Flammability of Some Vegetal Oils on Hot Surface

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Vegetal oils could be a solution to replace mineral oils, but their atypical behavior constrains users to test them. Tests on hot surface were done with the help of an original test equipment. The method is designed to imitate the worst scenario that could happen when fluid leakage reaches hot surfaces. The ignition temperature on hot surface for the tested vegetal oils is in a narrow range (495...510°C), higher than most mineral oils, this being due to the similar composition in fat acids.

Keywords: vegetal oil; rapeseed oil; olive oil; corn oil, soybean oil, flammability on hot surface

Industrial applications of vegetal oils include lubricants, emulsifying agents, plastifying agents, surfactants, solvents, fuels [1-3]. The concerns on environmental pollution and gradual exhaustion of resources of oil and natural gas were the causes of intensifying research to find alternatives, especially for mineral oils, such as vegetal or synthetic fluids. The non-toxicity and the rapid biodegradability of vegetal oils recommend them as more environmentally friendly fluids as compared to *classical* mineral oils [2, 4].

Using fluids implies the engineer to assume the risk of ignition that may be caused by a complex combination of interacting factors. The problem of designing systems with working fluids is to imagine rare scenarios that could happen and to offer a better solution in order to minimize this risk. Many accidents are the result of a sum of facts not anticipated by designer, producer and beneficiary in the exploitation of a technical system [5, 6]. Use of vegetal oils in food industry applications [7], as well as technical fluids [8], lubricants [9-11] and fuel recipes [12, 13] involves risk for ignition on hot surfaces.

This study presents the results of testing flammability of oils obtained from rapeseed, olive, corn and soybean. Tests were done on a hot surface, up to the fluid ignition.

Researchers have been focused their attention on vegetal oils, but their unusual behavior and particular set of properties [11-16], sometimes very different from those exhibit by mineral and synthetic oils, request the user to test them in order to certify their quality for particular applications. Today, specifications included in the datasheet for a technical fluid give information about tests on fire resistance and flammability [4, 17-23], besides other characteristics as shear stability, wear resistance: flash point, auto-ignition temperature, fire point, ignition temperature on hot manifold (at least, for fire-resistant fluids in high risk applications, as mine and explosive atmosphere, the pass of the test described in SR EN ISO 20823:2004, for the manifold temperature of 700±5°C).

Studies on how the fluids ignite when they reach a hot surface were done for investigating accidents or the behavior of flammable fluids like fuels in storage and use, even for ecological disasters [5, 19].

An investigation report in 2007 pointed out that, from 1980 to 2002, residential fires accounted for 29% of all fires in the United States [24, 25]. 33% of those residential fires were related to kitchen fires, which accounted for 47% of deaths caused by residential fires.

Toy [25] designed an experiment and a device for studying the fuel ignition in contact with a heated surface and the results have provided evidence of various fluid flow mechanisms. The turbulence level in the plume increases as the plate temperature increases.

Yuan [17] conducted a study on the ignition of non-fire-resistant hydraulic fluid sprays. An open flame and a hot steel surface were used as external heat sources. The minimum fluid temperature and minimum spray nozzle pressure that resulted in an ignition were measured. The degree of fluid atomization and the relative direction of its injection with respect to hot surface are discussed. The minimum hot surface ignition temperature was 450°C for a synthetic fluid and 490°C for a water-in-oil emulsion. Although the synthetic fluid and water-in-oil emulsion were classified as *fire-resistant*, their fine oil sprays were still ignitable with both open flame and hot surface under those test conditions. The key condition for the oil spray ignition is that the fluid is released in the form of very fine droplets. In real applications, the fine oil droplets can be generated from rupture of high pressure hydraulic fluid lines, high oil temperatures from the compression and friction inside the hydraulic system or the combination of both high temperature and high pressures.

Yule [26] also reported on the flammability of hydraulic fluids as sprays reaching a hot surface. The test may be used to rank fluids using parameters, such as luminosity and exhaust toxicity. Although the study made by Colwell and Reza [18] has shown that ignition probability is a well defined function of surface temperature for the specified experimental set-up. Data in the literature illustrate that hot surface ignition temperatures vary widely, depending on experimental conditions. For each tested fluid, the authors gave the range of temperature, from the highest temperature that the fluid did not ignite at all, to the lowest temperature that the fluid ignited any test. This temperature range is due to both statistical nature of data and parametric variations in test conditions, including changes in liquid injection location, air velocity and fluid injection methods (sprays and streams along with the associated mass flow rate of each).

