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MONITORING THE RHEOLOGICAL PROPERTIES OF THE VEGETABLE BASED CUTTING FLUIDS

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Abstract: *Cutting fluids are used to reduce the negative effects of the heat and friction on both tool and work piece. The cutting fluids produce three positive effects in the process: heat removal elimination, lubrication on the chip–tool interface and chip removal. This work proposes a development of a vegetable fluid based on sulfonate castor oil, that can be used in drilling process to replace the commonly used mineral oil based emulsion. The rheological properties of the vegetable fluids (sulfonate castor oil in pure state and used through drilling process) were investigated using shear viscosity rheological measurements. Supplementary tests have been made, regarding the thermal behaviour of the lubricants.*
Keywords: *rheology, bio-degradable fluid, drilling process, thermal*

1. INTRODUCTION

Cutting fluids are used to reduce the negative effects of the heat and friction on both tool and work piece. The cutting fluids produce three positive effects in the process: heat removal elimination, lubrication on the chip–tool interface and chip removal, [1 - 3].
The use of vegetable fluids makes possible the development of a new generation of cutting fluid where high performance in machining combined with good environment compatibility could be achieved. Interest in vegetable oil-based cutting fluids is growing. Compared to mineral oil, vegetable oil can even enhance the cutting performance, extend tool life and improve the surface finishing according to some recent analysis from industry.
A sustainable environmental development is achieved considering some important factors like biodegradability and toxicity of lubricants. On the other hand, the lubricants should be stable during usage under different operating conditions [4, 5]. Cutting fluids are consisting of base fluids and additives. Mineral oil, rapeseed oil and synthetic or native esters can be used as base fluids. If biodegradability should be considered, esters and vegetable oils are more indicate to formulate cutting fluids, because they are readily biodegradable in contrast to mineral oil.
In the use vegetable oil have some problems due to inadequate oxidative stability and problems associated with use in high or low temperature observed in this oil. The problem of poor oxidative stability can be mitigated by the structural modification of vegetable oil by chemical reactions. Sulphur and ozone modifications were used in theses reactions [6, 7].
Some of the substances included in the fluids composition can lead to problems to the working environment and in their disposal [8]. Cutting fluids can also affect the operator's health due to the formation of mists and smoke. These aerosols may cause dermatological and respiratory irritations [9]. Then these substances, additives, should be chosen carefully.
This work proposes a development of a vegetable fluid based on sulfonate castor oil, that can be used in drilling process to replace the commonly used mineral oil based emulsion, [10]. The rheological properties of the vegetable fluids (sulfonate castor oil in pure state and used through drilling process) were investigated using shear viscosity rheological measurements. Supplementary tests have been made, regarding the thermal behaviour of the lubricants.

2. EXPERIMENTAL PROCEDURE

The rheological measurements were performed on a Brookfield viscometer CAP2000+ equipped with four cone-and-plate geometry and using a Peltier system for controlling the temperature. The CAP 2000+ Series Viscometers are medium to high shear rate instruments with cone-plate geometry and integrated temperature control of the test sample material (Figure 1).
The technical parameters of the viscometer are:
- rotational speed ranges: 5 – 1000 rpm;
- temperature control of sample: 5 – 75°C;
- software for complete control and data analysis: CAPCALC32.

Figure 1: Geometry of Brookfield viscometer

The physical and chemical properties of the sulfonate castor oil are presented in Table 1, [5]. The bio-degradability of this cutting fluid is due to the large number of unsaturated ricinoelic acids from castor oil.

Table 1: Physical and chemical properties of the sulfonate castor oil, [5]

Parameter	Value
Aspect	Oily
Water content (%)	8 - 9
Colour	Chestnut
Acid number (mg KOH/g)	0.5 max.
Saponification number on dry basis (mg KOH/g)	68 - 82
pH	10.77
Flash point (^{0}C)	> 120
Pour point (^{0}C)	15 approx.
Density 20 ^{0}C (g/cm^{3})	1.12
Kinematic viscosity (cP)	129
Solubility	Soluble in water

The selected vegetable oil is obtained from a plant called with the scientific name *ricinus communis* or castor-oil plant, in English. This oil was selected for its chemical stability. In order to improve the oxidative stability and others problems with use at high temperatures (like temperatures reaching during drilling processes), the castor oil were structural modified using sulfurization.

To determine the rheological model of the bio-degradable fluids, it was used a test-type "shear rate imposed", with limits of variation of (50 … 2000) s^{-1} and a reference temperature of 20 ^{0}C. The tests were performed with a load up to 2000 s^{-1} and unloading to 50 s^{-1} in order to highlight the effects of thixotropy of lubricant.
The bio-degradable cutting fluid was tested in fresh state (emulsion with a concentration of 5% - 6%) and used state, after 500 working hours on a G20 drilling machine.

