

# The Effect of Some Additives on the Friction in Liquids Subject to Rotational Motion

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## Abstract

*In this paper was studied the effect of some additive substances (tensioactive agents) on the friction of some liquids (ethylene glycol, paraffin or mineral oil) subject to rotational motion in ring-shaped spaces. Also, it was expressed the effect of friction (viscosity) decreasing as a function of additive concentration, Taylor-Reynolds number, dependent on the flow space geometry, angular velocity and the liquid physico-chemical properties.*

**Key words:** *additive, friction, rotational motion, tensioactive agents*

## Introduction

The decreasing of internal friction in fluids subject to rotational motion or of friction between these one and the surfaces where the motion is done represents a research priority in the context of decreasing the energy necessary for transport processes.

This decreasing can be obtained using small quantities of substances with specific properties destined for decrease the appeared microturbulences or to ensure their drain and order during the forced motion. Thus, for the microturbulence decreasing can be used tensioactive substances (anionic, cationic or nonionic type), parallel or transversal magnetic fields and the drain can be ensured using polymeric solutions or microfibrinous materials [1-4]. The polymers used as additives needs to present long chain, low ramification and high-molecular weights [5]. In turbulent flow, the behaviour on friction for tensioactive compounds solutions with reducing properties of hydraulic resistance, depends on the size, number and the surface charge of mycelium. Liquids additivation has applications on oil transferring [6], sewerage nets [7], heat installations [8,9].

The modifications which appear during the additive process can be quantified through the measurement of the fluid layers shear stress when these are subject to a controlled motion. This modification is reflected on fluid viscosity.

In the case of liquids flow in ring-shaped spaces where the motion is transmitted through the rotation of a delimited space surface (the case of rotational viscometer), the layers velocity  $w$

decreases gradually from the maximum value (reached in contact with the rotating wall) to the minimum one (in contact with the fixed wall):

$$w_{\max.} = \pi \cdot d \cdot n; \quad w_{\min.} = 0 \quad (1)$$

The shear rate of the liquid layers  $\gamma$  is correlated to the ring-shaped space dimensions (the inner  $d_i$  and outer  $d_o$  diameter, the length  $H$ ) as well the angular velocity  $\omega$  or the revolution of the rotational surface  $n$  (rel. 2). The transmitted torsion moment  $M_t$  is expressed through the shear stress  $\tau$  (rel. 3):

$$\gamma = \frac{\omega \cdot r_e^2}{r_e^2 - r_i^2} = \frac{2 \cdot \pi \cdot n \cdot r_e^2}{r_e^2 - r_i^2} \quad (2)$$

$$M_t = 2 \cdot \pi \cdot H \cdot r_i^2 \cdot \tau \quad (3)$$

Through the shear stress correlation with the shear rate,  $\tau = f(\gamma)$  it is possible to establish the rheological equation (rel. 4a). For Newtonian fluids it has a line expression (rel. 4b) and the slope represents the liquid dynamic viscosity.

$$\tau = \tau_0 + K \cdot \gamma^m \quad (4a)$$

$$\tau = \eta \cdot \gamma \quad (4b)$$

The characterization of liquids flow in ring-shaped spaces is frequently expressed using the Taylor-Reynolds number,  $Ta_{Re}$  (rel. 5a,b), taking into account the angular velocity, radius of the rotating cylinder and the fluid properties (density  $\rho$ , dynamic viscosity  $\eta$  or kinematic viscosity  $\nu = \eta / \rho$ ) [10]. For  $Ta_{Re} \leq 60$  the flow regime is laminar.

$$Ta_{Re} = \frac{\omega \cdot r_i \cdot (r_o - r_i) \cdot \rho}{\eta} \quad (5a)$$

$$Ta_{Re} = \frac{2\pi \cdot n \cdot r_i \cdot (r_o - r_i)}{\nu} \quad (5b)$$

## Experimental details

It was studied the decreasing of shear stress and viscosity for some liquids with medium viscosity values: ethylene glycol-EG ( $\rho = 1114 \text{ kg} \cdot \text{m}^{-3}$ ), paraffin oil-PO ( $\rho = 880 \text{ kg} \cdot \text{m}^{-3}$ ), transformer oil-TO ( $\rho = 890 \text{ kg} \cdot \text{m}^{-3}$ ), using tensioactive additives: sodium lauryl sulphate-LSNa (the additives concentrations in liquids were 0.045%, 0.09% and 0.135% for ethylene glycol, respectively 0.056%, 0.112% and 0.17% for paraffin oil), nonylphenol ethoxylate NF-4 (concentrations were 0.25%, 0.5% and 0.75% for ethylene glycol, respectively 0.3%, 0.6% and 0.9% for paraffin oil) and a rotational rheometer. The main properties for the used additives are presented in Table 1.