Three characteristic causing the ignition of a fluid could be ordered as following: flash point < auto-ignition

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temperature < temperature of ignition on hot surface. The interval between these values depends on many test factors, especially when the ignition source is far from being ideal (as considered in the case of a pilot flame or an electrical spark) [18, 27, 28].

Koseki et al. [29] consider vegetal oils with high flash points of 300–330°C safer than lubricating oils with flash points of 220–300°C. However, about 10% of fires in Japan are related to vegetal oils, and experimental data on burning characteristics of vegetal oils are not enough to compare them to lubricating oils or fuels with high flash points. Since the flash points of vegetable oils are above 300°C, higher than those of fuel oils with flash points of 100°C and lubricating oils with flash points of 160-300°C, vegetal oils are considered to be relatively safer than hydrocarbon oils. However, it was found that the burning rate, radiant heat and flame height of vegetal oils are higher than those of fuel oil or some lubricating oils. This means that once a fire occurs, the fire propagation danger of vegetal oils is higher.

Ni et al. [30] pointed out the importance of studying flammability characteristics of vegetal oils as they are used in food industry where personnel has low training in preventing fire and few information on risk management and proposed particular solution for extinguishing fires implying cooking vegetal oils with a high auto-ignition temperature.

Based on the above documentation, the authors consider that for vegetal oils with very different fat acids concentrations [31], the fire characteristics have to be done by experiment, including tests that imitate accidents, as dropping the fluid on a hot manifold.

Experimental part

Testing methodology

The selection of hydraulic fluids and lubricants should include the basic criterion on reducing the risk of fire. Fire resistance of technical fluids has increasingly become a characteristic to be taken into account in any modern application (fig. 1).

The ignition of fluids on hot surface is very sensitive to the test conditions [4, 28, 30-33]. The results differ depending on how the heated fluid reaches the surface (spray, drop or droplets, continuous and intermittent flow etc.).

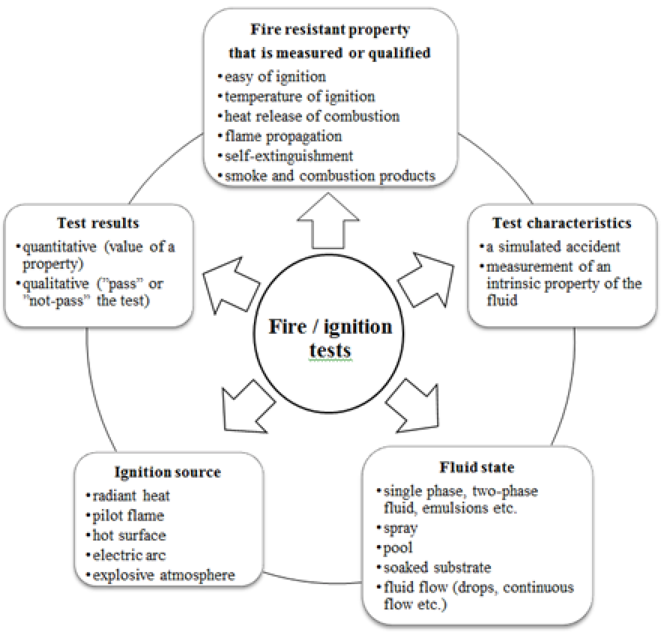

Fig. 1. Parameters involved in fire tests (adapted from Zinc) [4]

This study includes tests on soybean oil, rapeseed oil, olive oil, corn oil and the hydraulic oil OMV ISO VG 46 for comparing reason. All vegetal oils are obtained by cold pressing. International and European reglementations included testing the fluids on hot surfaces [34-39].

Many of Europe coal-producing countries base their requirements for fire-resistant hydraulic fluids on the Luxembourg Report, published by the European Coal and Steel Community's High Authority, which contains guidance on health and safety in the coal-mining industry and was prepared following a major accident and fire in a mine in Belgium, in 1956.

Considering the conditions imposed by the standard SR ISO 20823:2004 to have a precision temperature measurement of ±5°C, the authors applied the method of interval halving until the temperature at which the fluid does not burn in any of the three tests performed (the initial interval was 200…600°C). The tests were stopped when the difference between these temperatures was of 5...10°C.

The testing equipment (fig. 2) is functional at LubriTest Laboratory (Dunarea de Jos University of Galati, Romania). It offers a modulated design solution for testing fluid flammability on hot surfaces.

