CHEMILUMINESCENT EMISSION AND ACOUSTIC PRESSURE DYNAMICS MEASUREMENTS OF IMPINGING PROPANE DIFFUSION FLAME ON UN-COOLED CIRCULAR PLATE

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الملخص

تم في هذه الورقة قياس الانبعاث الضوئي الكيميائي والانبعاث السمعي معاً في نفس الوقت للهب الانتشاري المرتطم على قرص دائري مسطح عند اعدادات معملية مختلفة وذلك باستخدام تقنيتين مختلفتين هما الخلية الضوئية ونظام لاقط الصوت (الميكرفون). الغرض من هذا البحث هو معرفة نمط وسلوك وارتباط ديناميكية الانبعاث الضوئي الكيميائي بالانبعاث السمعي للهب الانتشاري المرتطم على الاسطح المستوية. الدراسة تضمنت قياس وتحليل ديناميكية اللهب عند ظروف تشغيل مختلفة كقطر الحارق والمسافة بين سطح الارتطام ومخرج فوهة الحارق. تم في هذه الدراسة اجراء التحليل الطيفي للإشارتين الضوئية والسمعية، وأيضاً الاختلاف الطوري بين الإشارتين وذلك باستخدام (Phase space diagram). تضمنت النتائج ديناميكية اللهب عند ظروف قبل انطفاء اللهب بقليل وهي الظرف التي تكون فيها عدم الاستقرارية للهب عالية جداً. أظهرت النتائج أن الاشارتين السمعية والضوئية لهما ارتباط قوي تحت كل الظروف المختلفة وأن الاشارتين تقريبا لهما اختلاف طوري 90 درجة. لذلك يجب أخذ الحيطة عند استخدام إشارات الانبعاث الضوئي السمعي في منظومات التحكم في عدم إستقرارية لهب الاحتراق.

ABSTRACT

In this paper, detailed simultaneous measurements of the chemiluminescent emission and acoustic pressure of impinging propane diffusion flame on the circular plate at different setup configurations have been carried out using two different techniques; light cell and microphone systems. The purpose of this research is to experimentally characterize the mode and correlate the global Chemiluminescence emissions and acoustic pressure dynamics of impinging diffusion flame jets. The study considers the measurement and analysis of the chemiluminescence emissions and acoustic pressure at different operating conditions including burner diameters and the distance between the impingement plate and burner exit (H/D). This study makes available very detailed power spectra of two simultaneously measured of signals. Moreover, phase space diagrams between two signals have been presented and analysed. The results show that the chemiluminescence and acoustic pressure at just before flame blowout have strong correlations under all operating conditions and the two signals are almost out of phase with approximately of 90 degrees. Care has to be taken in using the chemiluminescent emission and acoustic signals for control of combustion instabilities.

KEYWORDS: Diffusion Flame; Impinging Flame; Chemiluminescence; and Acoustic Pressure.

INTRODUCTION

Impinging flame jets are used widely in industry and manufacturing because of their high heat transport characteristics and tight spatial control of the heating. Impinging flame is used in heating or re-heating of stock in the metals and glass industries, flame holder in some heat engines, and in welding operations. However, impinging flame jets are not well understood.

Turbulent impinging flows have been widely investigated [1-13].Candel et al [2]. Experimentally studied an acoustically excited, premixed, laminar jet flame impinging on water cooled plate, they concluded that the net intensity of the sound level radiated by a perturbed laminar premixed flame increases compared to the noise from freely propagating conical flame when a plate is placed close to the nozzle. Zhang, et al. (1996, 1999) [9 and 10] employed a high- speed camera to visualise newly discovered disc-like flame and ring-like flame that apparently occur under the same flow conditions with different places of ignition.

