

# EFFECT OF WATER POLLUTION ON RHEOLOGICAL PROPERTIES OF LUBRICATING OIL

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## ABSTRACT:

This paper presents an experimental study of the rheological behaviour of water-in-oil mixtures without any additive, up to 10 % of mass water concentration, where the mixture is considered to be a Newtonian fluid. The selected oil is a classical turbine mineral oil. Viscosity was measured for five temperatures, ranging from 10 to 80°C, for droplet size below 30  $\mu\text{m}$ . A light decrease of viscosity was detected for water concentrations below 0.1 %. For concentrations greater than 0.2 %, viscosity increases with water concentration. Moreover, the variation of viscosity with temperature shows good correlation with both Walther model and Mac Coull & Walther model. Finally, a new model of water-in-oil mixtures viscosity as a function of temperature and concentration was defined.

## ZUSAMMENFASSUNG:

Dieser Artikel präsentiert eine experimentelle Studie des rheologischen Verhalten von Additiv-freien Öl-Wassermischungen (Wasserkonzentrationen bis zu 10%). Die Mischungen werden als Newtonsches Fluid betrachtet. Das verwendete Öl ist ein mineralisches Turbinenöl. Die Viskosität wurde für fünf verschiedene Temperaturen zwischen 10 und 180°C gemessen für Tröpfchendurchmesser, die 30  $\mu\text{m}$  nicht überschreiten. Eine leichte Viskositätsverminderung wird für Wasserkonzentrationen unter 0.1 % beobachtet. Für Konzentrationen oberhalb 0.2 % steigt die Viskosität mit der Konzentration des Wassers an. Die Abhängigkeit der Viskosität von der Temperatur stimmt mit dem vorausgesagten Verhalten der Walthers und Mac Coull & Walthers Modelle überein. Wir führen hier ein neues Modell für Wasser-in-Öl-Mischungen ein, welches die Temperatur- und Konzentrationsabhängigkeit beschreibt.

## RÉSUMÉ:

Cet article présente une étude expérimentale du comportement rhéologique de mélanges huile-eau jusqu'à une concentration massique de 10 % en eau. Les mélanges peuvent être considérés newtoniens. L'huile choisie est une huile minérale de turbines. La viscosité a été mesurée pour cinq températures différentes entre 10 et 80°C, pour des diamètres de gouttelettes ne dépassant pas 30  $\mu\text{m}$ . Une légère diminution de viscosité a été détectée pour des concentrations en eau inférieures à 0,1 %. Pour des concentrations supérieures à 0,2 %, la viscosité augmente avec la concentration en eau. La variation de viscosité avec la température respecte bien les allures prédites par les modèles de Walther et de Mac Coull & Walther. Enfin, un modèle de viscosité du mélange huile-eau en fonction de la température et de la concentration a été défini.

**KEY WORDS:** lubricant contamination, water-oil mixture, water-oil emulsion, viscosity, contamination rate, temperature

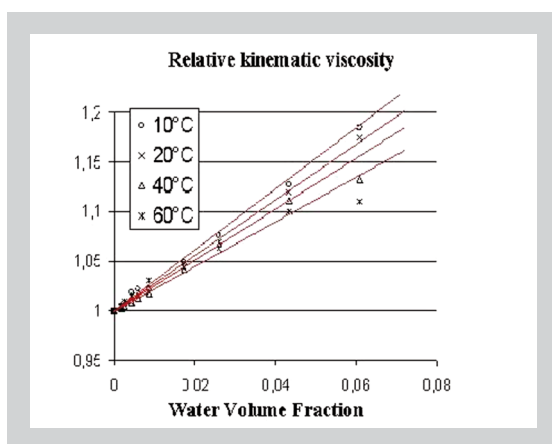
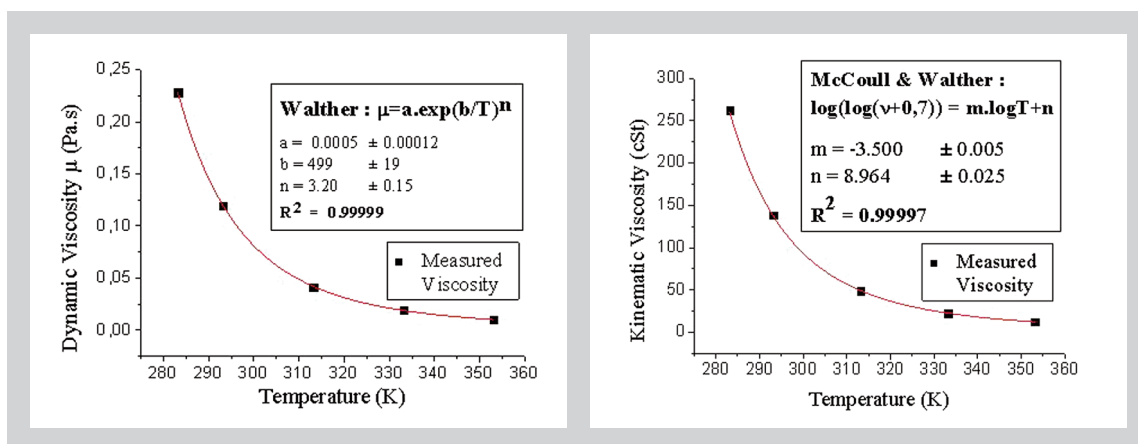
## 1 INTRODUCTION