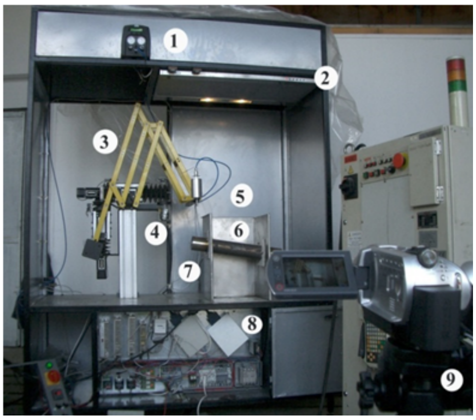

Fig. 2. Flammability test equipment

The flammability test equipment in figure 2 includes the following modules: 1 - a digital dispensing system, with adjustable volume and speed of the drip, 2 - a ventilated enclosure with protection against explosion, thermal insulating glass, exhaust outside the building of gas released by burning, 3 - a robotic system for displacing the dispenser, which can control the position of the dispenser along the manifold, 4 - a fluid reservoir, 5 - an enclosure for high temperatures and manifold, all made of refractory stainless steel, 6 - a heating thermostat (which can heat the manifold surface till 700±5°C), 7 - a temperature monitoring system with a thermocouple attached to the heated tube and protected by the same material, in a welded case on the manifold, 8 - an automation system for monitoring the equipment (including a dedicated software for controlling the equipment from a computer), 9 - a video camera for recording the test [40].

Such a test system has the following advantages: operator safety, good repeatability, difficult to be achieved in terms of making handmade test, providing video record of the test, that can reveal characteristics of interest for the operator (time to ignition, combustion appearance etc.), achievement of accuracy for test parameters within recommended ranges, reduced labor and time for operator and client.

The principle of the test method included in SR EN ISO 20823: 2004 is quite simple: a portion of the fluid to be tested (10 mL) is dropping from a predetermined height and with a specified dropping rate, on a heated manifold at 700°C or at a different temperature. The result of dripping is examined in terms of ignition or combustion, both on the manifold and in the tray below.

The test procedure involves the following five steps:

-The cleaning of the manifold outside surface is done, with the help of a cleaning solvent. The inclined surface has to be free of residues from previous tests. The heating element has to be checked to be electrically isolated and the equipment is not connected to the electric power source.

-The adjust of the dropping time with the help of preliminary tests (without heating the manifold), by manual or automatic adjustment of the fluid dispenser.

Connecting the heating element to the power source and waiting till the manifold reaches the specified temperature.

- Filling of the dispenser with 10 mL of fluid, at 20 to 25°C. Movement of the dispenser with the help of the robotic arm till it is above the point of manifold axis where the operator wants to drop the fluid (300±5 mm above the manifold surface).

- When the manifold has a stable temperature, the operator commends the dispenser to drop the fluid, at a constant dripping rate, so that 10 mL of fluid to be dropped out in 40 to 60 s.

The test is repeated two more times at the same temperature, from step 3 to step 5, for new positions on the manifold, each at least 50 mm above the previous one, prior to not overlap contact areas (if the dripping zones on the manifold are overlapped, another variable is introduced -clean or dirty surface of the manifold).

The comments made by ISO Technical Committee TC 28 [41] concluded that, although the experiment is simple, its implementation (equipment and procedure) is complex, mainly due to: the imposed conditions for the temperature measurement (its required accuracy ±5°C for a maximum temperature of 700°C), the automatic dispenser, which has to be tuned for the drip rate as tested fluids may have the viscosity in a wide range and the accurate positioning of the dispenser.

For this study, at least three tests were done for each temperature and oil grade. The following terms were introduced for characterizing the fluid flammability on hot surfaces [20, 42]:

- the maximum temperature for which at least for three tests, the fluid does not ignite,

- the minimum temperature for which at least for one test, the fluid ignites; this temperature could be considered the ignition temperature on hot surface.

The difference between the two temperatures depends on measurement accuracy are of maximum 10°C.

Results and discussions

There are several characteristics for describing the fire resistance of a fluid, including the flash point, the auto-ignition temperature or the fire point. Neither the flash point nor the fire point is dependent on the temperature of the ignition source (this being much higher). It is generally assumed that the fire points are higher with about 10°C than the flash point.

Analyzing the results reported by Cacareto [43], based on the experimental data for saturated esters and estimated values for pure unsaturated esters (table 1), the flash points of fatty acid ethyl esters increase with the carbon chain length and decrease with the number of unsaturations.