The experimental measurements were done using a viscometer with coaxial cylinders; the inner cylinder is rotative and the outer one is fixed. Through the temperature modification ( $25 \leq t \leq 60, ^\circ\text{C}$ ) it was followed the expression of viscosity dependence through an Arrhenius type relation (rel. 6a) and the calculation of its constants (rel. 6b): the activation

energy of viscous flow  $E_a$  and pre-exponential factor  $A$ . Through graphical representation  $\ln \eta = f(1/T)$ ,  $\ln A$  and  $E_a/R$  values are obtained:

$$\eta = A \cdot \exp.\frac{E_a}{R \cdot T} \tag{6a}$$

$$\ln \eta = \ln A + \frac{E_a}{R} \cdot \frac{1}{T} \tag{6b}$$

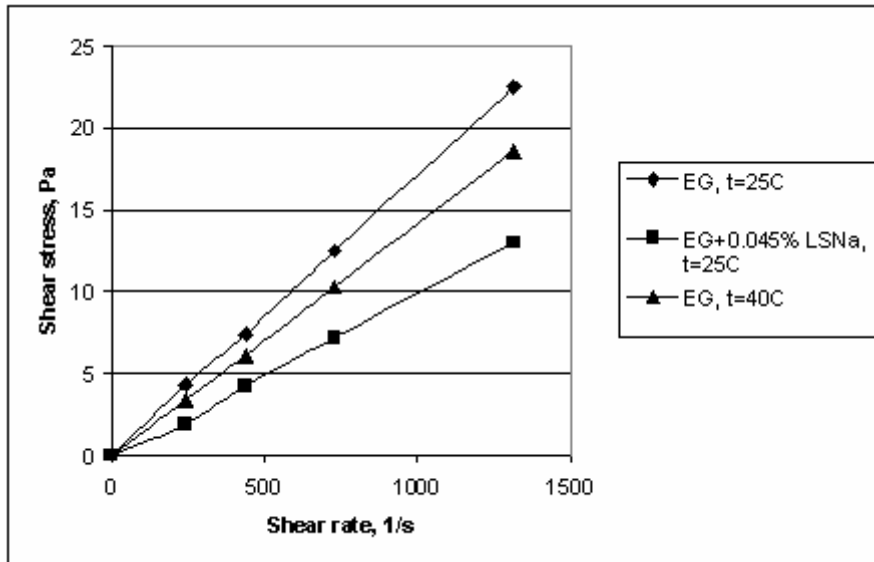
**Table 1.** The additives properties

Property	LSNa	NF-4
Molecular weight, $kg \cdot kmol^{-1}$	288	399
Surfactant type	anionic	nonionic
HLB value	-	8.9
Density at 20°C, $g \cdot cm^{-3}$	1.05	1.027
Viscosity at 25°C, cP	-	238
Solubility	excellent water-soluble	excellent oil-soluble

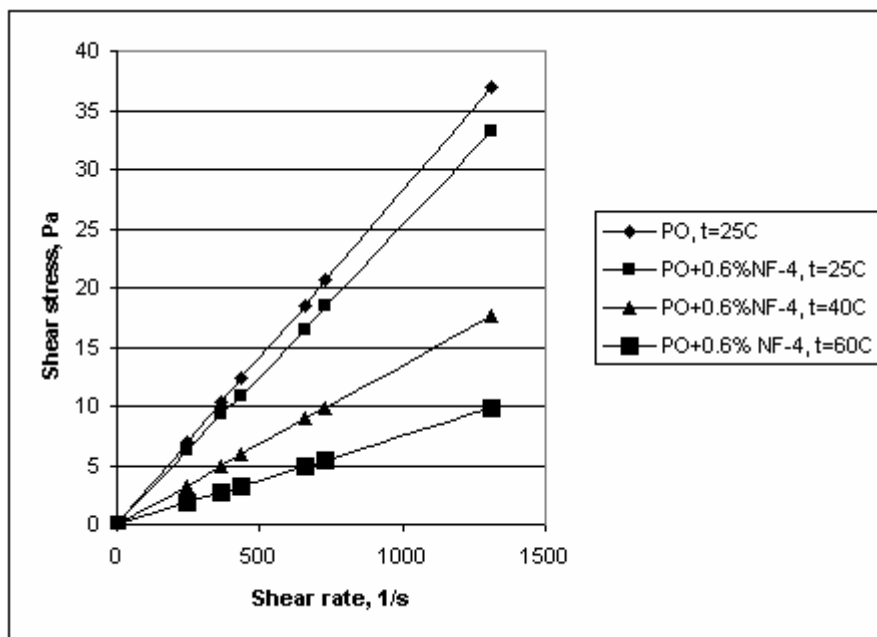
These constants can be correlated with the effect of friction decreasing and viscosity, respectively, when the additive substances are used [11].

