Available online at www.sciencedirect.com
ScienceDirect
Journal of Electrostatics 65 (2007) 506–510
Journal of ELECTROSTATICS
www.elsevier.com/locate/elstat

Research on the electrostatic properties of liquid dielectric mixtures

Maciej Zdanowski*, Józef Kędzia

Faculty of Electrical Engineering and Automatics, Technical University of Opole, Mikołajczyka 5, 45-272 Opole, Poland

Received 9 September 2005; received in revised form 19 October 2006; accepted 10 November 2006
Available online 11 December 2006

Abstract

This paper presents research results, which confirm the possibility of influencing the electrostatic charge tendency (ECT) of selected mixtures of purely insulating liquids. Tests were performed in a spinning disk system, where the factors influencing the value of the electrification current consisted of variable composition of the toluene–cyclohexane mixture, rotational speed, and a disk diameter. Liquid hydrocarbon mixtures displayed changes in ECT as well as classic insulation parameters such as resistivity and relative permittivity for concentration changes of the admixtures. These results can be used to assist the search for inhibitors of ECT and of aging processes in insulating oils.

Keywords: Static electrification; Electrification current; Transformer oil; Pure hydrocarbons; Spinning disk system

1. Introduction

The phenomenon of static electrification occurs on the border surface separating solid and liquid phases. Due to the mutual relocation of these phases, an electrostatic charge is generated in the vicinity of the separating layer [1–3]. An excessive accumulation of this charge can result in various types of hazards. In the chemical and petrochemical industries, for example, static electrification results in fire hazards due to the flow of electrifying liquids. In the electric power industry, hazards occur from the use of dielectric liquids, such as the oil which is used as an insulating and cooling liquid in power transformers. The low conductivities of oil and paper result in relatively long charge relaxation times in such systems. This scenario fosters the accumulation of electrical charges and a resultant electric field superimposed on the alternating field of the energized transformer. This phenomenon can lead to excessive electrical stress of the insulation, and consequently the initiation of partial discharges and possible permanent damage of the transformer [4,5].

In early research work on electrification, measurements of parameters such as flow speed, conductivity, and loss in real, working transformers were analyzed to determine their relationship to the density of generated electrostatic charge [6,7]. Economic considerations constrained testing on real systems, and the main research direction was shifted toward large model systems. Such systems allow for easy change of flow parameters, type of oil, and choice of the solid material. Work on model systems has made it possible to obtain a wide inventory of information on the electrification phenomenon [8,9] and the introduction of small laboratory systems to investigate numerous characteristics of the electrification process. These smaller systems included a flow system [10] and Oommen minitester [11,12], a Couette system having a spinning cylinder [13,14], and a system consisting of a disk spinning in water [15,16]. The complexity of processes taking place during electrification in such a physically and chemically complex liquid as electro-insulating oil led to a considerable discrepancy in the research results; this discrepancy which was mentioned, for example, occurred at CIGRE in 1994 [17]. As a consequence, research work was initiated and directed toward simpler liquids such as pure hydrocarbons and their mixtures, which are included in insulation oil [18–21].

*Corresponding author. Tel.: +48 77 4006365.
E-mail addresses: mzdano@po.opole.pl (M. Zdanowski), jked@po.opole.pl (J. Kędzia).

0304-3886/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.elstat.2006.11.006

The aim of our research is to determine the influence of various factors on the electrostatic properties of selected interhydrocarbon mixtures. The hydrodynamic, physicochemical, and electrical properties of such mixtures are all dependent on the particular components comprising such mixtures. The goal of the work is to relate the characteristics of mixtures to their resulting tendency toward electrostatic charge generation. Tests on simple mixtures can help identify different ways to limit their tendency to acquire electrostatic charge. It may also be possible to develop inhibitors of the electrification process in insulating oils.

2. Characteristics of experimental apparatus and insulating liquid

Tests on the electrostatic charge tendency (ECT) of dielectric liquids were carried out in the system of Fig. 1 using a spinning disk. The measuring setup was constructed around a 10-cm diameter, 13-cm high measurement container containing 500 ml of the liquid under test. Disk diameters of 3.5, 5 and 6 cm were positioned 2.5 cm from the container bottom. The rotating disk was driven by an electric motor of adjustable speed. Rotation speed was measured using a digital meter and non-contacting sensor. The electrification current was measured as leakage current to ground from the container using the electrometer shown in Fig. 2.

