CIE 1964 (CIEXYZ)/Illuminant D65/10°*

Rice oils	*Trichromatic components*			*Trichromatic coordinates*		
	X	***Y***	***Z***	***x***	***y***	***z***
Untested oil	*78.029*	*80.299*	*68.682*	*0.344*	*0.354*	*0.303*
Oil tested at 465 °C (test 1)	*77.613*	*79.782*	*67.231*	*0.346*	*0.355*	*0.299*
Oil tested at 470 °C (test 1)	*75.919*	*77.941*	*64.611*	*0.348*	*0.357*	*0.296*
Oil tested at 470 °C (test 2)	*53.270*	*53.572*	*31.952*	*0.384*	*0.386*	*0.230*

Table 2. *Chromatic coordinates (CIELAB system) for rice oils tested at various temperatures/ Illuminant D65/10°*

Rice oils	*Chromatic coordinates*			a^*/b^*	$(a^*/b^*)^2$	C^*_{ab}	h_{ab}
	L^*	a^*	b^*				
Untested oil	*91.82*	*3.83*	*13.53*	*0.28*	*0.08*	*14.06*	*74.21*
Oil tested at 465 °C (test 1)	*91.59*	*3.99*	*14.36*	*0.28*	*0.08*	*14.90*	*74.46*
Oil tested at 470 °C (test 1)	*90.75*	*4.16*	*15.17*	*0.27*	*0.0752*	*15.73*	*74.67*
Oil tested at 470 °C (test 2)	*78.21*	*6.50*	*28.88*	*0.23*	*0.051*	*29.60*	*77.32*

Our results show that by decreasing the brightness parameter of the tested oil by 14.82%, it is evident that the colour of the tested oil darkens as its temperature approaches the point where the oil burns. This is due to the effect of decreasing light absorption intensity as the temperature of the oil approaches the ignition point.

At the same time, the yellowness parameter increases as the test temperature is higher. Thus, the colour coordinate b* increases from 13.53, value corresponding to the standard oil, to 14.36 which corresponds to the first test of the oil at a temperature of 465 °C, respectively the highest temperature at which the rice oil did not ignite.

Moreover, the yellowness parameter value increases to 15.17 when the test temperature becomes 470 °C. According to the data in Table 2, the increase by more than 50% compared to the untested oil sample is highlighted, when the test temperature becomes 470 °C and the oil burns.

Relatively large differences in the variation of the yellowness parameter also resulted between the two tests (test 1 versus test 2) carried out on rice oil at the same temperature, respectively 470 °C. If in the case of test 1 the increase in the yellowness parameter is approximately 12% (variation by 1.64 units), in the case of test 2 this variation is more than 15 units (Table 3).

This shows that at the burning temperature the degree of yellowness is intensified compared to the condition where the oil is not burning, although the test temperature is the same. This is probably due to the organic compounds formed, such as hydroperoxides, during the heating of the tested oil.

Also, the data presented in Table 2 indicate a similar variation in the case of chroma, the rice oil subjected to test 2 at the temperature of 470 °C presenting the highest value of this chromatic parameter. The much higher value proves the superior colour intensity of the rice oil subjected to test 2 compared to that subjected to test 1, although the test temperature is the same.

The highest temperature at which the rice oil did not ignite, namely 465 °C, also corresponds to the lower values (14.9 and 74.46) of the chroma parameters, C^*_{ab}, respectively the hue angle, h_{ab}. Moreover, the colour variation, ΔE^*_{ab} [24] correlates directly with the test temperature at which rice oil burns (Table 3).

Table 3. *Experimental values of colour differences for rice oils tested at various temperatures*

Rice oils	ΔL^*	Δa^*	Δb^*	ΔC^*_{ab}	Δh_{ab}	ΔE^*_{ab}
Oil tested at 465 °C (test 1)	*-0.23*	*0.16*	*0.83*	*0.84*	*0.25*	*0.88*
Oil tested at 470 °C (test 1)	*-1.07*	*0.33*	*1.64*	*1.67*	*0.46*	*1.99*
Oil tested at 470 °C (test 2)	*-13.61*	*2.67*	*15.35*	*15.54*	*3.11*	*20.69*

3. Conclusions

Determining the minimum ignition point on a heated cylindrical surface of rice oil required 8 tests. For all tests in which the rice oil did not ignite (except for the oil tested at 450 °C) considerable smoke when the oil came into contact with the heated surface of the cylinder was observed.

In the case of tests where oil ignition has occurred, it is extinguished on contact with the surface of the oil pan (the oil does not sustain combustion in the pan). Oil burning on the surface of the heated cylinder continues even after the tests are finished, the recorded time varying between 7 seconds (at a temperature of 480 °C – test 1) and 2 seconds (at a temperature of 470 °C – test 2).

The maximum temperature at which rice oil does not ignite on a heated cylindrical surface is 465 °C.

The minimum temperature at which rice oil ignites on the hot surface is 470 °C.

The temperature of 470 °C keeps the oil burning to a very small extent after the test is over.

The highest temperature at which rice oil does not ignite corresponds to its maximum brightness parameter, respectively to a minimum chroma intensity. Increasing the test temperature by 5 °C leads to a decrease in brightness parameter, respectively a shift of the hue angle towards the second quadrant of the colour circle diagram, as well as an increase in chroma.

References

[1]. Colwell J. D., Reza A., *Hot surface ignition of automotive and aviation fluids*, Fire Technology, 41, p. 105-123, 2005.

