行政院國家科學委員會專題研究計畫成果報告

在均勻強勢對流中紊流場及不同溫度對液滴蒸發及引燃行為影響之研究

Effects of Free-Stream Turbulence and Temperature on the Evaporation and Ignition of A Single Liquid Droplet (1/3)

計畫編號：NSC 88-2212-E-009-019
執行期限：87年8月1日至88年7月31日

主持人：吳宗信[*]　　國立交通大學機械工程學系

中文摘要

本文章主要報告一座低速可變紊流強度以及溫度之風洞流場特性。此風洞的紊流強度範圍在 1-10%之間，溫度範圍在 300-500K 之間。在風洞出口處產生之均勻紊流流場區域範圍在 30x40mm 左右，紊流大尺度約在 1-3mm 之間。利用本風洞執行單顆 heptane 及 decane 液滴蒸發實驗，發覺 heptane 在測試紊流強度範圍內蒸發速率不受影響。然而，decane 液滴在紊流強度超過 1.5%以後，蒸發速率明顯增加，並維持此一速率直到 10%左右。

關鍵詞：液滴蒸發、紊流強度、紊流大尺度(Integral length scale)

Abstract

This article mainly reports the flow properties of a low-speed open-air wind tunnel constructed for future droplet evaporation experiments. A region, 40mm by 30mm, of nearly uniform flow properties at the exit of the wind tunnel is successfully achieved. Free-stream turbulence intensities are varied in the range of 1.0-10%, with integral length scales, in the range of 1-3 mm, comparable to initial droplet diameters. Free-stream temperature varies in the range of 300-500K, depending up the air speed. In addition, preliminary resluts of different liquid droplets, including heptane and decane, show that, for all tested liquids and fuels, the time history of droplet diameter follows d^2-*law* in the turbulent environments. Evaporation rate is insensitive with turbulence intensity, 1-10%, for heptane droplet; while increase dramatically with turbulence intensity larger than 1.5% for decane droplet, but attains a nearly constant value afterwards. Evaporation rate of both liquids, however, increases with Reynolds number of liquid droplet for all the liquid fuels tested.

Keywords: free-stream turbulence, integral length scales, droplet evaporation.

I. Introduction

Because of the importance of fundamentals and applications to spray combustion, liquid droplet evaporation has been studied intensively in the past, for details see Faeth [1] and Sirignano [2]. In the practical spray system, the liquid droplet evaporation phenomena is very complicated, comprising the liquid phase, the fuel vapor phase and the surrounding forced convection with turbulence, and the interactions among each others. Not only the understanding of liquid droplet evaporation is crucial in essence, it also plays an impotant role in determining the ignition time delay and ignition location of droplets.

There are numerous research conducted in the past attempting to study the evaporation process in a single liquid droplet [3]. Most expermental studies were carried out for a single liquid droplet in natural convection or laminar forced convection, while very few has been made to study the effects of turbulence in forced convection. On the other hand, most numerical studies has assumed no free-stream turbulence effects on the droplet evaporation rates, since the size of large eddy in the free stream turbulence is much larger than the droplet diameter, indicating the local laminar flow exists from viewpoints of droplet [4]. However, free-stream turbulence is composed of continuous spectrum of various lenth scales and time scales. Hence, there exists other smaller lentgh and time scales in the turbulence that might effect the evaporation rate of liquid droplets.

Based on these observations, the present experimental investigation was undertaken to better understand the evaporation of a single liquid droplet in turbulent environments. The study involved detailed laser velocimetry measurement of ambient mean velocities and turbulence properties at the exit of a nozzle-like wind tunnel, and the vaporation rates of a single liquid droplet in turbulence envrioments using high-speed CCD camrea. The ranges of test variables were as follows: Re=100-300, ambient turbulence intensities from 1.0% to 10%, l/d of 1-3, and l_K/d of 0.1. These conditions represents the excellent tests to the assumption of local laminar flow conditions imposed in the past research on evaporation of the single liquid droplet.

II. EXPERIMENTAL METHODS

A sketch of the experimental apparatus appears in Fig. 1. The configuration consisted of a turbulent upflowing air at the exit of a vertical, bell-shaped wind tunnel, with the tested, single liquid droplet supported on a droplet-hanging sytem. The turbulent air flow is produced by a variable speed blower. The blower is followed by an electric heater in the settling chamber, 7.5°-diffuser, a honeycomb flow straightener, 25-to-1 round-shaped contraction to provide a nonswirling uniform flow at the nozzle exit. From the preliminary tests air flows can be heated up to 500K. All hot parts of the wind tunnel was covered by heat-isulating materials. The nozzle exit is 48mm in diameter. A carefully machined perforated plate with different hole distribution was installed at the nozzle exit. Two types of perforated plates were considered, referring to Fig. 2. Mean and turbulent flow properties in the test section were measured using a traverible laser velocimeter with a dual-beam forward-scatter configuration, combining a 2.25:1 beam expander to yield a measurment volume of 50μm in diamter and 300 μm in length. The data is processed by the LDA signal processor (TSI, model IFA-100).

