CHEMILUMINESCENCE DYNAMICS MEASUREMENTS OF DIFFUSION FLAME USING LIGHT CELL AND HIGH SPEED CAMERA

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الملخص

تم إجراء مجموعة من التجارب العملية لتقدير مدى تردد الارتعاش الديناميكي للّهب الانتشاري الناتج من نفث وقود البروبان تحت ظروف الضغط الجوي مع تغير معدل تدفق الوقود من حالة التدفق الرقائقي إلى حالة الاطفاء للهب. ولغرض دراسة ديناميكية الانبعاث الضوئي الكيميائي الكلي للهب، تم استخدام تقنيتان لقياس وتحليل العلاقة بين نمط الارتعاش للهب الانتشاري ومعدل تدفق الوقود. حيث استخدمت الخلية الضوئية لقياس ديناميكية الضوء المنبعث من اللهب وتحويلها الى إشارة رقمية وهي التقنية البديلة في هذا البحث. وتم مقارنة النتائج بتقنية التصوير عالي السرعة الذي عن طريقه يتم تحليل الصور لقياس ديناميكية الارتعاش. أظهرت نتائج التحليل الطيفي لكلا التقنيتين بأن لهما نفس النمط الديناميكي، والذي أوضحت فيه أن تردد اللهب يعتمد على معدل تدفق الوقود، حيث كان في المدى ما بين 10 الى 22 هرتز، وهذا المدى مطابق مع الدراسات السابقة لقياس مدى الارتعاش للهب الانتشاري تحت نفس الظروف.

ABSTRACT

Experiments have been performed to estimate flame flicker frequency of free jet propane diffusion flame. The flame was produced at atmospheric pressure with a varying fuel flow rate from a laminar to the flame blowout conditions. In order to capture global chemiluminescence, two different optical techniques have been applied to an experimental investigation into the relationship between the flicker of a diffusion flame and the fuel flow rates. In this paper, the light cell technique and the high-speed camera technique have been used. Power spectral analysis was performed to obtain the frequency mode of the flicker signal, the experimental results obtained by both techniques for image pixel analysis and spectral analysis of signals have demonstrated that the flicker of a diffusion flame mode depends on the fuel flow rate, and the results show the flame mode was in the range of 10 to 22 Hz which is in very good agreement with previous study of flicker measurements of combustion flames under the same condition..

KEYWORDS, Diffusion Flame; Flickering; Optical System; chemiluminescence; Light Cell; CCD Camera; Combustion Instability.

INTRODUCTION

The flicker of a flame is an important physical parameter, which is associated with the characteristics of a combustion process. In addition, flickering frequency is an indication of flame instability. Experimental and theoretical studies have been performed to investigate the flame dynamics and combustion instability. There are two methods have been widely used for alleviating or eliminating combustion instabilities; passive and active control systems. The passive instability control method usually begins by modeling and analyzing a new combustion system. Then, according to the analyzed data,

