Chemical Physics Letters 662 (2016) 192–195

Contents lists available at ScienceDirect

Chemical Physics Letters

journal homepage: www.elsevier.com/locate/cplett

Research paper

Significantly enhanced impulse breakdown performances of propylene carbonate modified by TiO_2 nano-particles

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ARTICLE INFO

Article history:
Received 28 June 2016
In final form 14 September 2016
Available online 15 September 2016

Keywords:
Propylene carbonate
Nano-particles
Dielectrics
Compact pulsed power sources

ABSTRACT

Nano-fluids with KH550-grafted TiO_2 nano-particles homogenously dispersed into propylene carbonate exhibit substantially enhanced dielectric properties compared with the base liquid. Specifically, the breakdown stability of nano-fluids is dramatically improved for a small high-voltage electrode potential increasing rate, which has a potential to increase the reliability of the pulsed power system. On the other hand, the mean breakdown voltage of nano-fluids is more than 30% larger than that of base liquid when the high-voltage electrode potential increasing rate equals to 6 kV/μs, which will lead to a great increase in energy storage density of the pulsed power system.

1. Introduction

Modern applications have stimulated intense interest in the pulsed power technology towards high average power and compact structure [1–3]. Polar liquids with large dielectric constants and high dielectric strength are of major importance to the compact pulsed power sources [4]. As a kind of polar liquids, propylene carbonate (PC) has a large relative permittivity, low freezing temperature, high resistivity and low viscosity [5]. Compared with other typical polar liquids, such as deionized water or water/ethylene glycol mixtures, PC has relatively high chemical stability, which can hold the resistivity without decaying for longer periods of time in the pulse forming line. Moreover, Shu et al. [6] in Old Dominion University has demonstrated that PC has higher breakdown strength than that of deionized water.

However, despite much previous efforts have been devoted to explore the effective ways to increase the dielectric performances of liquid insulation, such as pressurization and purifying, major improvements are lacking [7–10]. In electrical engineering fields, various favorable results have shown that by adding nanoparticle suspensions into the liquid, the insulating properties of the base liquid can be enhanced [11–13]. Recently, we tried to disperse TiO_2 nano-particles into PC and investigated the effect of nano-particles on the pulsed breakdown performance of the base liquid.

2. Experiments

2.1. Surface modification of nano-particles and preparation of NFs

TiO_2 nano-particles with average diameter of 30 nm were obtained from Deco Island Gold Ltd. The morphology of nanoparticles was measured by using Scanning Electron Microscope, shown in Fig. 1(a). It reveals apparent agglomeration of nanoparticles due to considerably high surface energy and extremely large surface area/particle size ratio [14].

In order to improve the dispersion ability of nano-particles, γ-aminopropyltriethoxysilane coupling agent (KH550) was used to modify the nano-particle surface and the reaction scheme is illustrated in Fig. 2. Firstly, three $—OC_2H_5$ connected to Si were hydrolyzed and then the silanol was generated. After that, the silanol was condensed to be an oligomer. Then the hydrogen bond would be generated by the —OH groups both in the oligomer and on the surface of nano-particles. Finally, through drying or sulfidation processes, the covalent interactions would be formed between the coupling agent and nano-particles. Then, the nano-particles were uniformly dispersed into PC by the ultrasonic dispersion method and agate jar milling technique. Fig. 1(b) shows that the coupling agent KH550 effectively decreases the agglomerations of nano-particles and the size ranges from several nano-meters to several ten nano-meters. In this study, the proportion of nanoparticles in NFs samples was about 0.5 vol%.

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http://dx.doi.org/10.1016/j.cplett.2016.09.043
0009-2614/© 2016 Published by Elsevier B.V.

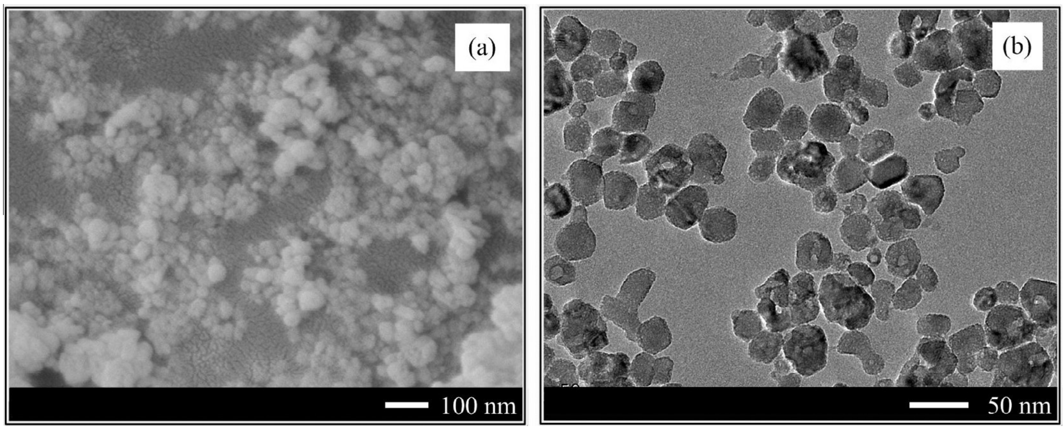

Fig. 1. (a) Scanning Electron Microscope image of outsourcing TiO_2 nano-particles and (b) Transmission Electron Microscope image of KH550-grafted TiO_2 nano-particles dispersed in PC.

