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Alkyd paint removal: Ionic liquid vs volatile organic compound (VOC)

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ABSTRACT

The drive towards safer technology in removing paint from substrate requires switching from hazardous volatile organic compounds to greener alternative solvents. Ionic liquids (ILs) have been considered as relatively green solvents and employed in many applications. This study focusses on investigation of ILs as alternative green solvents for paint removal. In this regard, five imdazolium based ILs were studied for alkyd paint removal on coated wooden substrate. The effect of various anions such as dicyanamide [DCA], bis (trifluoromethanesulfonyl) imide [NTf_2], hydrogen sulphate [HSO_4], acetate [OAc] and chloride [Cl] was investigated. For benchmarking and comparison, three volatile organic solvents such as toluene, acetonitrile, and ethanol were used. Microscopic images showed that [DCA] anion gave significant impact on alkyd removal. In addition, [Bmim][DCA] gave highest swelling percentage of 23% whereas the other ILs did not show significant swelling. Viscosity, anion size and alkyd paint-IL interactions played important roles in removal efficacy. The prolonged immersion time in [Bmim][DCA] decreased the pull off adhesion strength up to 83.3% and consecutively promoted paint detachment from substrate. Similar infrared pattern of bare wooden stick and [Bmim][DCA] treated coated wooden stick indicates significant removal of paint by IL. The experimental results demonstrate promising application of IL as a green solvent for paint removal.

1. Introduction

Organic solvents have been universally recognized as exellent agents for paint removal. Despite their remarkable competency, the majority of organic solvents such as isopropanol, toluene, xylene, solvent mixtures such as white spirits and the chlorinated solvents, methylene chloride possess environmental and health risks [1]. High exposure of organic solvents has reportedly led to unconsciousness and, in some cases, death [2,3]. These health and environmental concerns consequently urge the development of less hazardous cleaning methods.

Ionic liquids (ILs) are potential green solvents, composed of organic salts with melting points below 100 °C. Recently, ILs have been extensively investigated by both academia and industry for a wide range of applications, such as separation of aromatic and aliphatic hydrocarbons [4], direct conversion of glucose and biomass to chemicals [5], CO_2 absorption [6], dye removal [7], heavy metal extraction [8], drug delivery [9], surfactant and lubricant [10]. These potential applications are mainly contributed from the tunable properties of ILs and their negligible vapor pressure at room temperature. Moreover, ILs have emerged as environmentally benign alternatives to traditional volatile organic solvents [11]. For instance, ILs have been recently utilized for cleaning purposes. IL 2-ethylhexyl lactate (2EHL) was reported to exhibit comparable performance to hydrofluorinated ether (HFE) 7100 which is currently used in degreasing operations at Air Logistics Centers (ALCs) [12]. 1-ethyl-3-methylimidazolium acetate [Emim][OAc], 1-ethyl-3-methylimidazolium methane sulfonate [Emim][$MeSO_4$], 1-ethyl-3-methylimidazolium ethylsulfate [Emim][$EtSO_4$], and 1-ethyl-3-methylimidazolium triethylsulfonium bis(trifluoromethylsulfonyl) imide [SEt_3][NTf_2] were also reported as excellent candidates for cleaning agent [13]. Low vapor pressure of ILs allows them to interact with the paint during the prolonged time [14], thus it is anticipated that more effective removal would be achieved.

To the best of our knowledge, ILs have not been investigated for their potential application in removal of organic coating or paints. Earlier, M. F. Pacheco [15] reported the use of ILs in varnish removal from paintings. Different types of ILs were tested for removal of Dammar, poly(vinylacetate) (PVAc), retouching varnish and acrylic. It

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has been shown that [Bmim][DCA] is effective in removal of Dammar, poly(vinylacetate) (PVAc), retouching varnish while other ILs have selective effect on the removal of varnish. Even though this proves ILs potential capability for varnish paint removal, data on interaction of ILs with various organic coating or painting materials are unavailable.

