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Lubricating ability of two phosphonium-based ionic liquids as additives of a bio-oil for use in wind turbines gearboxes

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ABSTRACT

This study investigates the tribological behavior of two different phosphonium-based ionic liquids as additives to a bio-oil in steel-steel contact. One of the ionic liquids is halogen-free and will be compared to an ionic liquid that contains halogens. Bio-oil and ionic liquid mixtures containing 0.5, 1 and 2.5 wt. % of both ionic liquids are studied utilizing a combination of tribology and surface measurement techniques. These experiment include pin-on-disk tribometer, hydrology, corrosion, and surface spectroscopy measurements for the ionic liquid mixtures, as well as pure bio-oil for comparison. It is found that the presence of the ionic liquid additives significantly reduces the volume loss in the wear track, particularly under the higher speed studied, indicating a potentially significant improvement in function.

1. Introduction

The devices and systems we rely on daily operate through an exchange of energy. A significant portion of this energy is lost due to friction. Additionally, wear is a major cause of mechanical failure of these devices and systems [1, 2]. Most of these devices and systems use some form of lubrication to combat friction, wear and heat generation as well as minimize losses and improve efficiency. An average use of 35 million tons of lubricants per year is used globally. It is projected that the volume of lubricants will grow between 1.5% – 2% in the coming years [3]. The majority of these lubricants are mineral oil based, created from petroleum derivatives. It is estimated that up to 10 million tons of these lubricants enter and pollute the environment each year. Not only are they highly toxic, but have poor biodegradability [4, 5]. Increasing environmental regulations and public policy have ushered in the need for development and implementation of environmentally friendly, biodegradable lubricants. Vegetable oils display many properties desirable for lubrication and appear to be a viable solution to this problem [3, 6–9]. However, vegetable oils also possess negative properties such as poor thermal and oxidative stabilities, narrow viscosity ranges and poor low temperature properties that diminish their effectiveness as lubricants [3, 8, 10, 11]. It has been shown that these negative properties can be overcome through the use of additives [6, 7, 10].

Ionic liquids (IL's) are salts that exhibit a melting point below 100 °C. When melted, they form a liquid comprised entirely of ions. Usually they exist as a large organic cation paired with a smaller organic or inorganic anion. Over the past decade, IL's have emerged as high performance fluids for a variety of applications. Properties such as low vapor pressure, high thermal and chemical stability, nonflammability, high viscosity, broad liquid range, high ionic conductivity, wide electrochemical window, and miscibility with organic compounds make them ideal candidates for many engineering and chemical applications [12, 13]. In addition to the above mention properties, IL's have the ability to form absorbed ordered layers on material surfaces reducing friction and wear [14–16]. The use of IL's as a neat lubricant was first reported in 2001 [17]. Since then, IL's have shown promise as next generation lubricants [15, 18–21] and lubricant additives [22–26]. Many of the IL's used in lubricant additive research contain environmentally toxic halogen elements such as fluorine. IL's with fluorine in the anion have shown positive results in reducing friction and wear [27–30]. With environmental regulations and consciousness getting stricter, it is imperative to find more environmentally friendly alternatives. Research is also progressing with the use of halogen-free IL's in lubrication. Many studies have shown that halogen free IL's can also reduce friction and wear [15, 31–33].

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Table 1
Bio-oil properties.

Properties	Bio-oil
ISO Grade	46
Viscosity @ 40 °C (cSt)	46
Viscosity @ 100 °C (cSt)	6.8
Viscosity Index	98
Flash Point (°C)	225
Pour Point (°C)	−24
Sp. Gravity @ 15 °C	0.88

In this study, the tribological behavior of two phosphonium-based ILs, halogen-containing, Trihexyltetradecylphosphonium bis(trifluoromethylsulfonyl) amide [THTDP][NTf2] and halogen-free Trihexyltetradecylphosphonium bis(2,4,4-trimethylpentyl) phosphinate [THTDP][Phos], is investigated as additives of a bio-oil (BO) in steel-steel contact. BO-IL blends containing between 0 wt. % to 2.5 wt. % of each IL are studied using a pin-on-disk tribometer and interactions of ILs with steel surfaces are discussed.

2. Experimental

2.1. Lubricants

The base lubricant used in the study is a biodegradable oil based on synthetic esters and, at least 50% of which are produced from renewable source material. This lubricant is a low viscosity oil that has surpassed all the requirements to earn the European Union Ecolabel and its properties are summarized in Table 1.

2.2. Ionic liquids

The ILs used in this study were commercially available from Sigma-Aldrich (USA). Their molecular structure, name and abbreviation (code) are shown in Table 2. Both ILs have identical

Table 3
Lubricant Density and Viscosity Values.

Lubricant	Density at 22 °C (g/cm^3)	Dynamic viscosity (cP)	
		40 °C	100 °C
BO	0.915	45.9	8.5
BO+0.5% [THTDP][Phos]	0.915	45.1	8.5
BO+1% [THTDP][Phos]	0.915	46.6	8.6
BO+2.5% [THTDP][Phos]	0.915	52.7	9.1
BO+0.5% [THTDP][NTf2]	0.916	44.2	8.4
BO+1% [THTDP][NTf2]	0.917	44.2	8.5
BO+2.5% [THTDP][NTf2]	0.919	44.8	8.4

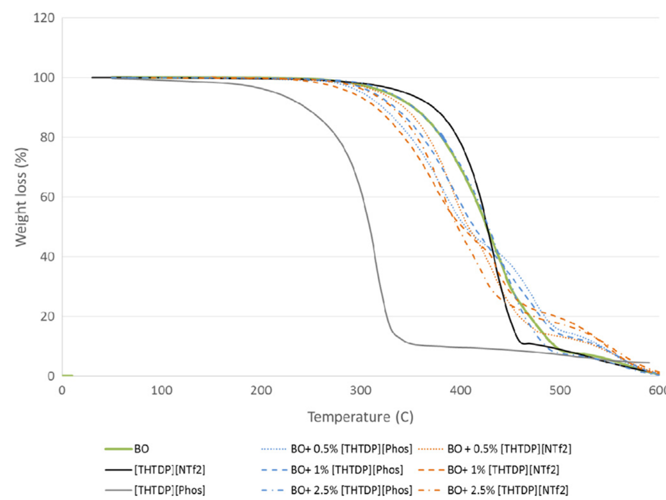
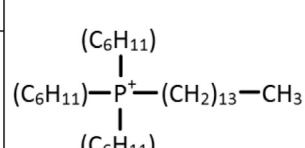
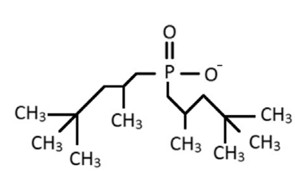
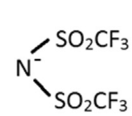


Fig. 1. TGA curves for the ILs, BO and lubricant mixtures.

Table 2
Molecular structure, name and abbreviation of ILs used in this study.

Code	Structure		IUPAC name
	Cation	Anion	
[THTDP][Phos]			Trihexyltetradecylphosphonium bis(2,4,4-trimethylpentyl)phosphinate
[THTDP][NTf2]			Trihexyltetradecylphosphonium bis(trifluoromethylsulfonyl) amide