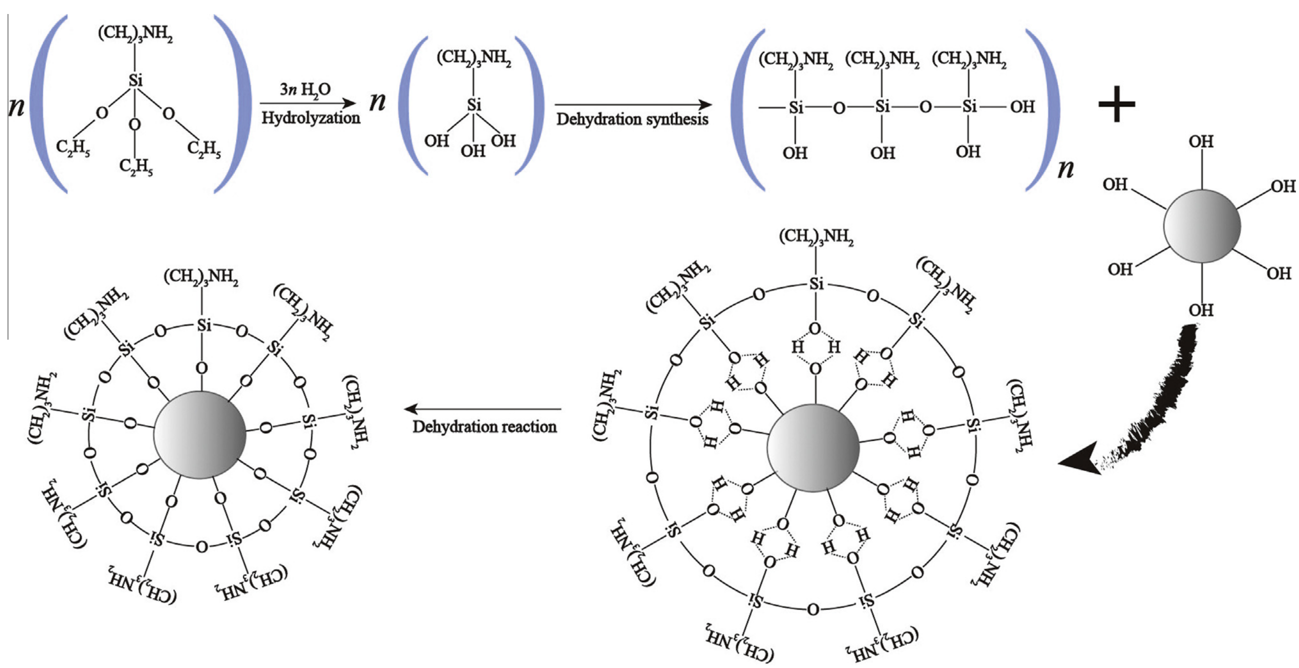

Fig. 2. Reaction scheme for preparing KH550-grafted TiO_2 nano-particle.

2.2. Impulse breakdown characteristics of PC and NFs

Impulse breakdown voltage and the time lag to breakdown of the liquid samples were measured [15]. The experimental apparatus mainly consists of the primary capacitor, a transformer, the secondary capacitor and the test cell, shown in Fig. 3. The circuit parameters are as follows: the primary capacitance (C_p) is 600 μF and the winding inductance (L_p) is 0.65 μH. In the secondary circuit, the secondary winding inductance (L_s) is 530 mH and the capacitance (C_s) is 1.95 nF. The primary capacitor was charged by commercial power supply and the test cell was in parallel connected to the secondary capacitor. Through changing the voltage applied on the primary capacitor, we could get different high-voltage electrode potential increasing rate, $A = 1.5–6$ kV/μs. The gap between electrodes was set to be 1 mm during testing.

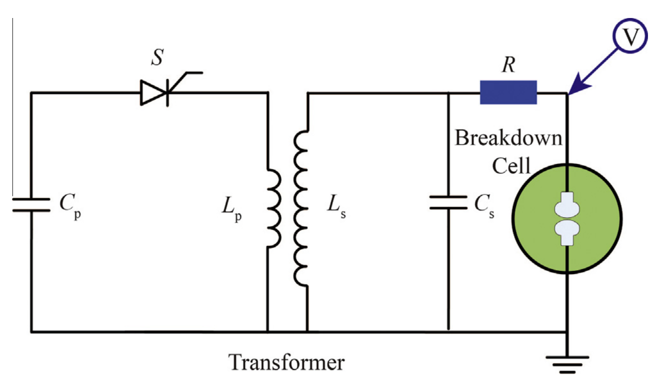

Fig. 3. Impulse breakdown measurement device.

3. Results and discussions

Fig. 4(a) shows the examples of measured voltage waveforms across the test gap, which is the mean breakdown voltage among twenty times of breakdown process for each sample. It is obvious that adding TiO_2 nano-particles into PC cannot only enhance the breakdown voltage, but prolong the charge time for each