Table 1

FLASH POINTS OF FATTY ACID ETHYL ESTERS [43]

Fatty acid ethyl ester	Flash point (±1°C)
C12:0 ethyl laurate	126.85
C14:0 ethyl myristate	150.85
C16:0 ethyl palmitate	160.85
C18:0 ethyl stearate	190.85
C18:1 ethyl oleate	153.85
C18:2 ethyl linoleate	155.85

Blin [1], Derimbas [44], Buda-Ortins [45], by their experiments, emphasis that auto-ignition depends on the grade of vegetal oil and also by the test procedure of obtaining it. The value of the flash point could vary in a range of 10…20°C, the auto-ignition temperature in a larger range, depending on the test conditions (table 2) [1, 44-46].

Ranking the information for the flash points as given in literature (table 2) and the ignition temperature on hot manifold, the authors conclude that flash points and this flammability characteristic of burning on hot surface are only poorly related, meaning that the rank is the same only for the extreme values of the two characteristics (for the hydraulic oil, the olive oil - rank 1 and 2 and the corn oil - rank 5). For soybean and rapeseed oils, the rank is inconclusive for a correlation between the flash point and the ignition temperature on hot manifold. This analysis underlines the importance of doing tests and not models for flammability behavior of fluids.

Based on studied documentation [43, 45-48] and test results, several conclusions may be formulated:

- for specified temperatures, some fluids (olive oil, corn oil, rapeseed oil) ignite at first drop on the hot manifold;

- for other oils (soybean oil, OMV ISO VG 46 hydraulic oil), ignition occurs with a delay of 3...10 s, very important, for example, in designing the fire protection systems.

Table 2

FIRE CHARACTERISTICS OF SEVERAL VEGETAL OILS

Oil	Flash point (°C)	Rank Flash point*	Auto-ignition point (°C)	Ignition temperature on hot surface (°C)	Rank Ignition temperature on hot surface*
Soybean	246 [2] 254.85 [14]	3-4	330 [21] 403…411 [5]	**510**	4-5
Corn	277 [2] 258.85 [14]	5	-	**510**	4-5
Olive	230.85 [14]	2	434…436 [5]	**495**	2
Rapeseed	257.85 [37] 246.00 [1]	3-4	351-361 398…433 (canola oil)[5]	**500**	3
Hydraulic oil OMV ISO VG 46	>250	1	-	**425**	1

Rank value is given by the authors (1 - the lowest value, 5 - the highest value)

Figures 3 to 7 present images from films recorded during the tests and supporting the conclusions drawn at the end of this study for the tested vegetal oils.

Figure 3 shows images from the movie made during the test with OMV ISO VG 46 hydraulic oil, the manifold having a temperature at which the oil does not ignite repeatedly (a), but observing the evaporation of volatile fractions (as white smoke). At the manifold temperature of 425±5°C, the oil burns on the tube (fig. 3b).

The rapeseed oil ignites after 20…30 s in the tests done at 500°C (fig. 4a), but the ignition starts after 3…5 s at 510°C (fig. 4b) and at first drop reaching the surface for 530°C (fig. 4c).

The soybean oil does not burn at 500°C (fig. 5a), but it releases a large volume of white smoke. It ignites after 2…3 s at 510°C (fig. 5b), after 2...6 s at 515°C (fig. 5c); the first flame is as violent as the test done at 510°C (compare fig. 5b to fig. 5c) and the flame propagates along the fluid stream and the fluid continues to burn in the tray bellow.

The flame is more intense at higher temperature (560°C), even in the tray (fig. 5c). This type of burning is very dangerous as it increase the risk to ignite other substances the leakage encounter in its way. Testing above 515°C, the oil ignites at first drop, but it intensely burns on the manifold and less oil volume is falling in the tray.