The fuel types of test liquid droplets include heptane and n-decane with diameters in the range of 1-2 mm. The liquid droplet was suspended at the tip of quartz fiber with diameter of about 100 μm and placed at the location of 5 mm away from the exit of the wind tunnel. A heat-shielding plate made of stainless steel plate was placed below the test liquid droplet to prevent pre-heating/evaporation of the droplet before experiment. As the test liquid droplet has been injected from the syringe and moved to the top of the heat-shielding plate, the plate is moved away and a high-speed CCD camera (Kodak Motion Corder Analyzer, monochrome Model SR-Ultra) is triggered to record the image of tested liquid droplet.

III. RESULTS AND DISCUSSION

In this section, results are presented most for the apparatus verification, while only preliminary results are reported for droplet evaporation. In addition, only results at room temperature are described in the following.

Evaluation of the Apparatus

The evaluation of the apparatus is mainly focused on the uniformity of mean and fluctuating velocity distributions and the temporal power spectra in the regions of interest and will be discussed, in turn, in the following.

Mean and Fluctuating Velocities

The uniformity of mean and fluctuating velocities along an across the tunnel at the exit of the contraction nozzle is a primary concern since it determines the homogeneity of the ambient environments. Radial distributions of steamwise and cross streamwise mean velocities at the exit of the wind tunnel are illustrated in Figure 3. These results are for air flows having velocity of 3.0 m/s at four different turbulence intensities 3, 5, 7 and 10 %, which are the typical test conditions for current study of droplet evaporation. The streamwise mean velocities are very uniform over the range of $r \leq 20$ mm at three different axial locations, x=10, 20 and 30 mm, within the regions of interest. In general, the variations of the streamwise mean velocities are less than 0.5 % in both the streamwise and radial direction. As expected, the cross streamwise mean velocities are practically zero in the same aforementioned regions.

Radial and streamwise distributions of streamwise and cross streamwise velocity fluctuations at the exit of the wind tunnel are also illustrated in Fig. 3. Both the streamwise and cross streamwise velocity fluctuations exhibit a slow variation (decreasing) in the streamwise direction and nearly constant in the range $r \leq 20$ mm. In general the streamwise velocity fluctuations are larger than the cross streamwise velocity ones with the averaged anisotropy of 1.4. Thus, the variations of the velocity fluctuations were negligible within the experimental uncertainties.

Temporal Power Spectra

The measured temporal power spectra densities of the streamwise velocity fluctuations at the mean velocity of 3 m/s at four different turbulence intensities of 3, 5, 7 and 10 %, are plotted as a function of normalized frequency, $f\tau_u$, in Fig.4. τ_u is generally on the order of 1 ms, depending upon the flow conditions. The differences between the measured power spectra at different locations are negligibe for streamwise and cross streamwise directions within experimental uncertainties. Similar trend is found for power spectrum density of cross streamwise velocity fluctuations as well. Integral legth scales, from Taylor hypothesis and power spectrum density data, are in the range of 1-3 mm, which is comparable to the tested liquid droplet size.

Droplet Evaporation

Typical preliminary results of normalized squared diameter of droplet as a function of time, at different free-stream speed and varous turbulence intensities, for heptane and decane are illustrated in Figs. 5 and 6, respectively. All data agree well with d^2*-law* within experimental uncertainties. It is clearly that the evaporation rate of heptane droplet increases with free-stream speed and rather insensitive with various turbulence intensities (1-10%). Evaporation rate of decane, however, increases dramatically at turbulence intensity of 3% and becomes nearly constant for even larger turbulence intensity. This interesting phenomena might be attributed to the relatively not-large integral length scale (1-3 mm) of free-stream turbulence as compared with initial droplet size. Certainly, this deserves further study to understand the physical process.

III. SELF EVALUATION

In the first year of the project we have completed a well-characterized open-air wind tunnel, as planned, which can be used for intensive study of droplet evaporation in the very near future. The preliminary results of droplet evaporation, which intrigues future study, are highly valuable in the field of spray modeling. Hence, it is expected that the results in the second year, which is already granted, will be very promising and, of course, is deemed highly appropriate to submit to academic Journal.