Lubrication circuits are subjected, from time to time, to water contaminations, either directly by means of a leakage and either by water condensation. A little quantity of water could be allowed while running the machinery, but when the quantity of water exceeds a critical value, the sys-

tem must be stopped and the contaminated oil must be replaced by a neat one. In the case of accidental contamination, like could happen after damages of heat exchangers, the water can penetrate lubrication circuits very quickly, and reach very high percentages, very far from the critical value, before the total shutdown of the

Figure 11 (above): Fitting of Walther model and Mc.Coull & Walther model to measured oil viscosity as a function of temperature.

Figure 12: Relative kinematic viscosity.



### 3 VISCOSITY MODELLING

In this section, emulsion concentrations are represented by water volume fraction. This volume fraction was calculated from mass fraction, water density and measured oil density. So each mass concentration can provide different volume fractions according to the temperature. For instance, a water concentration of 7 % by mass is equivalent to 6.15 % by volume at 10°C, and 6.08 % by volume at 80°C. Because of the lack of precision due to the important sedimentation at 10 % of mass water concentration, this concentration has been ignored in this section as well as measurements at 80 °C which have been ignored for the same reason.

In order to compare the effect of the temperature and the effect of water concentration on the viscosity, the relative kinematic viscosity  $v_r = v_{emulsion}/v_{oil}$  is plotted for all temperatures, according to water concentration (Figure 12). On this graph, the measurements corresponding to 0.1 % of water mass concentration are ignored, so the behaviour of relative viscosity is a pure increase with water concentration. It can also be seen on the graph that the relative viscosity decreases with the increase in temperature. Considering a linear variation of the relative kinematic viscosity with the water concentration, the effect of the temperature can be assumed to be a simple decrease of the line slope. This means:

$$v_r = 1 + \alpha(T)\phi \quad (2)$$

where  $\phi$  is the water volume fraction and  $\alpha(T)$  the decreasing function of temperature  $T$ . Several forms of  $\alpha(T)$  were tested. The admitted one was the linear relation, which provided better correlation with measurements. It has to be noted that this form can not be absolute, especially because it leads to negative values of slope beyond a temperature of about 145°C. Nevertheless, it remains pertinent to our field of study which doesn't overcome the temperature of 100°C. Considering  $\alpha(T) \cdot \phi$  very small comparing to 1, the development of the term  $\log(v_r)$  gives:

$$\log \log(v_r(\phi, T)) = \log \log(v_{oil}) + \frac{\alpha(T)\phi}{\log(v_{oil}) \ln^2(10)} \quad (3)$$

Now if  $\log \log(v_{oil})$  is given by the model of Mac Coull & Walther, our model becomes:

$$\log \log(v_r(\phi, T)) = m \log T + n + \frac{a\phi}{T^{m-1} 10^n} + \frac{b\phi}{T^m 10^n} \quad (4)$$

The optimal fitting to the experimental results gives the values of the parameters:  $m = -3.538$ ,  $n = 9.059$ ,  $a = -0.0037$ ,  $b = 1.546$  with a correlation factor  $R^2$  of 0.999982. Figure 13 shows a comparison between the model and the measurements, on the viscosity-concentration graphs, for 10 and 20°C (Figure 13a), and for 40 and 60°C (Figure 13b). The model shows better agreements with measurements at low temperatures, but still pertinent for all measurements.

### 4 CONCLUSION AND PROSPECTS

Oil-Water mixture viscosity has been measured for different temperatures and water concentrations without any additive. The effect of concentration on the viscosity was a slight decrease, according to Dadouche model, for very small concentrations. Beyond this point, a remarkable increase was observed, according to volume ratio

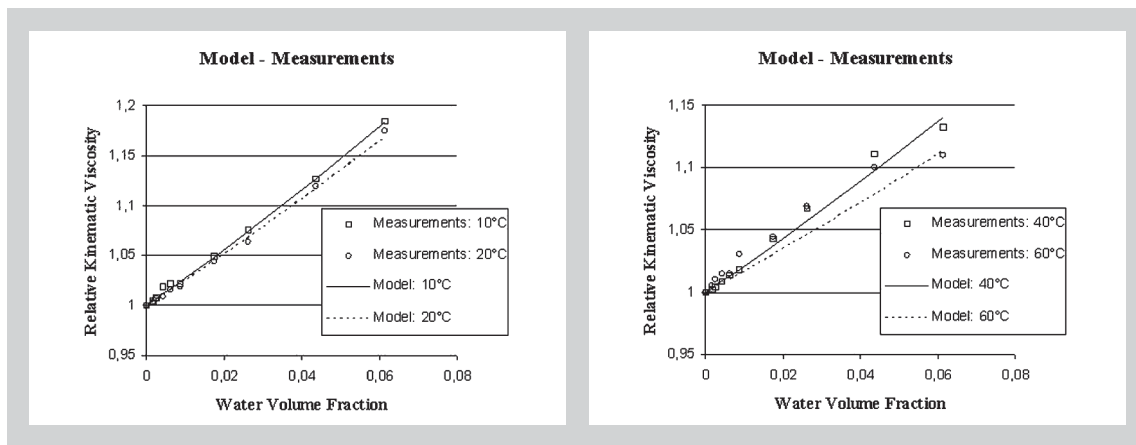


Figure 13: Comparison model and measurements.

