Journal of Aerosol Science 65 (2013) 49–57

Contents lists available at ScienceDirect

Journal of Aerosol Science

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

Technical note

Investigation of fine droplet generation from hot engine oil by impinging gas jets onto liquid surface

Mohammad Ali Ehteram [a,b], Hassan Basirat Tabrizi [a,*], Goodarz Ahmadi [c], Mohammad Safari [a], Mostafa Agha Mirsalim [a]

[a] Department of Mechanical Engineering, Amirkabir University of Technology, 424 Hafez Avenue, Tehran 15875-4413, Iran
[b] Iran Khodro Powertrain Company (IP-CO), Tehran 13988-13711, Iran
[c] Department of Mechanical and Aeronautical Engineering, Clarkson University, Potsdam, NY 13699, USA

ARTICLE INFO

Article history:
Received 7 May 2013
Received in revised form
1 July 2013
Accepted 1 July 2013
Available online 23 July 2013

Keywords:
Impinging gas jet
Droplet generation
Laser light scattering
Crankcase ventilation

ABSTRACT

The generation of fine oil droplets by impinging an air jet on an engine oil surface represents a new mechanism of atomization. The process was studied using high-speed imaging and laser light scattering. The gas that penetrates the surface leads to the formation of liquid ligaments that enter the high-velocity region of the gas jet where they are atomized to produce droplets with diameters smaller than 5 μm with a Sauter mean diameter of 1.21 μm.

The measured Sauter mean diameter was compared with a proposed semi-empirical analysis, and good agreement was found. The atomizer, based on this impinging air-jet mechanism, can be used to simulate the size distribution of oil droplets in engine crankcase ventilation and, therefore, is suitable for implementation in a laboratory test rig.

1. Introduction

In internal combustion engines, high-pressure combustion gases containing unburned fuel vapor and moisture leak from the end gap of the sealing ring into the crankcase. Such leakage, called blow-by, must be recycled according to emissions regulations into the combustion chamber with a crankcase ventilation system. The high-pressure blow-by leaks from a 0.3–0.4 mm ring end gap, impinges on the oil ligaments and produces oil droplets smaller than 5 μm. Before the blow-by leakage recycles into the combustion chamber, the oil droplets must be separated to reduce oil consumption, avoid emission of heavy hydrocarbon combustion products, decrease deposition on engine components, and increase catalytic converter lifetime. The typical vehicle engine uses inertial separators such as cyclone separators to separate these oil droplets (Meinig et al., 2004 and Ehteram et al., 2012).

This study focuses on developing an impinging gas-to-liquid surface oil atomizer capable of producing a droplet size distribution similar to the crankcase ventilation system. Because of high viscosity and surface tension of cool engine oil, atomization of it to the desired size value is very difficult. Hence, the atomizer must work properly in contact with the warm oil. The atomizer could then be implemented in test rigs to develop an effective engine oil separator.

In conventional pneumatic nebulizers, the liquid is drawn up to the high-speed jet core by the negative pressure of a high-speed flow by using a narrow tube. These atomizers have been widely implemented in inhalation and aerosol research (e.g. Pilacinski et al., 1990 and May, 1973).

* Corresponding author. Tel.: +98 2164543455; fax: +98 2166419736.
E-mail address: hbasirat@aut.ac.ir (H. Basirat Tabrizi).

0021-8502/$ - see front matter
http://dx.doi.org/10.1016/j.jaerosci.2013.07.004

Among its desirable characteristics, the spray should be stable, mono disperse, reproducible, and controllable (Hinds, 2012). The common air-blasting atomizer theoretically can produce the droplets in the desired size range in a crankcase ventilation system. However, in the case of warm engine oil, reduction of temperature in the atomizer results in a sharp increase of engine oil viscosity and causes jamming of the oil in the atomizer and liquid narrow tube (e.g. the viscosity of SAE 10w40 engine oil is 0.0148 Pa s at 90 °C and 0.239 Pa s at 30 °C).

In the performed pre-tests, it was found that injecting a gas from a nozzle under choked condition onto the hot surface of oil results in formation of very fine oil droplets from the liquid surface.