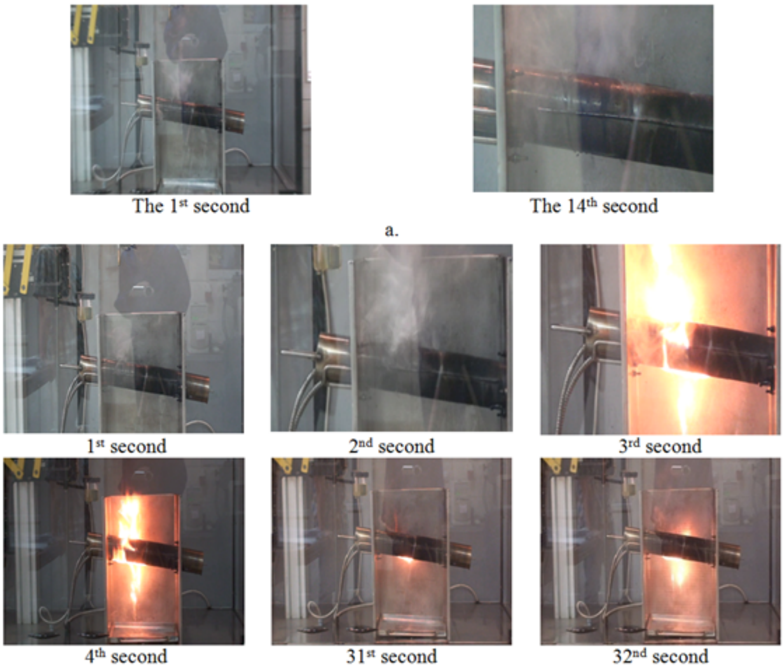

Fig. 3. Hydraulic oil, grade OMV ISO VG 46, tested for different temperatures of the manifold: a. the manifold surface of 420°C; b. manifold temperature of 425°C

Fig. 4. Rapeseed oil tested on the manifold having a temperature of 530±5°C: a. 1st s; b. 2nd s; c. 9th s

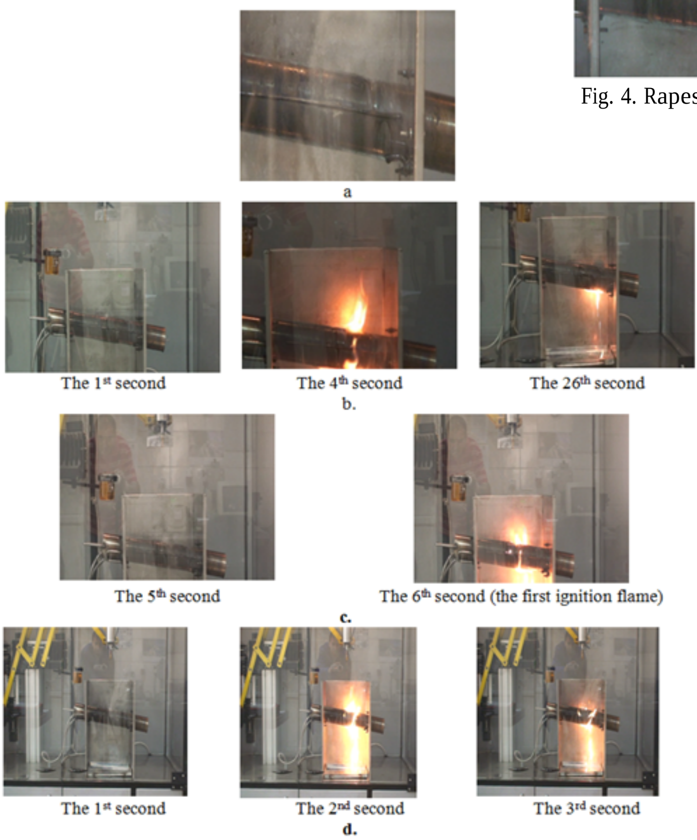

Fig. 5. The soybean oil, tested at different temperatures of the manifold: the manifold temperature of 500°C (the 21st s); b. the manifold temperature of 510°C;
c. the manifold temperature of 515°C; d. the manifold temperature of 560°C

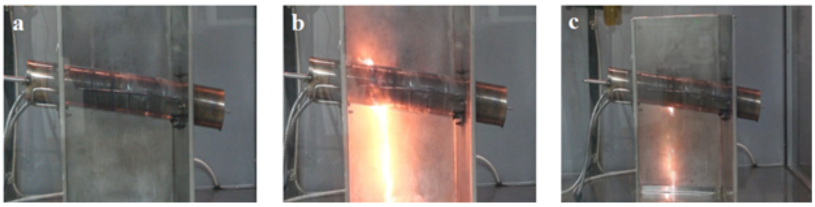

Fig. 6. The olive oil, tested at a manifold temperature of 500°C: a. 1st s; b. 2nd s; c. 23rd s