[2]. Goyal V., Carayon A. B., Meyer S., Gore J., Simmons R., *Hot surface ignition temperatures of hydrocarbon fuels*, AIAA SciTech Forum, 55th AIAA Aerospace Sciences Mtg, Grapevine TX, 2017.

[3]. Shaw A., Epling W., McKenna C., Weckman E., *Evaluation of the ignition of diesel fuels on hot surfaces*, Fire Technol 46, p. 407-423, 2010.

[4]. Dillard L. N., Ulcay M. S., Gore J. P., *Effects of pressure on minimum hot surface ignition temperatures (MHSIT) in hot air crossflows*, AIAA scitech 2021 forum (AISS 2021–1346), AIAA, Combustors IV, 2021.

[5]. LaPointe N. R., Adams C. T., Washington J., *Autoignition of gasoline on hot surfaces*, Fire Arson Investig., 56(2), p. 18-21, 2005.

[6]. Haussmann G. J., Matta L. M., *Flammable vapor ignition by engine exhaust systems*, Journal of Applied Fire Science, 11, p. 335-348, 2002.

[7]. Imamura T., Uehara K., Nakata K., Maruyama S., Kuwana K., *Quas-steady characteristics of flowing propane/air mixture ignited by a heated surface*, Fire Safety Journal, vol. 120, 10025, 2021.

[8]. McTaggart - Cowan G., Huang J., Turcios M., Singh A., Munshi S., *Evaluation of a Hot-Surface Ignition System for a Direct-Injection of Natural Gas Engine*, Proc. ASME 2018 Internal combustion engine div. fall tech. conf., v.1 large bore engines; fuels; advanced combustion, San Diego, 2018.

[9]. Deleanu L., Buzoianu D., Rîpă M., Crăciunoiu S., Drug A., *Flammability tests on hot surfaces for industrial fluids*, The Annals of University ''Dunărea de Jos'' of Galați, Fascicle VIII, p. 22–31, 2007.

[10]. Hansen R., *Reviewing conditions on a mining vehicle for possible ignition and fire behaviour – flammable and combustible liquids, Sustainable Minerals Institute*, The University Of Queensland Australia, 2022.

[11]. Li Y. L., Wang Y. H., Lu S. X., *Ignition of the leaked diesel on a heated horizontal surface*, Fire Safety Journal, vol. 45, p. 58-68, 2010.

[12]. Babrauskas V., *Ignition of gases, vapors and liquids by hot surfaces*, Fire Technology, 58, p. 281-310, 2022.

[13]. Șolea L. C., Deleanu L., *Flammability tests on hot surface for castor oil*, Mechanical Testing and Diagnosis, ISSN 2247-9635, vol. 4, p. 24-28, 2020.

[14]. Șolea L. C., Deleanu L., *Flammability tests for hemp seed oil*, Mechanical Testing and Diagnosis, ISSN 2247-9635, vol. 2, p. 5-9, 2021.

[15]. Georgescu C., Cristea G. C., Șolea L. C., Deleanu L., Sandu I. G., *Flammability of Some Vegetal Oils on Hot Surface*, Revista de Chimie, 69, no. 3, p. 668-673, 2018.

[16]. Zhengqiang X., Fan F., Xiaodong L., Yanning L., *Preparation of an environmentally friendly emulsion-type lubricant based on crude rice bran wax*, Petroleum, 5, p.77-84, 2019.

[17]. Rajaganapathy C., Rajamurugan T. V., Dyson Bruno A., Murugapoopathi S., Armstrong M., *A study on tribological behavior of rice bran and karanja oil-based TiO_2 nano bio-fluids*, Materials Today: Proceedings, 2022.

[18]. Rubalya Valantina S., Arockia Jayalatha K., Phebee Angeline D. R., Uma S., Ashvanth B., *Synthesis and characterisation of electro-rheological property of novel eco-friendly rice bran oil and nanofluid*, Journal of Molecular Liquids, p. 256-266, 2018.

[19]. Rani S., Joy M. L., Prabhakaran Nair K., *Evaluation of physiochemical and tribological properties of rice bran oil – biodegradable and potential base stoke for industrial lubricants*, Industrial Crops and Products, 65, p. 328-333, 2015.

[20]. Panchal T. M., Patel A., Chauhan D. D., Thomas M., Jigar V. Patel J. V., *A methodological review on bio-lubricants from vegetable oil-based resources*, Renewable and Sustainable Energy Reviews, 70, p. 65-70, 2017.

[21]. Albino Antunes S., Lanza M., Hense H., *Rheological properties of rice bran (Oryza sativa L.) oils processing and soapstock residue*, Industrial Crops and Products, 46, p. 111-116, 2013.

[22]. Crișan V. E., Dincă L., Bragă C., Murariu G., Tupu E., Mocanu G. D., Drașovean R., *The Configuration of Romanian Carpathians Landscape Controls*, Volume Diversity of Picea Abies (L.) Stands, Land, 12, 406, p. 1-18, 2023.

[23]. Crețu R., Șolea L. C., *Effect of the Temperature and Oxidation Time on Some Physicochemical Characteristics of the Rice Bran Oil*, The Annals of "Dunarea De Jos" University of Galati, Fascicle IX, Metallurgy and Materials Science, Year XI (XIV) September 2022, No. 3, p. 5-10, 2022.

[24]. ***, *CIE Technical Report., Colorimetry*, 3rd ed., Publication 15, CIE Central Bureau, Vienna, 2004.