3. RESULTS AND DISCUSSIONS

The rheograms characteristics for the bio-degradable cutting fluid in fresh state and used through drilling process are presented in Figure 2.

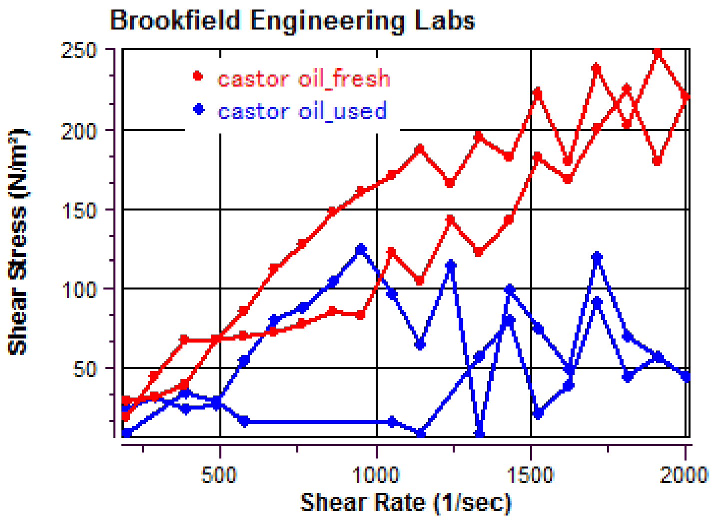

Figure 2: Rheograms for emulsion, in fresh and used state

It can be observed that in the fresh state, the emulsion is characterized by a reduced thixotropy, with small variations of the apparent viscosity versus shear rate. For the used emulsion, the thixotropic behavior increase, with large oscillations of the viscosity and a very unstable structure.
The rheological results where analyzed using regression analysis method and assuming the validity of two rheological models:

- the Newtonian model: $\tau = \eta \dfrac{du}{dy}$ (1)

- the power law model: $\tau = m\left(\dfrac{du}{dy}\right)^n$ (2),

where: τ - shear stress, η - viscosity, m - consistency index (which is equivalent to the Newtonian fluid viscosity), n - flow index (equal to 1 if the fluid is Newtonian).
The results presented in Table 2, according to the Newtonian model, show the decreasing of the viscosity for the used emulsion with almost 50 %, by comparison with fresh emulsion. If the power law model is assumed (Table 3), it can observed that the fresh fluid is characterized by a clearly Newtonian behavior (n = 1.05). For the used fluid, its behavior is non-Newtonian (n = 0.461), with a very poor correlation coefficient of the results.

Table 2: Rheological parameters of fresh and used emulsion (Newtonian model)

State	Viscosity, Pa·s	Corr. coeff.
Fresh	0.0663	0.512
Used	0.0425	0.294

Table 3: Rheological parameters of fresh and used emulsion (Power law model)

State	Consistency index, Pa· s^n	Flow index	Corr. coeff.
Fresh	0.053	1.05	0.591
Used	1.65	0.461	0.282

In order to emphasize the differences between fresh and used emulsion, two thermal tests have been made, at three different values of the shear rate: 250 s^{-1}, 500 s^{-1} and 750 s^{-1}. The results are presented in Figure 3 for the fresh emulsion and in Figure 4 for the used emulsion.

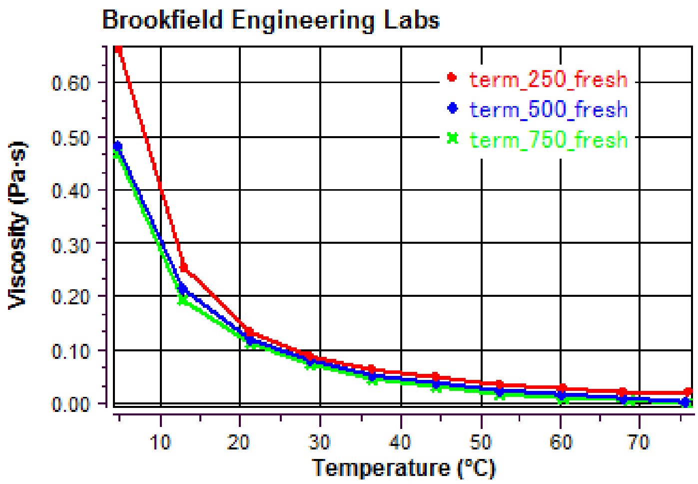

Figure 3: Variation of the viscosity with temperature for the cutting emulsion, in fresh state

