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Electrohydrodynamic atomization two-phase flow regime map for liquid hydrocarbon under pulsed electric fields with co-gas flow

J.S. Chang[a], C. Ayrault[a], D. Brocilo[a], D. Ewing[b], G.D. Harvel[a,*], K. Urashima[a], H. Hirata[c], S. Matsumoto[c], P. Fanson[d]

[a] *McMaster Institute of Applied Radiation Sciences, McMaster University, Hamilton, Ont., Canada*
[b] *Department of Mechanical Engineering, McMaster University, Hamilton, Ont., Canada*
[c] *Toyota Motor Corporation, Toyota, Japan*
[d] *Toyota Motor Engineering and Manufacturing North America, Ann Arbor, MI, USA*

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Abstract

The electrohydrodynamic atomization (EHDA) process has been used in various industrial processes, usually with a dc voltage applied to the electrodes or with induction charging by dc high voltage downstream of atomization nozzles. A pulsed high voltage has also been applied to the EHDA electrode in a liquid–liquid system in order to achieve spark free EHDA. EHDA in confined spaces often requires a co-current gas flow and liquid droplet flow. EHDA in a gas–liquid two-phase system, under applied pulse high voltages with a co-current gas flow, was considered experimentally in this investigation. A two-phase flow regime map was presented for decane and diesel fuel as the working liquids. The pulse high voltage was applied using an ignition-coil type pulse power supply with a hollow atomization electrode, where the charging power to the coil is provided by a 30 V dc power supply. The sheath gas flow was parallel to the liquid flow direction (co-current flow). Experiments were conducted for applied charging voltages from 0 to 25 V (with maximum pulse voltages of 0–27 kV); decane flow rates of 2, 4 and 6 mL/min; air co-current flow rates of 0.45, 2.2 and 4.4 L/min; and applied pulse repetition rates of 100–400 Hz. Experiments were also conducted for dc applied high voltages from 0 to 35 kV with decane flow rate from 2 to 6 mL/min to provide a reference. Experimental results show that droplet flow, liquid column with droplet flow, liquid column and partial atomization, and full atomization flow patterns are present. The two-phase flow regime maps for pulse operation is different from those for dc operation, and have shown a significant dependence on the frequency of the pulses or the pulse repetition rate.

Keywords: Electrohydrodynamic atomization; Flow regime map; Liquid hydrocarbons; Pulsed energization

1. Introduction

The dc energized electrohydrodynamic atomization (EHDA) of dielectric liquid has been investigated by many researchers [1–5]. Pulsed energized EHDA tests for a two immiscible liquid system show significant dependence on the frequency of the applied voltage [6]. Sato [7,8] observed that the droplets generated were synchronized with the frequency of the applied ac voltage. While limited pulsed studies have been performed, no comprehensive studies have been conducted on the two-phase flow patterns generated by a pulsed energized EHDA for gas–liquid systems. This work investigates the fundamental characteristics of pulse high voltage driven EHDA for a gas–liquid system. The two-phase flow regime transition was studied in detail.

2. Experimental apparatus

The EHDA tests were performed using the apparatus shown in Fig. 1. Experiments were performed with both decane ($C_{10}H_{22}$) or diesel fuel (nominally a mixture of $C_{10}H_y$ to $C_{22}H_y$). The decane or diesel fuel was injected through the high voltage electrode that consisted of a ceramic support (300 mm in length and 25 mm in diameter)

*Corresponding author. Tel.: +1 905 721 8668x2859; fax: +1 905 721 3046.
E-mail address: Glenn.Harvel@uoit.ca (G.D. Harvel).

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and a hollow electrode (15 mm in length, 0.6 mm i.d. and 0.9 mm o.d.). The dielectric liquid was supplied using a peristaltic pump that ensured a constant flow rate through the system. The ground electrode in this system was an aluminum ring around the ceramic tube. The entire system was placed within a 10 cm i.d. glass chamber with co-flow air injection ports at the top of the vertical cylindrical chamber as shown in Fig. 1. This air flow exited from a T-junction on the side of the tube below the bottom of the electrode, while the liquid flowed out of the chamber bottom, as shown in Fig. 1.

The flow pattern for the EHDA was characterized for a range of different flow rates and negative polarity voltages applied to the hollow electrode. The pulse voltage wave-form for these tests were generated by the pulse power supply as shown in Fig. 2. The power supply consisted of an intermittently charged automobile type ignition coil. The charging of the ignition coil was controlled using a function generator connected to an in-house triggering circuit. The discharge current from the pulse power supply was measured using a Tektronix Digital Phosphor Oscilloscope (TDS 5054), with an Ion Physics Corporation current transformer (CM-500-L). The pulse voltage was measured by the Tektronix digital oscilloscope via a high voltage probe (Tektronix P6015A). The flow pattern for EHDA with a dc applied voltage was also characterized (as a reference) using a Glassman dc high voltage power supply (Series EW).