redesigning or modifying the combustion system to avoid the potential factors that may induce combustion instability. Many researchers including Steele [1], Straub et al. [2] and Smith et al. [3], have reported that axial adjustments in the location of the fuel spokes will have a positive impact in eliminating thermoacoustic instabilities. Some researchers have avoided passive control because it cannot adapt changes in the system and also the development of passive control combustion systems is costly and time consuming, in additional; it is specific to a particular combustor design. The other method used for the thermoacostic instability control is the active control method. This method has been proposed as a different approach to eliminate combustion oscillations. Active control uses an external control device to mitigate the combustion instability. Different researchers have proposed several modeling diagnostics and sensors. The most common form of control uses information from a pressure transducer. For example, Masahiro et al. [4] studied experimentally the soot suppression of acetylene diffusion flame by applying acoustic oscillation. Walter at el. [5] used an open-close tube to study flame excited oscillations. The sound pressure was measured with a microphone located at different ports and the signal sent to the side mounted loudspeaker (close-loop system) after filtering. For fast flame dynamics monitoring response for an active control and due to many sources of noise coming from compressors, turbines and other things in power plant, the researchers and experts invented alternative techniques that presented in an optical system to avoid those noises. The advantage of optical technique method is detecting the signals that coming from the flame only. Moreover, it is Non-intrusive and has a fast time response. Hamidreza et al. [6] conducted an experiment in a high-pressure burner to investigate the effects of fuel flow rate and chamber pressure on the flickering frequency behavior of methane-air diffusion flames, by using a high speed camera and photomultiplier. Yingping, et al. [7] investigated the relationship between the flicker of a diffusion flame and the burner diameter; they studied the effect of the equivalence ratio on the flicker of a premixed flame by using a high-speed Charge Coupled Device (CCD) camera. Their experimental results obtained by both motion image analysis and spectral analysis. Manikantachari, et al. [8] compared between three different burners; contoured burner, straight pipe burner and orifice burner, in measuring the natural flickering of Methane diffusion flames by using a high-speed digital camera at the rate of 300 frames per second for different fuel flow rates. Paola Raffaella [9] employed Rijke tube to analyze premixed flame and obtain the frequency by image processing. There is number of studies used Laser induced fluorescent (LIF) measurements. For example, Christophe, Volker [10], A. Arnold, R. et al. [11].K. A. Watson et al. [12] compared between two different measurements techniques, Particle Image Velocimetry (PIV) and Planar Laser Induced Fluorescence (PLIF).

In this paper, the power spectrum analysis of free jet propane diffusion flame with a varying fuel flow rate is investigated. Two different optical techniques are used; the Light cell and high-speed camera to capture global chemiluminescence.

METHODOLOGY

To attain a better understanding of flame dynamics, global chemiluminescent emissions of the total light emitted from diffusion flame at different flow rates is measured by using two different techniques; light cell and high-speed camera. In the first technique, the signal from light cell were recorded with sampling rate of 40,000 Hz, LabVIEW software have been utilized for data acquisition, monitoring and analyses.. In the second technique, high-speed camera, which captures the flame images, with

sampling rate of 420 frame/second. The images then finally processed using Matlab software to calculate the frequency mode.

EXPERIMENTAL SETUP

The experimental setup of the test rig used in this work is illustrated in Figure (1). The burner is a single copper fuel pipe of 0.5 cm inner diameter, there is an orifice at the end of the tube which reduces the overall inner diameter to 0.7 mm. The pipe is connected to a compressed propane gas cylinder. The fuel is regulated by a control valve and measured by a rotameter. To measure the chemiluminescence emission light cell system was utilized and high speed camera used as an imaging tool to capture the luminous flame. The high speed camera has the ability to take up to1000 fps with a resolution 480 (width) × 360 (height) pixels. A known source of light driven by a frequency-varying power supply was employed to calibrate the measurement system and the results of the calibration showed that the relative error between the measured frequency and the standard frequency is no greater than 1%.
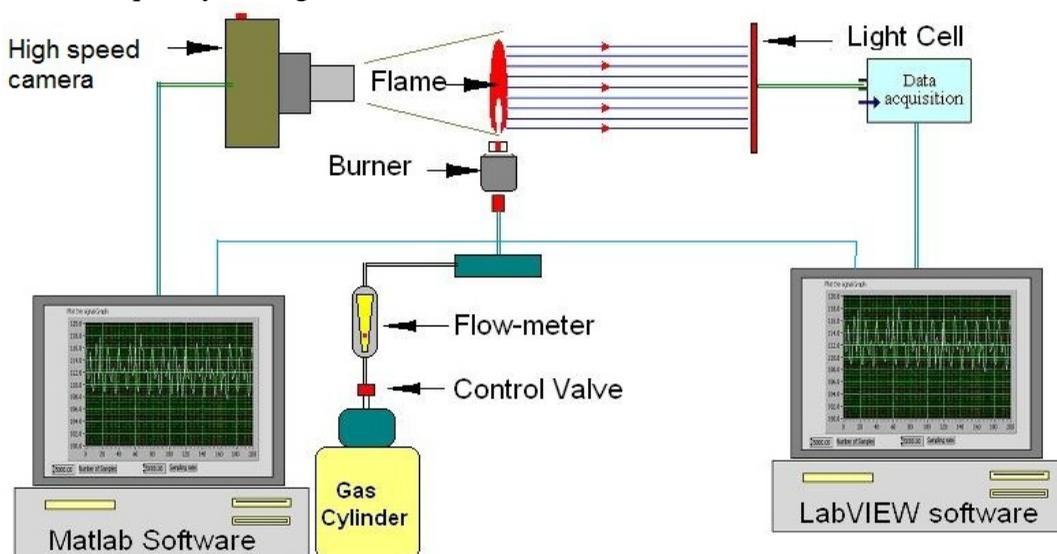
Figure 1: Schematic of the experimental configuration of the chemiluminescence measurement system.