The case of the turbulent impinging diffusion flame has been receiving an increasing interest in both practical applications and academic studies for two reasons. Firstly, is because impinging flame often focuses on efficiency of the heat transfer problem in wide range of practical applications such as heating and melting processes. The second reason is that the impinging diffusion flame is a common type of fire configuration, which is very rational to be linked to fire safety problem. There are both practical and purely scientific reasons for studying impinging turbulent flames. Zhang and Bray [9], experimentally identified five basic modes (disc ring, cone, envelope and cool central core) of a premixed impinging flames on a water-cooled plate, these modes depending on the nozzle-to-plate distance and the exit velocity. The ignition point plays a significant role to establish the different modes. Abulkasem and Zhang [12] measured the flow structure of the cold flow impinging jet and premixed impinging disc flame on un-cooled flat plate using LDA technique. With a similar experimental setup as in reference [9] Chan and Zhang [3] observed an instability when turbulent flame is in the disc flame regime. They found that this instability is strong source of combustion-generated noise. The spectrum exhibits a much higher power spectral density (PSD) in low frequency range compared to the one of a cold flow with the same mean nozzle flow. Zhang (2000) [11] showed very detailed velocity vector map of turbulent reacting impinging flows by using PIV techniques. Temperature and scalar quantity maps besides the velocity vector map of flames provide important information on the global flow structure. The development of high power lasers has provided a powerful tool for non-intrusive, time-and-space resolved measurements in combustion flows.

Asgyer. et al. (2008) [13] use three different techniques, chemiluminescence emission measurements of two radicals species, laser Doppler anemometer, and acoustic signal processing of premixed turbulent impinging flames on flat plate without excitation. The focus was on the chemiluminescence emissions of C_2 and CH radicals with the other two techniques providing supplementary information. Unfortunately, not much work can be found on this aspect.

This work presents a systematic study of the flame dynamic modes of turbulent diffusion impinging flames related with global chemiluminescence emissions and combustion noise, by using optical and acoustic techniques.

EXPERIMENTAL SETUP

The experimental apparatus is shown in Figure (1). It consists basically of a burner unit, a fuel supply, a circular steel plate, a light cell optic system for the collection of chemiluminescent emissions, a microphone system for pickup the acoustic pressure of the combustion noise, and data collection system, and a camera. The burner is a single copper fuel pipe of 0.7 cm inner diameter. There is an orifice at the end of the tube which reduces the overall inner diameter to the burner diameter, in this paper three different diameters were used, d_1 = 0.75mm, d_2 = 1.2mm, and d_3=1.7mm as shown in the Figure (2). The pipe is connected to a compressed propane gas cylinder. The fuel is regulated by a control valve and measured by a rotameter, where their volume flow rates can be accurately adjusted. The nozzle exit can be positioned at different height (H) along the central axis of a impingement plate. The burner was attached to an adjustable platform so that the height between the burner nozzle exit and the plate could be adjusted. The impingement surface is a circular steel plate 100 mm in diameter (D) and 15 mm in thickness (t), see Figure (3). It was placed 50 mm and 100 mm above the burner nozzle (H); in this paper H/D are 0.5 and 1. The whole stand and combustion unit are made rigid and heavy to avoid any movement or vibration during testing.

The fuel flow rate were modulated to fuel flow rate just before the flame blowout, the fuel was released from the copper nozzle and surrounded by ambient air and hereby created a diffusion flame before it impinged on the plate. In this paper, experiments with three different settings are included and the corresponding operating conditions are given in Table (1)

Table 1: Operating conditions of the experiments

Burner diameter (d) [mm]	Flow rate [Lrs/min] rate (LTRS/MIN)		Velocity [m/sec]		Re	
	H/D=0.5	H/D=1	H/D=0.5	H/D=1	H/D=0.5	H/D=1
0.7	0.680	0.55	25.64	20.74	4678	3783
1.2	1.89	1.1	27.84	16.20	8126	4729
1.7	4.37	1.64	32.07	12.04	13263	4977

For acoustic pressure measurements a microphone system has been used, the electrostatic (capacitor) type of microphone is used to pick up the acoustic signal; the microphone is located close to the edge of impingement plate in this paper; with a distance of 20 cm. The microphone is connected to a data acquisition system through an amplifier to increase the voltage from few mille-volts to few volts. To measure the chemiluminescence emission, a light cell optical system was utilized; outputs from the light cell were displayed and stored in a PC. National Instrument DAQ card and Labview software have been applied for data acquisition, monitoring and analyses. The digital camera was used to acquire the images of the flame with a single shot. The digital-camera was supported by a tripod. The camera support base was adjusted to an angle of 45 degrees relative to the plate surface, as shown in Figure (1) The horizontal distance between the tripod and the burner vertical axis was 0.5 m.

