Energy 34 (2009) 1560–1564

Contents lists available at ScienceDirect

Energy

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

Mass diffusion coefficients of oxygenated fuel additives in air

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A R T I C L E I N F O

Article history:
Received 18 February 2009
Received in revised form
24 June 2009
Accepted 25 June 2009
Available online 8 August 2009

Keywords:
Mass diffusion coefficients
Fuel additive
Digital holographic interferometry
1,2-Dimethoxyethane
2-Methoxyethyl ether

A B S T R A C T

In this work, an experimental system based on digital real-time holographic interferometry for measuring the mass diffusion coefficients of fluid is introduced. The method of processing interference fringe hologram is also introduced thoroughly. By uncertainties analysis and experimental verification, the accuracy of this system is validated. The experimental uncertainties in temperature and mass diffusion coefficient are estimated to be no greater than ± 0.16 K and ± 0.2%, respectively. On this basis, mass diffusion coefficients of two fuel additives: 1,2-dimethoxyethane (ethyleneglycol dimethyl ether, GDME) and 2-methoxyethyl ether (diethylene glycol dimethyl ether, DGM) in air were measured at $T = (278.15–338.15)$ K under atmospheric pressure, and polynomial was fitted by the experimental data.

1. Introduction

Recently, with the gradual reduction of conventional energy reserves such as coal and petroleum, research and promotion of new energy is becoming more urgent [1,2]. The researches include: using biodiesel as alternative fuel for the conventional gasoline or diesel oil [3]; using fuel cell [4], hydrogen [5] or natural gas instead of gasoline to power automobile, etc. Among all of the research the use of mixed fuel is considered to be a convenient and simple way to alleviate the problem of worldwide energy crisis. Mixed fuel is a mixture of conventional liquid fuel and fuel additives. Research shows that the addition of oxygenated fuel additive to gasoline or diesel oil will accelerate the process of combustion, shorten the combustion time in the internal combustion engine, greatly improve the combustion performance and efficiency, and effectively reduce the emissions of harmful off-gas such as NO_x, CO_x, HC and soot etc., [6,7]

The mass diffusion coefficient of the fuel additive in air is an important thermophysical property to study the spray, atomization, and combustion processes of the mixed fuel in a combustion engine, and it is also a key parameter for the numerical simulation of the combustion process [8]. Therefore, theoretical predictions and experimental research on mass diffusion coefficients of fuel additives are of great importance. A literature review indicated that there is a dearth of accurate data on mass diffusion coefficients of oxygenated fuel additives in air. In this work, a detailed experimental investigation on the diffusivity of two kinds of oxygenated fuel additives in air was made. An experimental system based on digital holographic interferometry was constructed by our group. By uncertainty analysis and experimental verification, the uncertainties of temperature and mass diffusion coefficient are estimated to be no greater than ±0.16 K and ±0.2% [9], respectively. On this basis, mass diffusion coefficients of fuel additives: 1,2-dimethoxyethane and 2-methoxyethyl ether in air were measured at different temperatures from 278.15 K to 338.15 K under atmospheric pressure.

2. Experimental system and measuring theory

Fig. 1 shows the optical system of digital real-time holographic interferometry. All the optical parts are required to be installed on the optical shockproof apparatus to reduce the influence of the environment shark. From Fig. 1, we can see that the laser beam was emitted from a He–Ne laser and was reflected by a mirror, and it then went into a spatial filter in which it was expanded. Then, the expanded laser beam was collimated by an achromatic doublets lens into a parallel laser beam. The parallel laser beam was split into a reference beam and an object beam by a beam splitter. The object beam passed through the diffusion cell and recorded the diffusion information. Finally, both the object beam and the reference beam interfered at the beam splitter to form the interference fringe, which was collected by a CCD camera and recorded on a computer.

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doi:10.1016/j.energy.2009.06.057

Nomenclature

D_{12}	mass diffusion coefficient [cm^2/s]
c	concentration of liquid [mol/L]
t	moment of getting interference fringe hologram [s]
z	the direction of one-dimensional mass diffusion [mm]
C_i	the parameters of fitted polynomial
D_0	the pre-exponential factor of Arrhenius formula [cm^2/s]
E_D	the activation energy for the diffusion process [kJ/mol]
u	the uncertainty in the experimental measurement
U	the expanded uncertainty in the experimental measurement
k	the confidence coefficient of uncertainty
$\Delta\psi$	wrapped phase difference [rad]
$\Delta\varphi$	continual phase difference [rad]

Fig. 2 shows the diffusion cell used in this work, and it is an improved version of our previous apparatus reported before [9]. In order to make sure the experiment goes on in a stable temperature environment, the diffusion cell is placed in the thermostatic water bath whose temperature could be controlled form (0–80) °C with an uncertainty of ±0.2 °C.

In order to calculate the mass diffusion coefficient from the interference fringe image, the primary goal is to establish the relationship of mass diffusion coefficient and the phase information of object wave. Along with the development of the mass diffusion in the experiment, the refractive index of the solution changes continuously and the phase of object wave which pass through the solution changes responsively, and it leads to the continuous change of interference fringe on the hologram. So if we extract the phase of object wave from the interference fringe image and use the relationship established above, we can finally calculate the mass diffusion coefficient.