RESULTS AND DISCUSSIONS

One of the stable operating ranges for the burner is dependent on the fuel flow rate, the effect of fuel flow rate on the flickering phenomena of diffusion flames are presented in this paper. The detailed global optical diffusion flame spectra measured at varying fuel flow rate from a laminar fuel flow rate to the flame blowout conditions. Time-series signals of the global chemiluminescence of the flame are measured by two different techniques, a light cell technique with a sampling rate of 40,000 Hz, and high speed camera used as an imaging tool to capture the luminous flame with a sampling rate of 420Hz. For the light cell technique, each intensity of chemiluminescence was normalized by each maximum peak value. The results of the Global chemiluminescence yield variation with varying fuel flow rate. Figures (2, 3, 4, 5 and 6), each consists of a flame shape, a time-series signals, a power spectrum and auto-correlation for both techniques.

It can be seen clearly from power spectrum that, the peak frequency for the unexcited laminar diffusion flame have a single dominant frequency during laminar operating conditions, according to the previous study the laminar flame flickering mode between 10 to 15Hz. and with strong correlation as it can be seen in auto-correlation.

At laminar diffusion flame; harmonics is more visible; some figures show that there are many strong sub-harmonics for example at Reynolds number (Re) = 1209 by using both techniques, see Figure (2). On the other hand, the sub-harmonic frequencies are not observed at high Reynolds numbers (Turbulent Flames). It can be seen clearly that, there is exist of a distinctive frequency peak for the natural laminar jet diffusion flame. This typical flickering frequency of 13 Hz agrees well with other published data [Huang et al (1999) [7], that was used a Charge Coupled Device (CCD) camera for spectra analysis. Above the 15Hz, the flame became turbulent and many of frequencies appeared, as shown in the figures, at turbulent mode, the noise can be also heard.
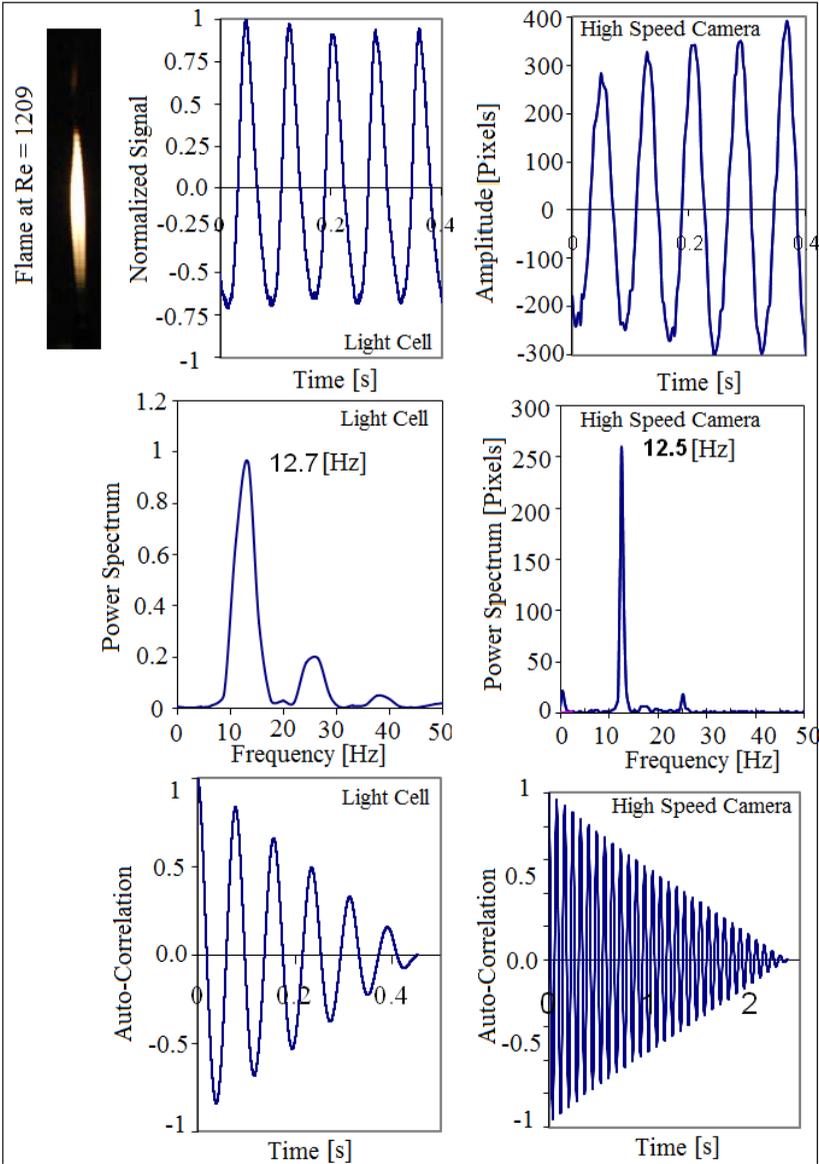
Figure 2: Flame image, Time-series, power spectrum, and auto-correlation at Reynolds number (Re) = 1209, by using both techniques (light cell and High speed camera)
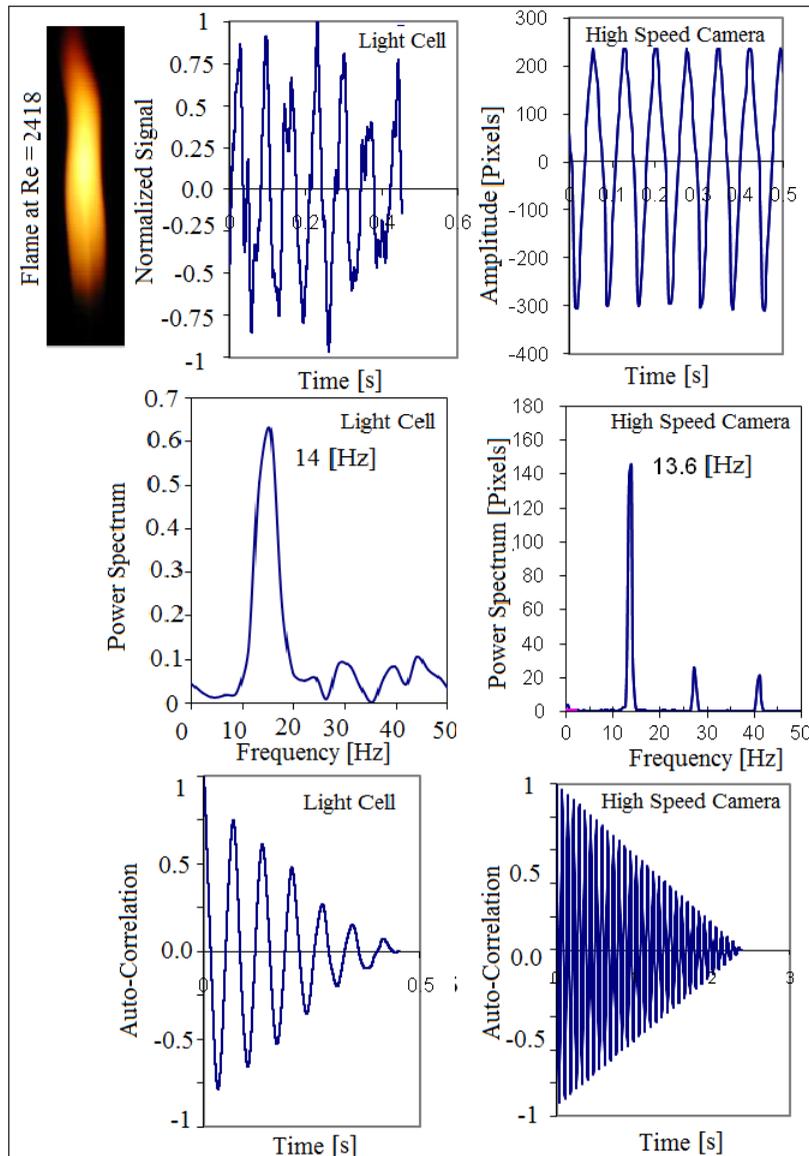
Figure 3: Flame image, Time-series, power spectrum, and auto-correlation at Reynolds number (Re) = 2418, by using both techniques (light cell and High speed camera)