## Results

From experimental data it is observed the Newtonian behaviour both for the based liquids and the additivated one (Fig. 1a and 1b), as well the shear stress and dynamic viscosity decreasing in additives presence.



**Fig 1a.** Shear stress vs. shear rate for ethylene glycol



**Fig 1b.** Shear stress vs. shear rate for paraffin oil

In Tables 2a and 2b are presented the rheological equations and the viscosity decreasing in comparison with the based liquid at different temperatures and additive concentrations.

**Table 2a.** The influence of temperature and additive type

Based liquid	Additive	Temperature, °C	Rheological equation	Viscosity decreasing, %
EG	-	25	$\tau = 0.0171 \cdot \gamma$	-
		40	$\tau = 0.0101 \cdot \gamma$	-
		60	$\tau = 0.0058 \cdot \gamma$	-
EG	LSNa, 0.135%	25	$\tau = 0.0138 \cdot \gamma$	19.3
		40	$\tau = 0.0079 \cdot \gamma$	21.8
EG	NF-4, 0.75%	25	$\tau = 0.0157 \cdot \gamma$	8.2
		40	$\tau = 0.0093 \cdot \gamma$	7.9
PO	-	25	$\tau = 0.0282 \cdot \gamma$	-
		40	$\tau = 0.0145 \cdot \gamma$	-
		60	$\tau = 0.0090 \cdot \gamma$	-
PO	LSNa, 0.169%	25	$\tau = 0.0243 \cdot \gamma$	13.8
		60	$\tau = 0.0078 \cdot \gamma$	13.3
PO	NF-4, 0.6%	25	$\tau = 0.0253 \cdot \gamma$	10.3
		60	$\tau = 0.0076 \cdot \gamma$	15.5
TO	-	25	$\tau = 0.0168 \cdot \gamma$	-
		40	$\tau = 0.0108 \gamma$	-
		60	$\tau = 0.0073 \cdot \gamma$	-
TO	NF-4, 0.9%	25	$\tau = 0.0156 \cdot \gamma$	7.1
		40	$\tau = 0.0088 \cdot \gamma$	18.5

**Table 2b.** The influence of additive type and concentration ( $t = 25^\circ\text{C}$ )

Based liquid	Additive	Additive concentration, %	Rheological equation	Viscosity decreasing, %
EG	LSNa	0.045	$\tau = 0.0142 \cdot \gamma$	17.0
		0.135	$\tau = 0.0138 \cdot \gamma$	19.3
	NF-4	0.250	$\tau = 0.0159 \cdot \gamma$	7.0
		0.750	$\tau = 0.0157 \cdot \gamma$	8.2
UP	LSNa	0.169	$\tau = 0.0243 \cdot \gamma$	13.8
	NF-4	0.300	$\tau = 0.0268 \cdot \gamma$	5.0

Through the measurements achievement at different temperature values it was possible to establish the  $E_a$  and  $A$  constants (Table 3).

**Table 3.** The constants from Arrhenius equation

Based liquid	Additive	Medium viscosity decreasing, %	Arrhenius equation	
			$E_a, kJ \cdot mol^{-1}$	$A \cdot 10^7, Pa \cdot s^{-1}$
EG	-	-	25.63	5.51
	LSNa 0.135%	20.5	27.65	1.97
	NF-4 0.75%	7.6	26.23	3.98
UP	-	-	26.92	5.18
	LSNa 0.169%	13.5	26.95	4.61
	NF4 0.6%	12.9	28.44	2.57

Hydrodynamic regime increasing leads to an accentuated decreasing of the ratio between the shear stress (experimental determined) and the dynamic pressure calculated with the maximum velocity value,  $\tau/p_{dyn}$  (Table 4).