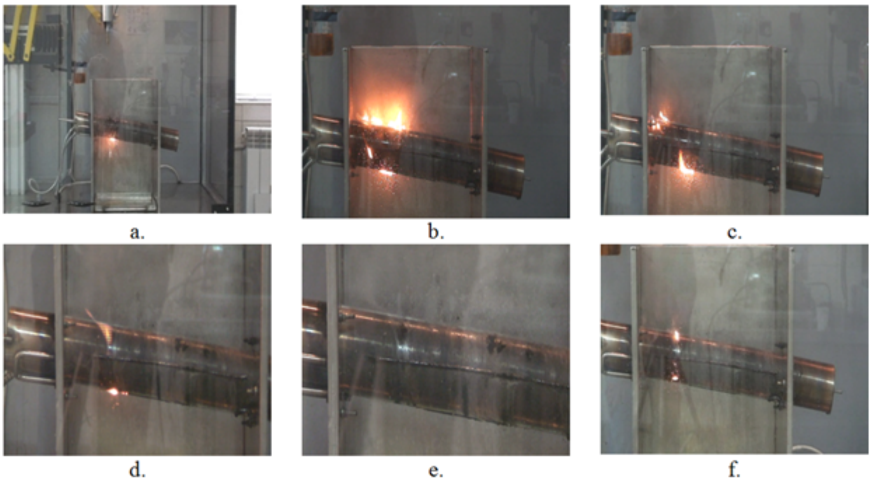

Fig. 7. Images selected from the film recording the corn oil, the manifold surface being 515°C:a. 2nd s; b. 6th s; c. 7th s; d. 21st s; e. 22nd s; f. 30rd s

Table 3
COMPOSITION IN FAT ACIDS OF THE TESTED OILS

Fat acid	Composition of the oil (%)			
	Olive	Soybean	Corn	Rapeseed
C14:0	-	0.11	0.05	0.05
C16:0	12.6	12.7	12.4	**4.84**
C16:1	**1.2**	0.13	Nd	0.06
C17:0	0.1	0.05	0.12	0.14
C17:1	0.1	0.06	0.05	-
C18:0	-	5.4	2.1	0.14
C18:1	**79.3**	**21.6**	**28.45**	**62.73**
C18:2	**4.7**	**52.4**	**54.1**	**22.4**
C18:3	0.8	5.7	1.1	7.5
C20:0	0.4	0.25	0.4	0.5
C20:1	0.25	0.2	0.35	1.25
C22:0	-	0.5	0.1	0.3
C22:1	-	0.16	-	-
C24:0	0.16	0.2	0.1	-

The olive oil ignites after 4…7 s at 495°C, but it burns at first drop for tests done at 500°C (fig. 6) and it continues to burn when the fluid falls in the tray. Thus, the olive and soybean oils have higher risk to spread the fire as they continue to burn when they leave the hot surface.

The corn oil is less predictable: at tests done at 510°C, the oil ignites after only 2 s and in tests done at 515°C (fig. 7), the time to ignition was of 6…18 s and the flame has an intermittent character; for manifold temperature of 520°C, the flame becomes continuous, but variable in height and intensity.

From figure 3b, one may notice that the hydraulic oil does not burn in the tray, in contrast to the tested vegetal oils, especially the soybean oil (fig. 5) and the olive one (fig. 6).

The soybean oil violently ignited and the flame was spreading around the manifold. The oil was burning during its fall and also in the tray below (fig. 5b and d). The oil dropping on the hot surface causes white smoke all the time the fluid was dropped and the oil is leaking on the manifold without ignition (fig. 5a).

The hydraulic oil burns in the tray (fig. 3b), with higher intensity for higher temperature above the ignition temperature on hot manifold (425°C). At lower temperature of the manifold, but closer to 425°C, the hydraulic oil releases a large volume of white smoke (fig. 3a).

Many research works point out that the composition of fluids influence their characteristics and behavior in exploitation [3]. The authors suggest that the composition quality and not the quantity will determine this flammability characteristic. It is very probably that a very small amount of fat acid (like C16:1 and C17:1 in the olive oil) will act like as an ignition starter and then the other components will burn.

The temperature of ignition on hot surface is different for different grades of oil, but the results presented in this study are in a relatively narrow range as compared to mineral oils, such as presented in other papers [4, 20, 42]. This relatively narrow range of ignition temperature is due to the similarity of the chemical compositions of tested oils (table 3).

The lowest temperature of ignition on hot surface was obtained for the olive oil that has a very peculiar distribution of the fat acid percentage in composition: it is rich in fatty acid C18:1 (80%) as compared to the other three tested oils. It has the highest concentration of shorter chain fat acids (C16:0, C16:1 and C18:1) as compared to the other tested oils. Further investigation is needed to asses this conclusion.

The behavior of these vegetal oils when testing their flammability on hot surfaces is characterized by a small range of temperature for ignition on hot manifold (15°C) (fig. 8), but the burning process may be, qualitatively, very different and this is important when ranking the fluids in a risk assessment.

It was noted, however, that the tested oils can be ranked based on the temperature of ignition on hot surface (table 2). Unlike the flash point and the auto-ignition point of a fluid, which are considered better defining the fire-resistance characteristics of a fluid, hot surface flammability characteristics are not fundamental properties of a fluid and are highly dependent on the set of factors involved in the test method: the fluid manner of reaching the surface, the local air circulation, the surface shape and the volume of fluid, etc. [4, 20].