REFERENCE

1. Faeth, G.M., *Prog. Energy Com. Sci.*, Vol.9, pp.1, 1983.
2. Sirignano, W.A., *Prog. Energy Com. Sci.*, Vol.9, pp.291, 1983
3. Frossling, N. *Gerlands Gerlands Beitrage zur Geophysik*, Vol.52 (1/2), p.170, 1938.
4. Megaridis, C.M. and Siriginano,

W.A., *ASME Winter Meeting*, Dallas, Texas,1990.

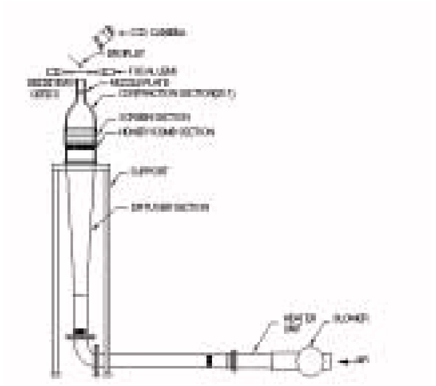


Fig. 1 Sketch of open-air wind tunnel.

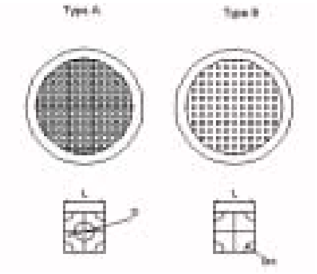


Fig. 2 Sketch of two types of perforated plate.

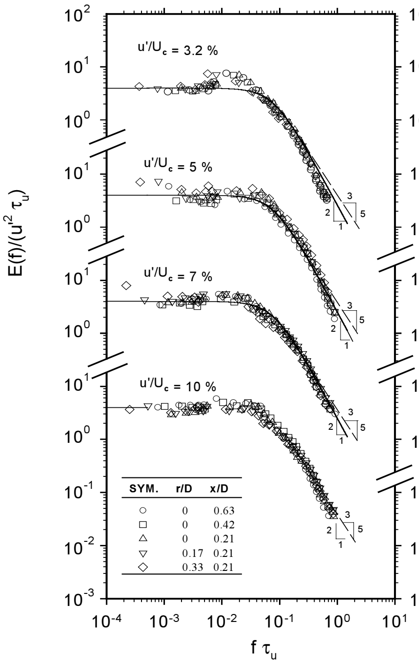
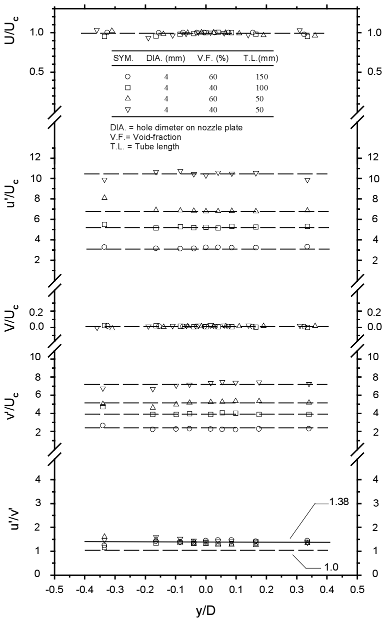


Fig. 3 Mean and fluctuating properties of turbulent environments.



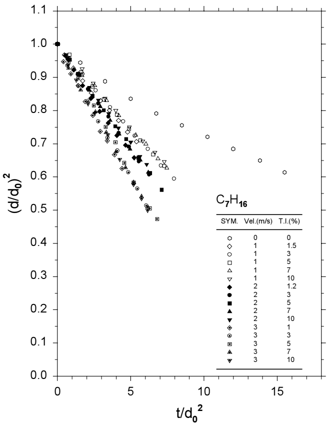


Fig. 4 Power spectrum density of streamwise velocity fluctuations.

Fig. 5 Squared diameter of heptane droplet as a function of time.

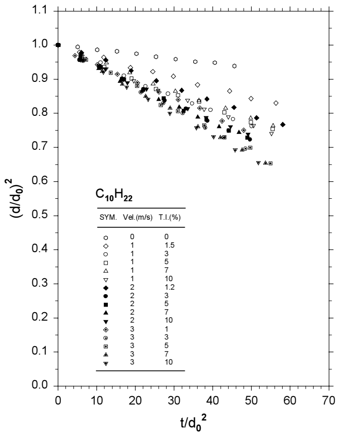


Fig. 6 Squared diameter of decane droplet as a function of time.