The electrometer, based on the National Semiconductor LMC6001 BiFET op-amp, had an input resistance $10^{15}\,\Omega$ and an input bias current no greater than 25 fA. The 1000-MΩ feedback resistor made possible measurements as low as ±5 nA. The 500-kΩ input resistor limited input current to safe levels in cases of significant electrostatic potential on the electrometer input [16].

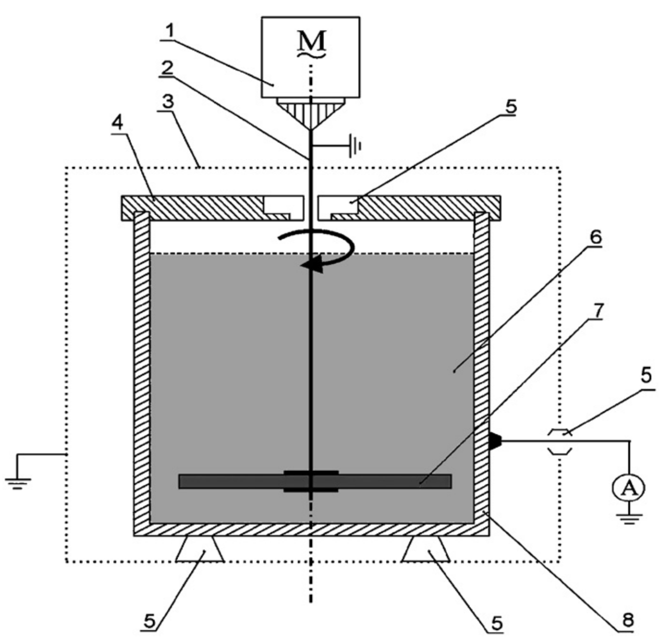

Fig. 1. Diagram of the system with a spinning disk in liquid for studying the electrification of insulating liquids: (1) propulsion motor; (2) grounded, rotating mandrel; (3) Faraday cage; (4) cover; (5) insulator; (6) liquid; (7) disk; and (8) measurement container.

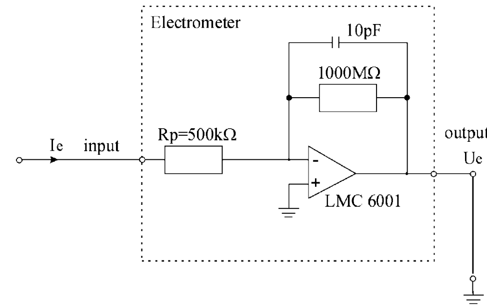

Fig. 2. Schematic diagram of the electrometer used to measure charging current.

Liquid electrification increases as the disk begins to rotate. The resulting charge density q_w, occurring via the selective adsorption of ions at the disk–liquid interface, begins its distribution throughout the entire liquid volume. In steady state, beyond the laminar sub-layer, the volume density increases to the value q_0 whose value depends, according to Abedian–Sonin model [22], on the electrochemical properties of the interphase surface, the rotational speed, and the disk diameter. The value of q_0 can be measured using a variety of laboratory devices, including the absolute charge sensor (ACS) developed at MIT [23], and a system incorporating a double-Nelson chamber [24]. However, this volume charge is not distributed uniformly and depends greatly on the hydrodynamic flow distribution inside the container. Consequently, it is more convenient to simply measure the current to the disk as a measure of the electrification process.

For our tests, chemically simple, pure hydrocarbons liquids having well-known properties were used. Toluene was used to represent the aromatic hydrocarbons, and cyclohexane the naphthalene hydrocarbon group. Table 1 shows the chemical and electrical properties of these two liquids.

3. Analysis of results

3.1. Analysis of the ECT research results

Fig. 3 shows measured dependencies of electrification current on the rotational speed of a 6 cm disk spinning in toluene and cyclohexane. A nearly linear increase with rotational speed is evident. Electrification current with cyclohexane is much lower than that of toluene, which has a much higher ECT. Fig. 4 shows the dependence of electrification current of a 2% mixture of cyclohexane in toluene on the rotational speed of disks of various diameters. As was observed with pure hydrocarbons, these mixtures also show a linear dependence of current with respect to disk rotational speed. The level of the current also depended on the size of a spinning disk. These data are