

## Electrically tuneable viscosity of Ionic Liquids

VITO TIČ

**Abstract** Viscosity is an essential property of lubricant, as it affects its capacity to form the lubricating film or to reduce friction and wear. One of highly desirable effect in tribology is to be able to control the viscosity of the lubricant externally in real-time without changing the lubricant. One of the possibilities is to apply an electric field to the lubricant. Since ionic liquids are solvent-free electrolytes, their properties can be usually altered by applying voltage. This preliminary research results reveal that viscosity of tested ionic liquid can be tuned by means of applying DC voltage.

**Keywords:** • ionic liquid • viscosity • friction • electric field • hydraulic fluid •

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CORRESPONDENCE ADDRESS: Vito Tič, University of Maribor, Faculty of Mechanical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia, e-mail: vito.tic@um.si.

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## 1 Introduction

The simplified definition of “ionic liquids” says that ionic liquids (ILs) are liquid or molten salts. The ionic liquid consists fully of ions. Cations (usually organic) and anions (usually inorganic) present in ionic liquids are so formulated that the resulting salts hardly crystallize. Therefore, the ionic liquid is liquid in a wide temperature range [1]. An important feature of ionic liquids is the possibility of adaptation of these physical-chemical properties through changing the nature of the anion and cation. The number of possible combinations is extremely high, that is why the best ionic liquid is supposed to be adapted for any case of use.

Another important feature of ionic liquids is the fact, that the ionic liquids are solvent-free electrolytes, so their properties can be usually altered by applying voltage. Several studies [2-5], which reveal that tribological properties of ionic liquids can be electrically tuned, were inspiration to us to conduct a preliminary research on possibility of electrically adjusting viscosity of tested ionic liquid. Namely, previous researches conducted at University of Maribor showed that selected IL for testing is a very promising candidate for new state-of-the-art lubricant and hydraulic fluid.

## 2 Ionic Liquids as lubricants

The ionic liquid lubricating properties have been tested many times in many ways. It has been proved that in most cases they are better than the conventional lubricants' properties. That can be explained with the fact that ionic liquid have a unique bipolar structure allowing them easy adsorption to sliding surfaces of mechanical parts in contact. Consequently, an effective boundary film reducing friction and wear is formed. That applies, particularly, to lower contact pressures and large surface areas.

Because of many good properties the ionic liquids are ideal candidates for new lubricants usable in harsh operating conditions, where conventional oils and greases or solid lubricants fail. A few studies in this sphere have already been carried out.

The cation and anion selection in ionic liquid and forming of ion side chains impose the basic ionic liquid properties, resulting in creation of adapted lubricants and lubricant additives [6]. For the first time, the ionic liquid as very

promising highly capable lubricants were mentioned in 2001 [7], lately, they have aroused high interest in the sphere of tribology.

### **3 Viscosity of ionic liquids**

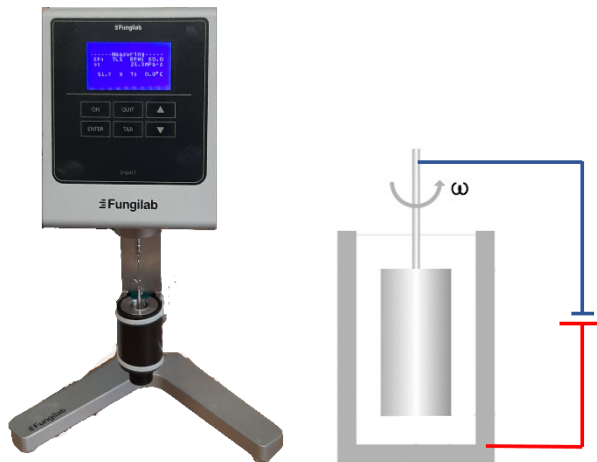
As there are a great number of possible ionic liquids, there are also so many different viscosities; usually, they are in the range from 0.035 to 0.500 Pas [8]. Similarly as in mineral oils the temperature in numerous ionic liquids has a strong impact on viscosity. In researches, so far, it has been proved that contaminants, particularly water (even small quantity from ambient air), have a great influence on the measured viscosities.

Viscosity of ionic liquids can be measured by one of the three viscometer types: with falling ball, capillary or rotational. So far we have measured kinematic viscosity of selected and tested IL, which is 18.6 mm<sup>2</sup>/s at 40 °C and 5.1 mm<sup>2</sup>/s at 100 °C with a viscosity index of 229, making it a perfect candidate for a low friction and low viscosity energy saving lubricant.

In order to be able to apply electrical voltage to the ionic liquid during the test, the rotational viscometer was chosen for this experimental setup. Rotational viscometer is such a type where a solid shaped body named cylinder or spindle is rotated immersing in the fluid whose viscosity is to be measured. A typical rotational viscometers work on the principle that the torque required to turn an object in a fluid is a function of the viscosity of that fluid. From the measurements of rotational speed of the solid body and the required torque, the viscosity is calculated.