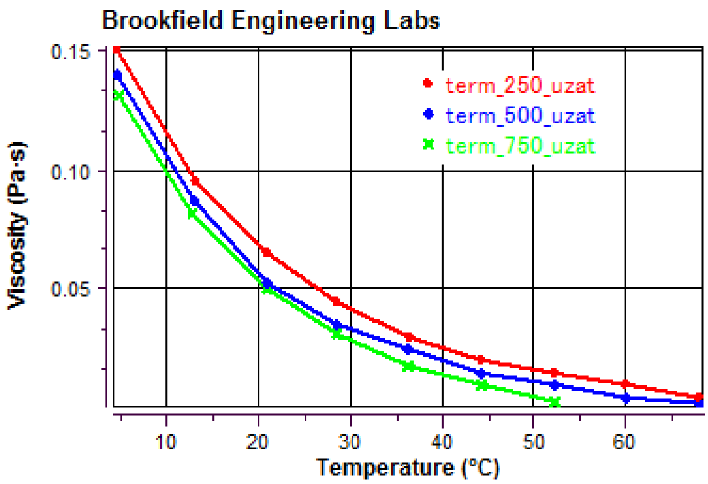

Figure 4: Variation of the viscosity with temperature for the cutting emulsion, in used state

Analyzing the Figures 3 and 4, it can be observed an important difference between fresh and used emulsion, regarding the variation of the viscosity with temperature. At low temperatures, the viscosity of the used emulsion decrease 4 times by comparison with fresh emulsion.

Also, at any temperature, the viscosity of the fresh emulsion doesn't depend on the shear rate, which emphasize the Newtonian behavior of the fluid. From this point, the used emulsion is very sensitive to the variation of the shear rate.

4. CONCLUSIONS

The bio-degradable cutting fluids, based on sulfonate castor oil, so called “green cutting fluids”, have good lubricating properties, high viscosity index, non-toxic and better bio-degradable ability.

The emulsion of sulfonate castor oil has a strong Newtonian behavior in fresh state. If the emulsion is used through drilling process, the viscosity decrease and an important thixotropy can be observed.

Therefore, the rheological methods are very useful to evaluate the wear degree of a fluid and to emphasize the life time for a concrete application.

From this study, it can be concluded that the new developed vegetable based fluids could be a promising alternative to mineral based emulsions for its use as metal working fluids, not only thanks to their environmentally friendly characteristic but also due to their technical properties.

REFERENCES

[1] Booser, R., 1994, CRC hand book of lubrication and Tribology. *CRC press Inc, BOCA RATON*.

[2] John, J., Bhattacharya, M., Raynor, P. (2004). Emulsions containing vegetable oils for cutting fluid application. *Colloids and Surfaces A: Physicochem. Eng. Aspects*, 237, 141-150.

[3] Woods, S. (2005). Going Green. *Cutting Tool Engineering* 57 (2), pp. 48-51.

[4] Cetin, M. H., Ozcelik, B., Kuram, E., & Demirbas, E. (2011). Evaluation of vegetable based cutting fluids with extreme pressure and cutting parameters in turning of AISI 304L by Taguchi method. *Journal of Cleaner Production*, *19*(17), 2049-2056.

[5] Kuram, E., Ozcelik, B., & Demirbas, E. (2013). Environmentally Friendly Machining: Vegetable Based Cutting Fluids. In *Green Manufacturing Processes and Systems* (pp. 23-47). Springer Berlin Heidelberg.

[6] Deiab, I., Raza, S. W., & Pervaiz, S. (2014). Analysis of Lubrication Strategies for Sustainable Machining during Turning of Titanium Ti-6Al-4V Alloy. *Procedia CIRP*, *17*, 766-771.

[7] Kolawole, S. K., & Odusote, J. K. (2013). Performance Evaluation of Vegetable Oil-Based Cutting Fluids in Mild Steel Machining. *Chemistry and Materials Research*, *3*(9), 35-45.

[8] Debnath, S., Reddy, M. M., & Yi, Q. S. (2014). Environmental friendly cutting fluids and cooling techniques in machining: A Review. *Journal of Cleaner Production*.

[9] Padmini, R., Krishna, P. V., & Rao, G. K. M. (2014). Performance assessment of micro and nano solid lubricant suspensions in vegetable oils during machining. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 0954405414548465.

[10] Mendoza, G., Igartua, A., Arizaga, I., Aspiazu, F. & Santiso, G. (2012). Metal Working Fluids Based on Vegetable Oils for Grinding Operations. *Journal of Mechanics Engineering and Automation* 2, 638-646