Lubricating Oil Condition Monitoring Enabled by Triboelectric Effect

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Lubricants can extend machine lifetimes by orders of magnitude, which is widely used in machine systems [1]. Using lubricants is the most effective way to control friction and wear because the mechanical interfaces are commonly lubricated and separated by fluid lubricating films. Therefore, the lubricant is an important source of information to detect machine failures, comparable to the role of human blood in detecting and preventing diseases [2]. For example, low oxidation stability of lubricating oils may result in oil acidification and carbon deposition under high-temperature aging [3]. Therefore, the real-time detection of lubricants is of great importance to protect machine systems. Traditional lubricant monitoring sensors include optical methods, acoustic emission detection methods, and electromagnetic inducted technologies [4]. However, these methods can only provide limited information with relatively low accuracy [5-6] and most conventional detection sensors are quite large and require an external power supply.

This research presents a feasible way to prepare and apply a self-powered triboelectric sensor for lubricant degradation monitoring. The fluorinated DLC film was deposited on Al by bipolar-type plasma-based ion implantation & deposition (PBII&D) [7] to fabricate free-standing mode triboelectric nanogenerator (TENG) with nylon working as another friction layer. Two commonly used lubricants, PAO base oil and commercial engine oil (0W20) were thermally aged under 150 ℃ for 4 - 96 h respectively as shown in **Figure 1**.

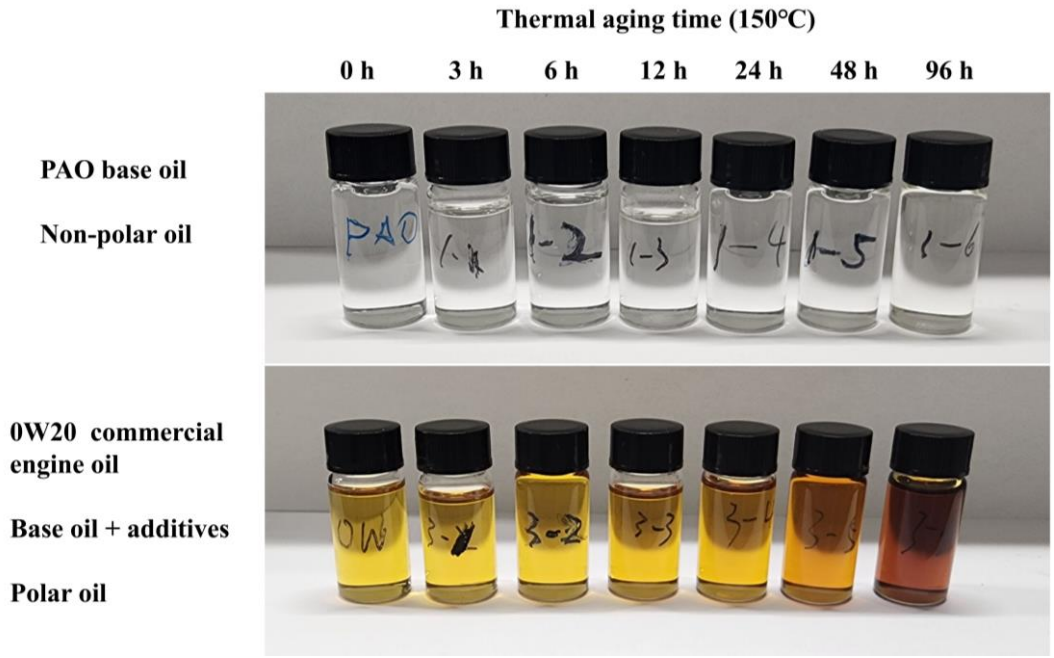

Fig. 1 Lubricants with different aging times.

The 20 μL aged lubricants were then added to the frictional interface of TENG, and the electrical outputs were recorded under a normal load of 5 N and a sliding velocity of 2 Hz.. As shown in **Figure 2**, the electrical outputs for both PAO and 0W20 decrease with increasing aging time. The output of PAO 4 keeps half compared with fresh oil, while 0W20 almost degrades to 0 V. These

results indicate that thermal aging greatly affects the output of TENG, and thus can effectively monitor the degradation degree of lubricating oils. Previous research shows that the acid value increases with the prolongation of aging time, indicating that acid substances are generated during the aging process. These acidic substances are most likely carboxylic acids (-COOH) and aldehydes (-CHO) [8]. These polar functional groups increase the permittivity of lubricants to make them easily polarized and neutralize the surface charge by liquid flow, resulting the output reduction.

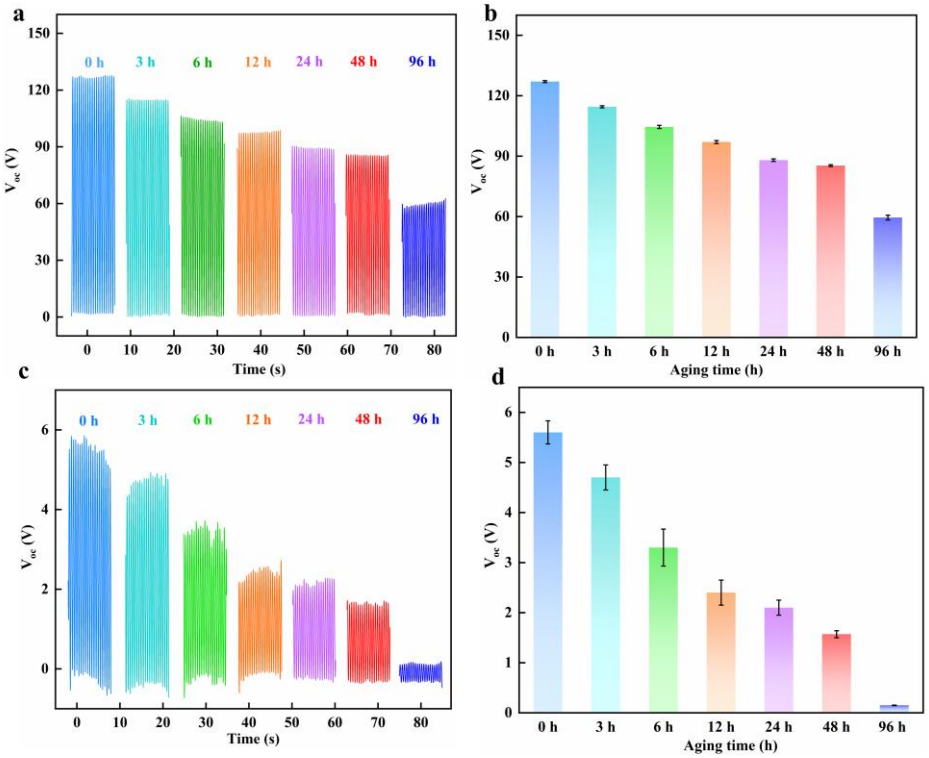

Fig. 2 Electrical outputs using lubricants with different aging times. (a) Voltage signal of PAO 4, (b) histogram with error bars for PAO 4, (c) voltage signal of 0W20, and (d) histogram with error bars for 0W20.

The proposed method can sensitively detect the degradation of lubricants by electrical signals. The electrical output dramatically decreases with the increasing thermal aging time due to the increasing polarity of lubricants. It is believed that this self-powered triboelectric sensor has the great advantage of monitoring the service performance of lubricating oils for different mechanical systems in a cost-efficient way.

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