From Figures (5 and 6), at turbulent conditions some of multiple dominant frequencies can be observed, and extends over a wide range of frequencies, and the auto-correlation indicates weak correlation because the signal is random distributions.

At high Reynolds number, the flame colour is observed to be blue either partly or completely. It seems that the burning part is well mixed and behaves like a premixed flame. Therefore the fuel has been burnt fully in that very small combustion volume of the flame, the flame is fully turbulent when the flow rates close to blowout conditions. The flame shape in this case is three-dimensional. The flame would lift off and finally blow out if the flow rate level increased to certain values, in this burner size conditions the maximum mode frequency is 22 Hz at Reynolds number (Re) = 4837. This indicates that the high jet velocity condition may have enhanced the mixing of the fuel gas and the surrounding air just above the burner nozzle. It can be seen from the results that the dominant frequency of the chemiluminescence emission is a sensitive to the fuel flow

rate. It is clear from the figures that the chemiluminescence emission power spectrum show that the frequency increases with increasing the Reynolds number (Re), this is because of high turbulence generated at high Reynolds number (Re).

Figure (7) shows a brief but decisive comparison between the flame frequency obtained by the two different techniques; the light cell and the high-speed imaging. The coefficient of determination (R2) is close to one, which indicates that the results obtained by the two techniques are in good agreement.
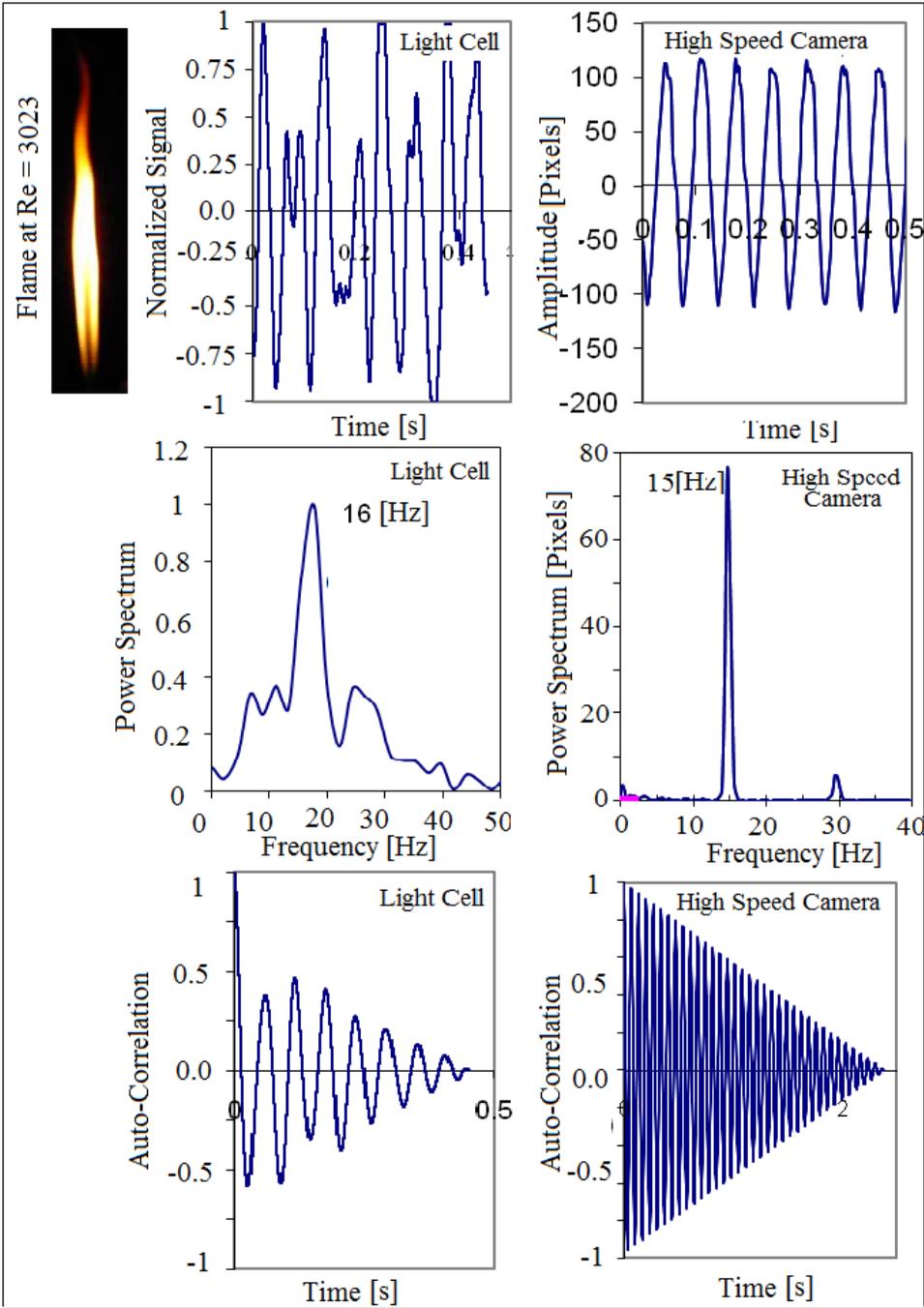
Figure 4: Flame image, Time-series, power spectrum, and auto-correlation at Reynolds number (Re) = 3023, by using both techniques (light cell and High speed camera)