**Table 4.** The shear stress and  $\tau/p_{dyn}$  modifications

Cylinder revolution $n, s^{-1}$	Peripheral velocity $w$ , $m \cdot s^{-1}$	Shear stress $\tau, Pa$	Dynamic pressure $p_{dyn}, Pa$	$\tau/p_{dyn}$ ratio	Hydrodynamic regime, $Ta_{Re}$
<b>EG-without additive, <math>t=25^\circ\text{C}</math></b>					
0.75	0.046	4.3	1.16	3.71	2.97
1.35	0.083	7.4	3.80	1.95	5.34
2.25	0.138	12.5	10.5	1.19	8.90
4.05	0.249	22.5	34.1	0.66	16.0
<b>EG+ LSNa 0.045%, <math>t=40^\circ\text{C}</math></b>					
0.75	0.046	2.4	1.16	2.07	5.02

1.35	0.083	4.45	3.80	1.17	9.05
2.25	0.138	7.37	10.5	0.70	15.1
4.05	0.249	13.1	34.1	0.38	27.2
<b>TO-without additive, t = 25°C</b>					
0.75	0.046	4.7	0.93	5.05	2.43
1.35	0.083	8.7	3.04	2.86	4.37
2.25	0.138	14.2	8.40	1.69	7.29
4.05	0.249	22.1	27.3	0.81	13.1
<b>TO+NF4 0.9%, t=40°C</b>					
0.75	0.046	2.2	0.93	2.37	4.64
1.35	0.083	3.9	3.04	1.28	8.35
2.25	0.138	6.5	8.40	0.77	13.9

By analogy with the process of fluids flow in right pipe-lines and the pressure lost through friction, it is possible to represent the  $\tau/p_{dyn} = f(Ta_{Re})$  dependence, Fig.2. The aspect of this dependence indicates an accentuated decreasing when the hydrodynamic regime increase.

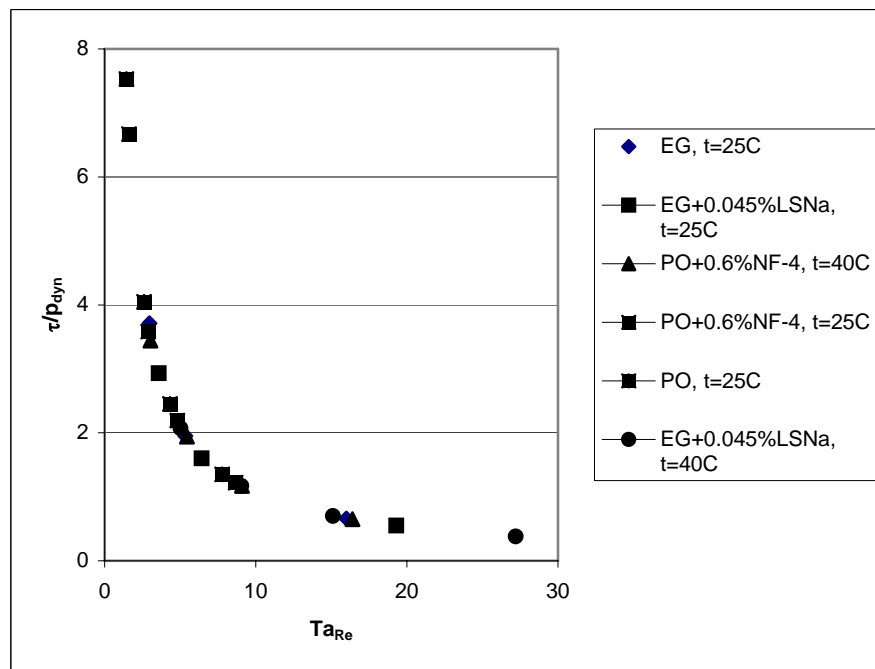


Fig 2.  $\tau/p_{dyn}$  ratio vs. hydrodynamic regime

## Conclusions

- liquids additivation using tensioactive compounds leads to both shear stress and viscosity decreasing (until 20%);
- the increasing of additive concentration accentuated viscosity decreasing;

- the additivation effect is less important on the activation energy and more pregnant on the pre-exponential factor  $A$ ;
- graphical representation  $\tau/p_{dyn} = f(Ta_{Re})$  placed the results after a parabolic curve, with the points superposition without important modifications, depends on the liquid type, the additive concentration and type and temperature, respectively.

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## Efectul unor aditivi asupra frecării în lichidele supuse mișcării de rotație

### Rezumat

În lucrare se studiază efectul de aditivare a unor substanțe tensioactive (lauril sulfat de sodiu, nonilfenol polietoxilat), asupra frecării (vâscozității) în lichide (etilenglicol, ulei de parafină, ulei mineral) supuse mișcării de rotație în spații inelare. De asemenea, a fost evidențiat efectul scăderii forțelor de frecare în funcție de concentrația și tipul aditivului folosit, valoarea criteriului Taylor-Reynolds, dependent de geometria spațiului inelar, viteza unghiulară și proprietățile fizico-chimice ale lichidului.