### **4 Measurement setup**

The dynamic viscosity of tested IL at room temperature (approx. 20 °C) was measured using Fungilab Smart rotational viscometer with cube ( $\phi$  19 mm) and sphere ( $\phi$  17,5 mm x 32 mm) setup. To test the possibility of adjusting viscosity by means of applying electrical field to the ionic liquid, a DC voltage ranging from 4 V to 7 V was applied between the cube and the rotating sphere, as shown in Figure 1. While applying the electrical field to the tested IL, the dynamic viscosity was constantly measured and recorded. Additionally, also the electrical voltage and electrical current were measured and recorded.



**Figure 1: Fungilab Smart rotational viscometer (left) and scheme of applied voltage to tested liquid (right).**

## 5 Results

Since tested IL is electrically conductive (as well as most ILs), an electrical current passes through the liquid when voltage is applied, as results show in Table 1. Given the gap of 0.75 mm between the rotated sphere and cup we needed to apply at least 5 V of DC voltage between the sphere and the cup in order to alter the viscosity of tested IL.

After applying more voltage (7 V) the first tests have revealed that the dynamic viscosity of IL at room temperature can be raised from starting 30 mPas to 200 mPas and even higher, resulting in more than 600 % increase in dynamic viscosity. Of course, some equipment and test limitations occurred when trying to dynamically, in real-time, measure viscosity over such broad band.

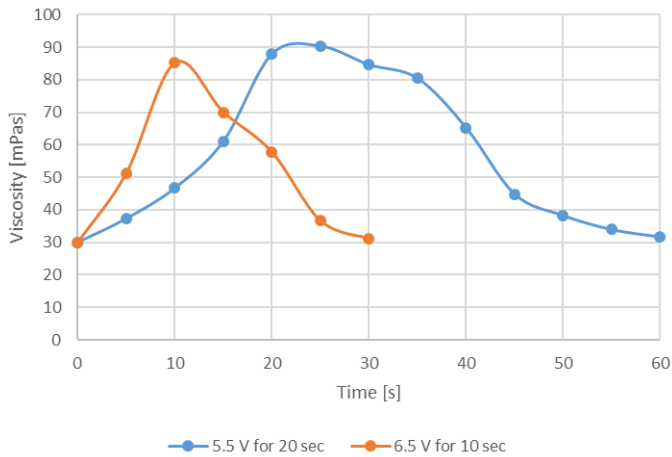
After performing first tests to confirm that the dynamic viscosity of tested IL can be heavily influenced by applying an electrical field, we made several measurements (presented in Table 1) by applying different DC voltages from 4 V to 7 V. It can be seen that the current passing through the liquid is not linear to applied voltage.

**Table 1: Measurement results**

Voltage [V]	Average Current [A]	Viscosity without applied electric field [mPas]	Viscosity with applied electric field [mPas]
4	0.01	30	30
5	0.03	30	35
5.5	0.3	30	> 100 (out of range)
6	0.6	30	> 100 (out of range)
7	1.2	30	> 100 (out of range)

The results confirm that electrical field applied to tested IL affects its bipolar structure and thus its tribological properties since electric excitation changes the position and alignment of cations and anions.

The rate of viscosity change for two measurements at 5.5 V and 6.5 V is presented in Figure 2. Since this setup of rotational viscometer allowed us only measurements up to 100 mPas, in the first measurement 5.5 V was applied to IL between 0 and 20 seconds, and 6.5 V was applied to IL between 0 and 10 seconds in second measurement. The results reveal that higher voltage raises viscosity more quickly in comparison to lower voltage. It can also be seen, that viscosity is also altered for some period of time even after the voltage is disconnected.

**Figure 2: Ionic liquid viscosity change when applying DC voltage.**

During the test we have noticed some changes to the ionic liquid. When applying more voltage and heavily rising the viscosity, the tested IL begun to foam at the surface. Also, when we have performed several measurements and raised the viscosity several times, the liquid changed its colour and became much darker. And at the end, we could not repeat the first test (7 V) to rise the viscosity up to 600 %. Thus, we assume that not only the colour, but also the structure and properties of tested IL have permanently changed.

## 6 Conclusion

The paper presents preliminary research findings about the possibility of electrically adjusting viscosity of tested IL (producer ProIonic GmbH) as a very promising candidate for new state-of-the-art lubricant and hydraulic fluid. Although results confirm that the viscosity can be raised by applying voltage to tested IL, the preliminary research left us with more questions than has given us answers. Definitely, more detailed research with better equipment is suggested in the future to investigate the effects of applying different electric fields to IL, such as AC, DC or PWM with different frequencies and amplitudes.

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