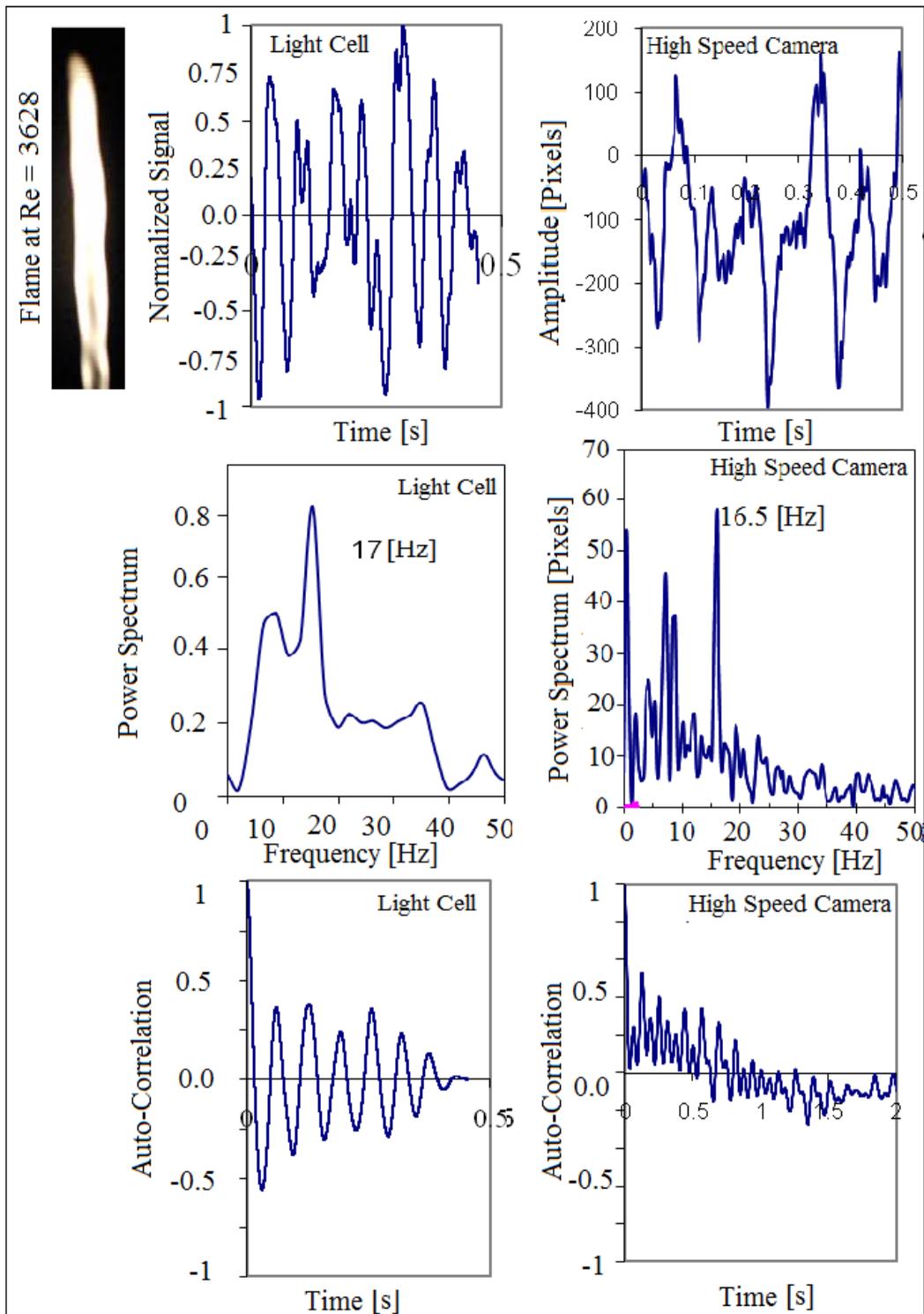
Figure 5: **Flame image, Time-series, power spectrum, and auto-correlation at Reynolds number (Re) = 3628, by using both techniques (light cell and High speed camera)**
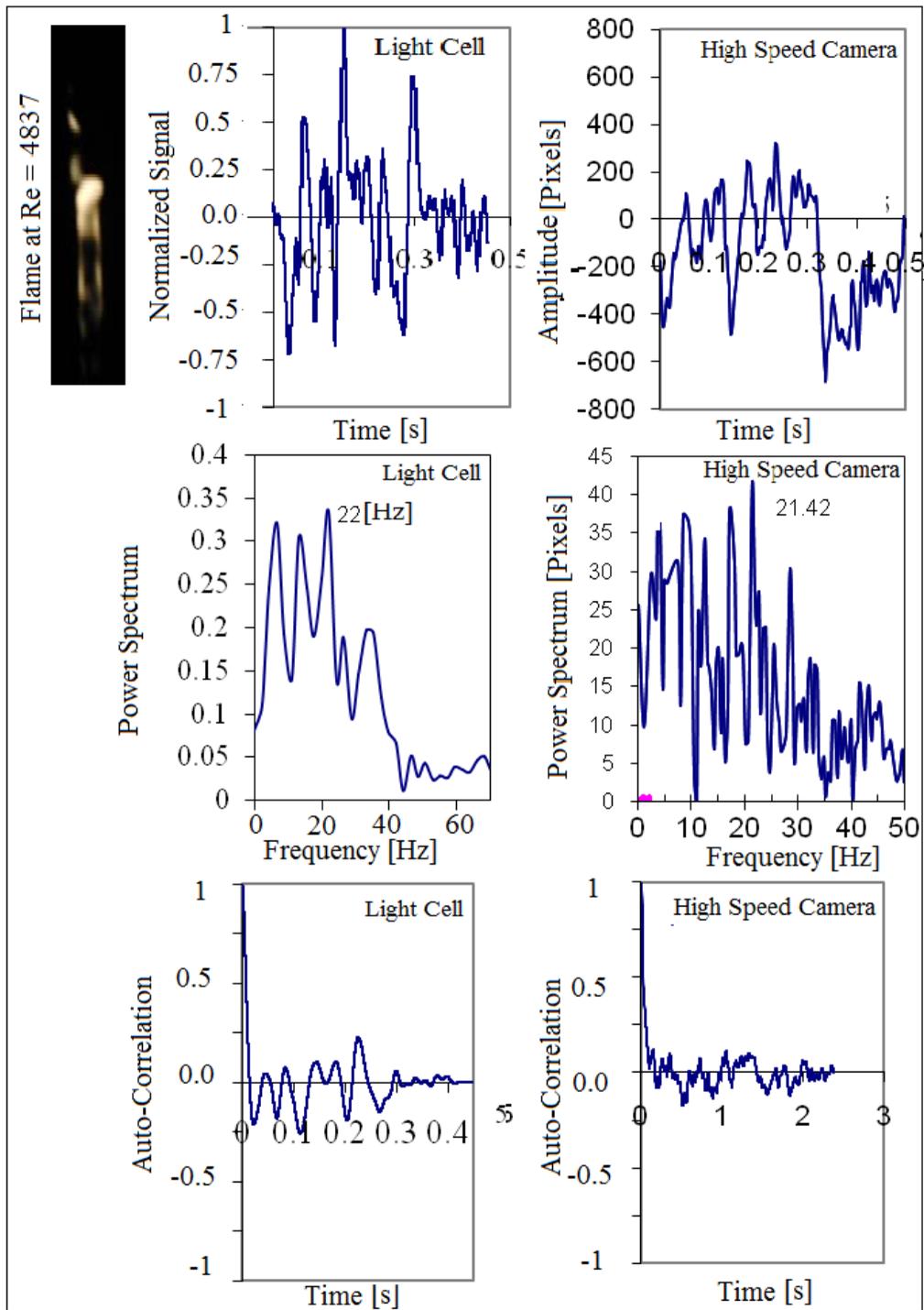
Figure 6: Flame image, Time-series, power spectrum, and auto-correlation at Reynolds number (Re) = 4837, by using both techniques (light cell and High speed camera)
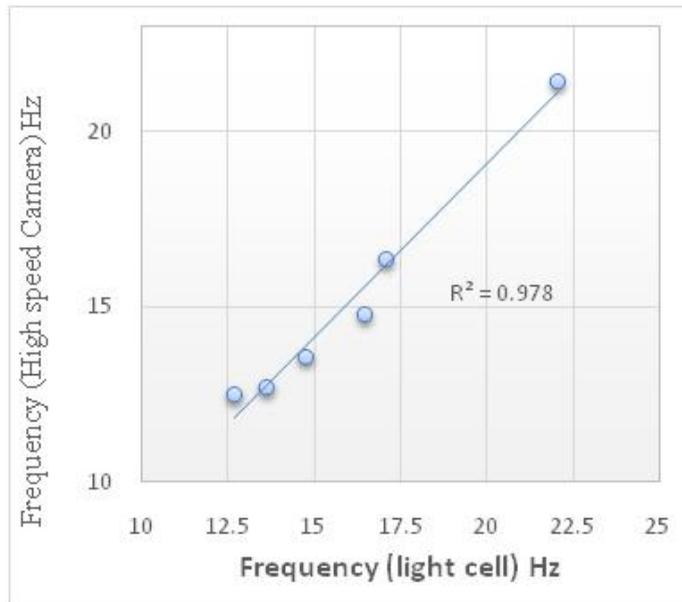
Figure 7: Coefficient of determination.

CONCLUSION

The flame characteristics of propane free jet diffusion flame has been experimentally examined in this paper. An experimental approach have been followed in this work in the hope of studying flame dynamics and combustion instability of jet diffusion flames from different aspects. A free jet diffusion propane / air stabilized burner on the rim and with liftoff has been studied. The motivation behind studying these flames is the using of light cell as an alternative technique to measure the chemiluminescence emission instead of the conventional techniques, such as photomultiplier, Laser Induced Fluorescence (LIF), Particle Image Velocimetry (PIV), and high-speed Charge Coupled Device (CCD) camera. The results of this technique have been compared with a high-speed camera as a conventional technique. From the results, it can be seen that both techniques are in very good agreement. The overall difference in frequency measurements between the two different chemiluminescence techniques is less than 2.7%. In addition, the alternative technique has good advantages: easy to use for a control system of combustion instability, small in size compared with the other techniques, and much cheaper.

ACKNOWLEDGMENT

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