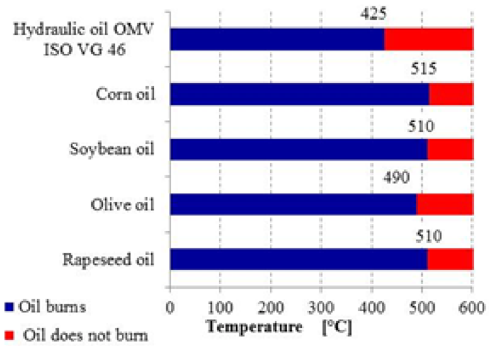

Fig. 8. Temperature of ignition on hot surface for the tested oils (temperature accuracy ±5°C

Conclusions

The tested vegetal oils (soybean oil, rapeseed oil, corn oil and olive oil) burn during their fall in the tray, at a specified temperature for each one (table 2), a process that presents a big risk to ignite other items that the burning fluid may meet when it leaks or falls. Tests were made in a metallic box, but in real applications, the fire may encounter substances having lower fire points and the resulting flame will be intensified.

All tested vegetal oils have the ignition temperature on hot manifold higher than that of the hydraulic oil, tested as a reference fluid. The conclusion would be that if there are no other criteria to fulfill, these oils offer a lower risk for hydraulic applications. Of course, in practice, the specialists have to find production process that will make these oils more stable (including oxidation stability, viscosity index, etc.).

These results are useful for extending the use of vegetal oils in industrial applications as lubricant, working fluids for mechanical cutting, thermal treatment, even as emulsions.