For one-dimensional mass diffusion, the mass diffusion coefficient D_{12} can be expressed as equation (1), which was introduced by the second Fick's law [10]

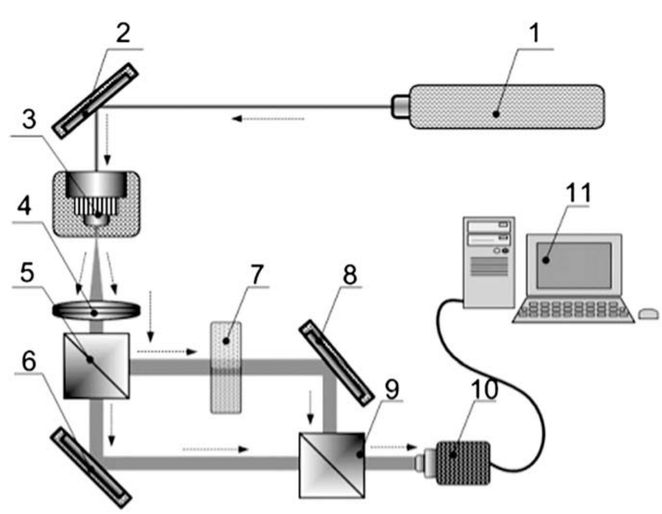

Fig. 1. Optical system of digital real-time holographic interferometry. (1) He–Ne laser, (2) mirror, (3) spatial filter, (4) achromatic doublets lens, (5) beam splitter prism, (6) mirror, (7) diffusion cell, (8) mirror, (9) beam splitter prism, (10) CCD camera, and (11) computer.

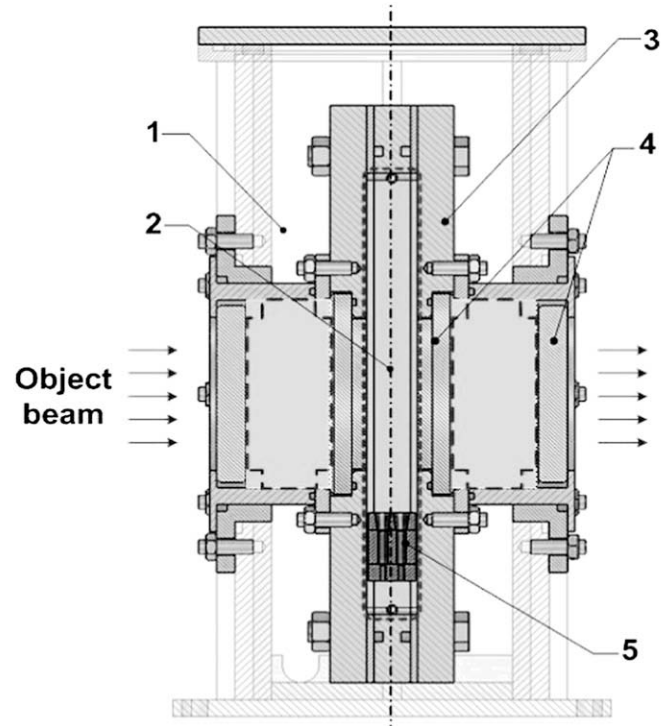

Fig. 2. Diffusion system. (1) Thermostatic water bath, (2) diffusion zone, (3) diffusion cell, (4) optical glass, and (5) honeycomb.

$$\left(\frac{\partial c}{\partial t}\right) = D_{12}\left(\frac{\partial^2 c}{\partial z^2}\right) \tag{1}$$

where, D_{12} is the mass diffusion coefficient, z is the direction of diffusion, t is the elapsed time of diffusion, and c is the concentration of the liquid, which is a function of z and t. From the linear relationship between phase difference of object beam and solution's concentration, the final equation for calculating D_{12} can be deduced as [11]

$$D_{12} = \Delta z_m^2 \frac{t_1/t_2 - 1}{8t_1 \ln(t_1/t_2)} \tag{2}$$

where, t_1 and t_2 are the moments of collecting the interference fringes, Δz_m is the vertical distance between the two extreme points of the solution's concentration difference, as shown in Fig. 3.

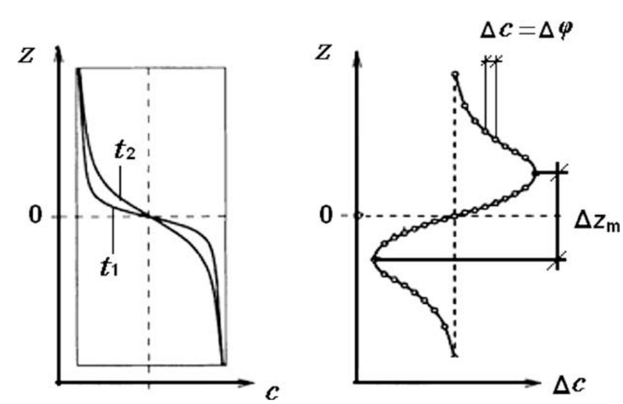

Fig. 3. Distributions of concentration and its change.