Typical waveforms of the discharge current, discharge voltage, and discharge power for the pulse power high voltage operated at 200 Hz with the EHDA system are shown in Fig. 3. The results show that the pulse duration was less than 1 ms with most of the power discharge

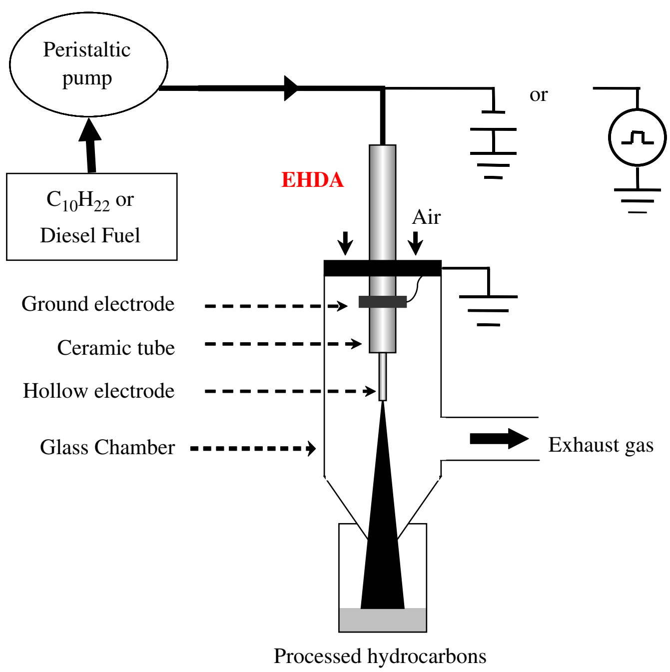

Fig. 1. Schematic of the electrohydrodynamic atomizer (EHDA) system.

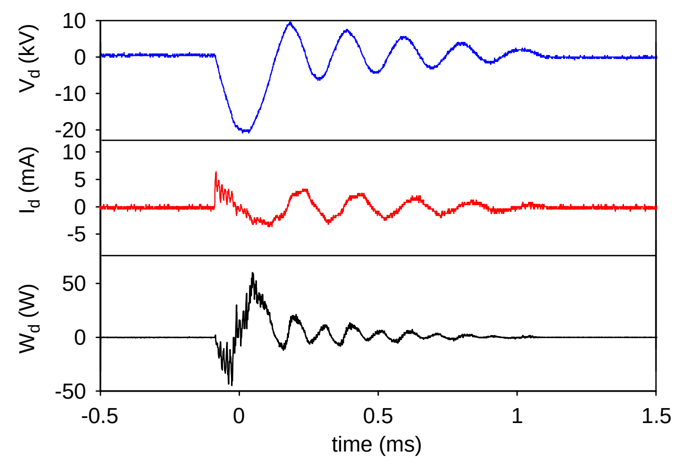

Fig. 3. Typical waveforms of the discharge voltage (−20 kV), discharge current, and discharge power for a decane flow rate of 4 mL/min, an air flow rate of 2.2 L/min and a repetition rate of 200 Hz.

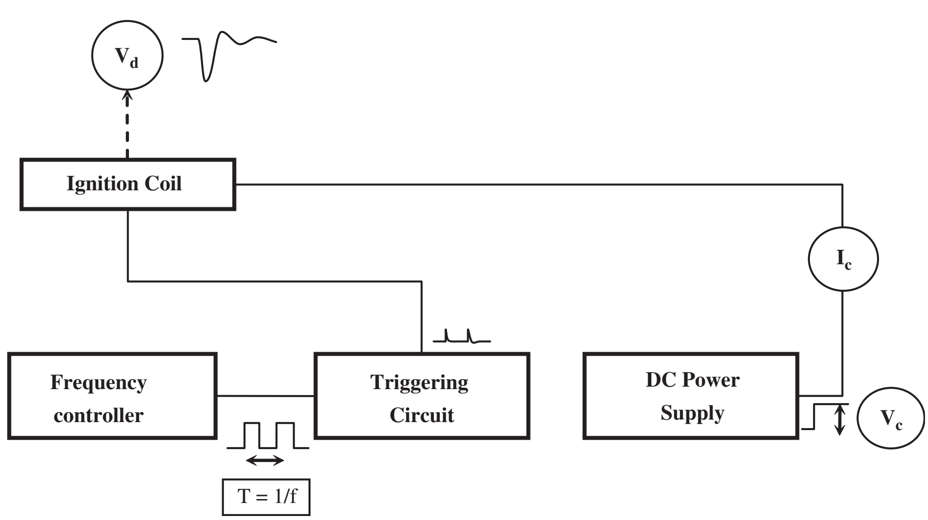

Fig. 2. Block diagram of the pulse power supply.