Alkyd polymer is a commercial organic coating paint commonly used on wood, metal, plastic, composite, and other substrates. Its removal from substrates such as interior and exterior households and lab equipment often becomes important for several reasons. The replacement of VOC solvents used for removal of alkyd paint with greener solvent is crucial to meet the environmental and safety standards. Therefore, this study aims to explore the potential application of 1-butyl-3-methylimidazolium based ILs for alkyd paint removal from wooden substrate. The removal efficiency was evaluated with respect to the type of anion, viscosity, and swelling behavior of ILs. Similarly, microscopy, FTIR analysis and pull off adhesion test were performed to confirm the removal of alkyd paint after application of ILs. Furthermore, the solubility behavior of alkyd polymer in ILs and Flory Huggins interaction parameter were predicted from the solubility parameters data. For comparison and benchmarking, the performance of conventional VOC solvents (toluene, acetonitrile and ethanol) is also determined.

2. Materials and method

2.1. Materials

A commercial black colored alkyd based paint (TopPaint brand) was obtained from local market. As shown in Table 1, ILs were purchased from Merck, whereas, the VOC solvents i.e., toluene, ethanol and acetonitrile were obtained from Sigma Aldrich. All solvents were used in pure form as received. The chemical structures of ILs and alkyd polymer are listed in Table 1.

2.2. Methods

Dry and clean wooden sticks were coated with alkyd polymer paint, using a simple dip-coating method where the wooden stick was first immersed in the coating material (alkyd polymer) for a period of 5 min. Then, the wooden stick was removed and allowed to air dry for one week long in order to attain stronger adhesion between the wooden substrate and paint material. The coating thickness of 85 ± 16.5 µm was measured using Digital Micrometer (Digmatic Mitatyo). Tests were conducted on the dry coating film formed on the wooden substrate.

The paint removal test was conducted by immersing the coated wooden stick in the IL and VOC solvents, and periodic paint removal was carried out with and without swab aid for ILs and VOCs immersed samples, respectively. Similarly, the swelling test was conducted by immersing the coated wooden substrate in IL and VOC solvents. Samples were periodically removed and the coating surfaces were wiped with a dry tissue paper. The weights of dry and solvent treated wooden stick were measured gravimetrically and the percentage solvent uptake was calculated using equation [16,17]:

$$M_t = \frac{m_2 - m_1}{m_1} \times 100\% \quad (1)$$

M_t is the percentage solvent uptake at time t, m_2 is the weight of solvent treated coated wooden stick and m_1 the weight of dry coated wooden stick. ILs and VOCs solvent uptake measurements were performed at room temperature (24.6 ± 0.5 °C).

2.3. Characterizations

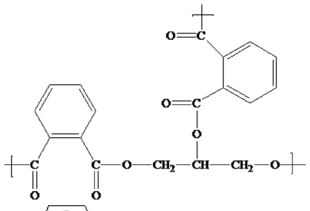
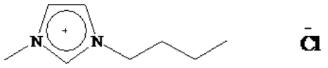
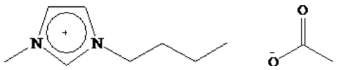
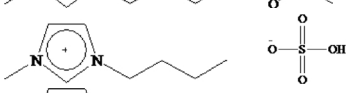
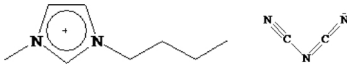
Digital microscope (GXM-Dino-Lite AM4113ZT Pro Digital Microscope) was used to observe the effect of various ILs and VOCs on the surface of alkyd polymer coating paint. The microscopic images were captured periodically for both ILs and VOCs treated samples. Fourier transform infrared spectroscopy (Thermo Scientific Nicolet iS5, FTIR) was used to identify the functional group differences in the coated wooden stick substrate before and after ILs treatment. Viscometer (Anton-Parr, SVM3000) was used for measuring the viscosity and density of the solvents. Hydraulic Adhesion Tester (Elcometer 108) was used to evaluate the adhesion strength of the alkyd paint on the wooden substrate, where the force required to pull off the 284 mm^2 area of coating material from its substrate.

3. Result and discussion

3.1. Ionic liquids

Microscopic images of the coated wooden surface were periodically

Table 1
Chemical structures of alkyd polymer and ILs used in this study.

Name of material	Abbreviations	Chemical structure
Alkyd polymer	Alkyd	
1-Butyl-3-methylimidazolium chloride	[Bmim][Cl]	
1-Butyl-3-methylimidazolium acetate	[Bmim][OAc]	
1-Butyl-3-methylimidazolium hydrogen sulfate	[Bmim][HSO_4]	
1-Butyl-3-methylimidazolium dicyanamide	[Bmim][DCA]	
1-Butyl-3-methylimidazolium bis(trifluoromethanesulfonyl)imide	[Bmim][NTf_2]