The laser diffraction method is widely used for the measurement of the droplet size distributions produced by nebulizers. Clark (1995) found this technique is robust and reliable. Hence, in this study, the laser light scattering technique was used to measure the droplet size distribution and the variations of droplet size with injection pressure and orifice diameter. The drops size distribution was compared with that of the common diesel and petrol engines and good agreement was found. In the present atomization mechanism there is no additional liquid tubes and issues with the jamming of warm oil in the atomizer.

Depending on the average gas jet velocity and distance to the liquid surface, different modes of surface deformation, dimpling, splashing and penetrating was reported in the literature (Molloy, 1970). In impinging gas on the liquid surface, droplets can be generated by horizontal and vertical cavity oscillations, shearing by the gas stream, breakup of large droplets, entrainment into a gas stream, and by the growth of the ripples (Hwang & Irons, 2011).

Banks and Chandrasekhara (1963) investigated the process of a gas jet impinging on and penetrating into a liquid. They performed a number of experiments in which the cavity depth, diameter and peripheral lip height were measured. In addition, they pointed out the process of droplet formation in the penetrating modes.

However, the detailed mechanism of fine droplet generation from high-speed gas impinging on and penetrating a liquid surface has not been fully understood yet. Also, there is no a direct equation to predict produced drops size distribution in the penetrating mode.

Therefore, to clarify the mechanism of generation of these fine droplets, the average thickness and height of oil ligaments were measured using high-speed imaging. Then the velocity of the free jet was estimated at the ligament position using an analytical solution for velocity of turbulent circular jets. Finally, the droplet size was predicted by substituting the gas jet velocity and ligaments thickness into an equation proposed by Lefebvre (1992) and was compared with the measured light scattering value. In addition to generalize the presented atomization method to other applications, the measuring were repeated for water as the atomized liquid and compared with the semi-empirical estimated value.

2. Theoretical analysis

2.1. Impinging gas jet to liquid surface

As stated earlier, the mechanism of oil droplet generation by injected gas penetration into liquids has not been reported in the literature. In this study, high-speed imaging of droplet generation in a transparent vessel was used for better understanding of the droplet generation mechanism. The pictures, captured with the high-speed camera at 1200 frames/s, and the schematic illustration of the penetration mode are shown in Figs. 1 and 2. These figures indicate the key steps in the

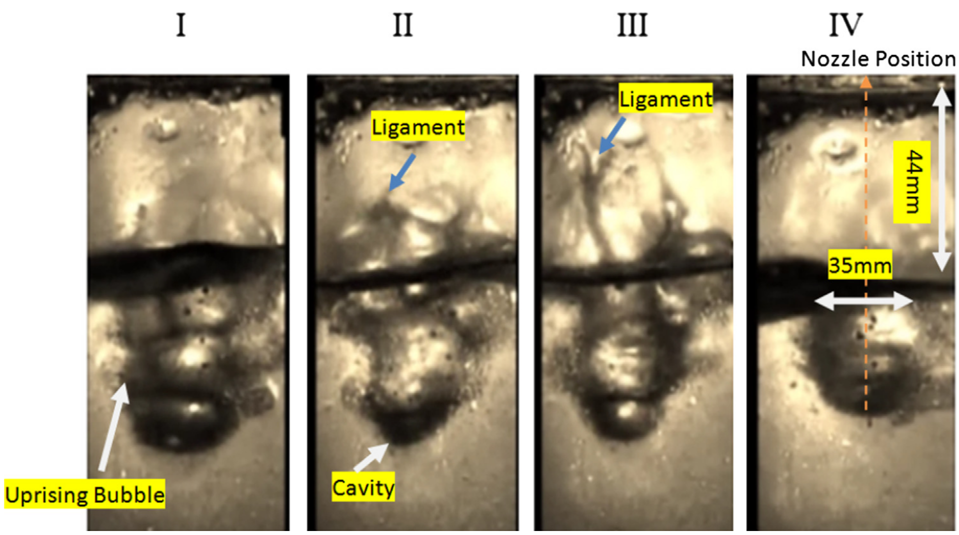

Fig. 1. High speed images of key steps of oil atomization in penetrating mode.