models, while the effect of temperature was to decrease the slope of relative viscosity curves. The experimental results presented here are valid for concentrations under 3 % and the corrections given to the experimental values above this point would need to be validated. Other attempts could be carried out to reach a higher accuracy, as to make correction tests at each measurement temperature, in a thermal controlled environment. Walther model and Mac Coull & Walther model were validated for oil viscosity, as well as for the case of water-in-oil emulsions. A new model of emulsion viscosity according to the temperature and the concentration has been defined.

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#### REFERENCES

[1] Pal R, Rhodes E: A novel viscosity correlation for non-newtonian concentrated emulsions, *J. Colloid Interface Sci.* 107 (1985) 301–307.  
 [2] Cantley, Richard E: The effect of water in lubricating oil on bearing fatigue life, *ASLE Trans.* 20 (1976) 244 – 248.  
 [3] Eachus AC: Water, water everywhere nor any drop to drink, *Trib. & Lub. Tech.* (2005) 33 – 39.  
 [4] Dadouche A, Dmochowski W: On the effects of oil contamination on the performance of plain journal bearings, 5<sup>th</sup> EDF & LMS Poitiers Workshop (2006).  
 [5] Tadros THF: Fundamental principles of emulsion rheology and their applications, *Colloids Surfaces A* 91 (1994) 39 – 55.  
 [6] Pal R: Evaluation of theoretical viscosity models for concentrated emulsions at low capillary numbers, *Chem. Eng. J.* 81 (2001) 15 – 21.  
 [7] Urdahl O, Fredheim AO, Loken KP: Viscosity measurements of water-in-crude-oil emulsions under flowing conditions: A theoretical and practical approach, *Colloids Surfaces A* 123 – 124 (1997) 623 – 634.  
 [8] Lionberger RA: Viscosity of bimodal and polydes-

perse colloidal suspensions, *Phys. Rev. E* 65 (2002) 061408.  
 [9] Zaman AA, Dutcher CS: Viscosity of electrostatically stabilized dispersions of monodispersed, bimodal, and trimodal silica particles, *J. American Ceramic Soc.* 89 (2) (2006) 422 – 430.  
 [10] Wang W, Gong J, Ngan KH, Angeli P: Effect of glycerol on the binary coalescence of water drops in stagnant oil phase, *Chem. Eng. Res. Des.* 87 (2009) 1640 – 1648.  
 [11] Taylor GI: The viscosity of a fluid containing small drops of another fluid, *In Proc. Royal Soc. London, serie A*, 138 (1932) 41 – 48.  
 [12] Richardson EG: The formation and flow of emulsion, *J. Colloid Sci.* 5 (1950) 404 – 413.  
 [13] Mooney M: The viscosity of a concentrated suspension of spherical particles, *J. Colloid Sci.* 6 (1951) 162 – 170.  
 [14] Brinkman HC: The viscosity of concentrated suspensions and solutions, *J. Chem. Phys.* 20 (1952) 571 – 572.  
 [15] Krieger IM, Dougherty TJ: A mechanism for non-newtonian flow in suspensions of rigid spheres, *Trans. Soc. Rheol.* 3 (1959) 137 – 152.  
 [16] Barnea E, Mizrahi J: On the effective viscosity of liquid-liquid dispersions, *Ind. Eng. Chem. Fundamen.* 15 (1976) 120 – 125.  
 [17] Phan-Thien N, Pham DC: Differential multiphase models for polydispersed suspensions and particulate solids, *J. Non-Newtonian Fluid Mech.* 72 (1997) 305 – 318.  
 [18] Choi SJ, Schowalter WR: Rheological properties of nondiluted suspensions of deformable particles, *Phys. Fluids* 18 (1975) 420 – 427.  
 [19] Yaron I, Gal-Or B, On viscous flow and effective viscosity of concentrated suspensions and emulsions – Effect of particle concentration and surfactant impurities, *Rheol. Acta* 11 (1972) 241 – 252.  
 [20] Mac Coull N, Walther C: Viscosity-Temperature chart, *Lubrication* June 1921.  
 [21] Ronningsen HP: Correlations for predicting viscosity of W/O-emulsions based on North Sea Crude oils, *Proc. SPE Int. Symp. Oil Field Chem, Houston Texas* (1995).  
 [22] Farah MA, Oliveira RC, Caldas JN, Rajagopal K: Viscosity of water-in-oil emulsions: Variation with temperature and water volume fraction, *J. Petrol. Sci. Eng.* 48 (2005) 169 – 184.  
 [23] www.thermexcel.com.