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References

1.BLIN, J., BRUNSCHWIG, C., CHAPUIS, A., CHANGOTADE, O., SIDIBE, S.S., NOUMI. E.S., GIRARD, P., Renew. Sust. Energ. Rev., **22**, 2013, p. 580.
2.ERHAN, S.Z., Industrial Uses of Vegetable Oils, Champaign, AOCS Press, 2005.
3.BOGATU, L., DRAGOMIR, R., Rev. Chim. (Bucharest), **66**, no. 5, 2015, p. 722.
4.ZINK, M.D., Proc. of the 48th National Conf. on Fluid Power Chicago, Illinois, USA, 4–6 April 2000, paper 105-8, p. 3.
5.HATAMURA, Y., Structure and Expression of Failure Knowl- edge Database, http://www.sozogaku.com/fkd/en/infen/mandara.html, 2005.
6.KOBAYASHI, M., TAMURA, M., Leakage and fire from a flange with a special shape at the reactor outlet at a gas oil medium-pressure hydrocracker, http://www.sozogaku.com/fkd/en/cfen/CC1300006.html, 2003.
7.GAO, Y, LIU, Q.K, CHOW, W.K., WU, M., Fire Safety J., **63**, 2014, p. 101.
8.DASGUPTA, S., AGRAWAL, S.L., BANYOPADHYAY, S., CHAKRABORTY, S., MUKHOPADHYAY, R., MALKANI, R.K., AMETA, S.C., Polym. Test., **28**, 2009, p. 251.
9.QUINCHIA, L.A., DELGADO, M., A., VALENCIA, C., FRANCO, J.M., GALLEGOS, C., Ind. Crop. Prod., **32**, 2010, p. 607.
10.QUINCHIA, L.A., DELGADO, M.A., FRANCO, J.M., FRANCO, J.M., SPIKES, H.A., GALLEGOS, C., Ind. Crop. Prod., **37**, 2012, p. 383.
11.ERHAN, S.Z., SHARMA, B.K., PEREZ, J.M., Ind. Crop. Prod., **24**, 2006, p. 292.
12.SHAHID, E.J., JAMAL, Y., Renew. Sust. Energ. Rev., **12**, 2008, p. 2484.
13.BARNWALL, B.K., SHARMA, M.P., Renew. Sust. Energ. Rev., **9**, 2005, p. 363.
14.CUNHA, S.C., OLIVIERA, M.B.P.P., Food Chem., **95**, 2006, p. 518.
15.GIACOMELLI, L.M., MATTEA, M., CEBALLOS, C.D., J. Am. Oil. Chem. Soc., **83**, 2006, p. 303.
16.GAN, H.L., CHE, MAN, Y.B., TAN, C.P., NORAINI, I., NAZIMAH, S.A.H., Food Chem., **89**, 2005, p. 507.
17.YUAN, L., J. Loss. Prevent. Proc, 19, 2006, p. 353.
18.COLWELL, J.D., REZA, A., Fire Technol., **41**, 2005, p. 105.
19.DAVIS, S, KELLY, S., SOMANDEPALLI, V., Fire Technol., **46**, 2010, p. 363.
20.DELEANU, L., CIORTAN, S., 17th Intern. Colloquium Tribology, Tribology, Germany, 19 - 21 January 2010, Esslingen Technische Akademie, p. 217.
21.VLAD, S., Mat. Plast., **40,** no. 3, 2003, p. 112.
22.GIURCAN, V., RAZUS, D., MITU, M., SCHRODER, V., Rev. Chim. (Bucharest), **64,** no. 12, 2013, p. 1445.
23.MURARIU, M., RUSU, M., BORDEIANU, A., COTESCU, S., IBANESCU, C., Mat. Plast., **37,** no. 3, 2000, p. 82.
24.MADRZYKOWSKI, D., HAMINS, A., MEHTA, S., Needs Workshop Proc. NIST Special Publication 1066, 2007.
25.TOY, N., NENMENI, V.I., BAI, X., DISIMILE, P.J., 4th Intern. Aircraft & Cabin Safety Research Conf., 2004.
26.YULE A, J. MOODIE, K., Fire Safety J., **18**, 1992, p. 273.
27.CEREMPEI, A., MURESAN, E.I., CHIRILA, L., SANDU, I., Rev. Chim. (Bucharest), **67,** no. 10, 2016, p. 2039.
28.CEREMPEI, A., MURESAN, E.I., SANDU, I., CHIRILA, L., SANDU, I.G., Rev. Chim. (Bucharest), **65,** no. 10, 2014, p. 1154.
29.KOSEKI, H., NATSUME, Y., IWATA, Y., J. Fire Sci., **19**, 2001, p. 31.
30.NI, X., CHOW, W., K., LI, Q., Tao, C., J. Fire Sci., **29**, 2011, p. 152.
31.VLACHOS, N.,SKOPELITIS, Y., PSAROUDAKI, M., KONSTANTINIDOU, V., CHATZILAZAROU A., TEGOU E., Anal. Chim. Acta, **573-574**, 2006, p. 459.
32.LI, Y-L, WANG, Y-H., LU, S-X., Fire Safety J., **45**, 2010, p. 58.
33.PASCARU, D., Rev Chim (Bucharest), **61**, no. 11, 2010, p. 1097.
34.*** BS EN 13463-5:2011. Non-electrical equipment intended for use in potentially explosive atmospheres - Part 5: Protection by constructional safty c.
35.*** Directive 1999/92/EC of the European Parliament and of the Council of 16 December 1999, on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.
36.*** Directive 98/37/EC of the European Parliament and of the Council of 22.06.1998 on the approximation of the laws of the Member States relating to machinery.
37.*** Directive ATEX 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast).
38.*** FM Global. Approval Standard for Flammability Classification of Industrial Fluids, Class 6930, 2009.
39.*** Health and Safety Executive. HSE Approved specifications for fire resistance and hygiene of the hydraulic fluids for use in machinery and equipment in mine
40.DELEANU, L., Patent application OSIM A/00319/2013, Romania, 2013.
41.*** ISO/TC 28 N 2139:2003. Explanatory report for ISO/CD 20823.
42.DELEANU, L., GEORGESCU, C., CIORTAN, S., SOLEA, L., Proc. of World Tribology Congress, Torino, Italy, 8–13 September 2013, paper no. 775.
43.CARARETO, N.D.D., KIMURA, C.Y.C.S., OLIVEIRA E.C., COSTA M.C., MEIRELLES A.J.A., Fuel, **96**, 2012, p. 319.
44.DERIMBAS, A., Fuel, **87**, 2008, p. 1743.
45.BUDA-ORTINS K, Report, University of Maryland, USA, May 2010, http://drum.lib.umd.edu/bitstream/1903/11333/2/Buda_Ortins_ResearchPaper.pdf.
46.JAIN, A., NYATI, P., NUWAL, N., et al., Proc. of the 11th Intern. Symposium on Fire Safety Science, Canterbury, New Zealand, 10 – 14 February 2014, paper no. 11-163.
47.BRODNJAK-VONCINA, D., KODBA, C.Z., NOVIC, M., Chemometr. Intell. Lab., **75**, 2005, p. 31.
48.PHILLIPS W.D., Journal of Synthetic Lubrication, **23**, 2006, p. 39

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