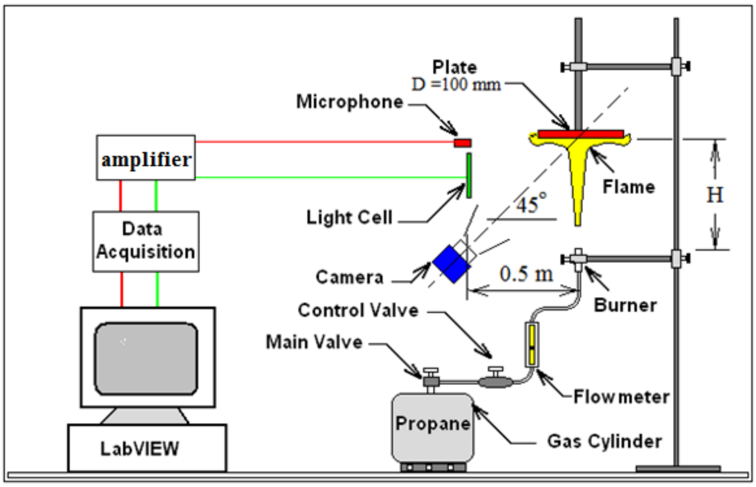

Figure 1: Layout of the Experiment.

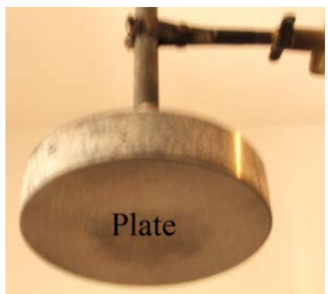

Figure 2: Burner **Figure 3: Plate**

RESULTS AND DISCUSSIONS

This paper presents the results of intensive experimental studies that have been performed on impinging diffusion flames. The analysis and discussion of the results are presented in detail. The aim of the experimental investigation is to study the flame dynamics of reacting flow at different conditions (with different burner diameter and, plate to nozzle separations H/D). Two different techniques were used to measure the Chemiluminescence emission and acoustic pressure simultaneously. In the present study, flame light at different setup conditions had been measured by using the light cell, also the microphone system had been used to measure the acoustic pressure emitted from the flame. This paper three different burner diameter (d_1= 0.7mm, d_2 = 1.2mm, and d_3 = 1.7mm) were tested at different H/D of 0.5 and 1.

Figures (4, 5), and 6 show the characteristic flame behaviour during the increase of fuel flow rate from a laminar to the flame blowout conditions, at H/D = 1 and different Burner diameter of 0.7 mm, 1.2 mm and 1.7 mm. From results; clearly that flame at low flow rate was yellow in colour, flame front is smooth in shape, and flame stabilized on the rim of the burner. By increasing the flow rate of fuel, the flame became partially blue in colour, and flame start to lift off. At high fuel flow rates the flame became completely blue in colour, flame was stabilized on the flat plate, and the flame became noisy. At this condition of high Turbulence, the jet propane diffusion impinging flame became completely blue in colour and take shape of disc flame, this indicates that the flame lift off have enhanced the mixing of the fuel and the surrounding air in the regime of cold flow between the burner nozzle and impingement plate.

Compared to free jet diffusion flame, the flame was earlier blowout. Because of the impingement plate; the flame is stabilized without extinguish. Further increases of fuel flow rate, the flame will blowout. Corresponding to these figures of results, the Chemiluminescence emissions and acoustic pressure have been measure from a laminar flame to blowout at sampling rate of 2500 sample/sec, light cell positioned at distance 30 cm from the centre of the impingement plate, and the microphone at distance 20 cm from the centre of the impingement plate, as shown in Figures (7, 8 and 9), where α , β, λ and γ in the figures are the stages of flame history from laminar (α region - yellow), transitional (β region- yellow and blue), turbulent (λ region - blue) and (γ region)blowout respectively. At laminar conditions of flame, the Chemiluminescence of the global light is very high in amplitude, because of high intensity of light of laminar diffusion flame, by increases the fuel flow rate, the signal amplitude decreases gradually, because the flame became blue, and the intensity of light decrease until the flame blowout. For the acoustic signals, the subfigures (B) show that, at laminar conditions the flame is very quiet. Once the flame became turbulence the flame became noisy, the flame noise increases, at very high flow rate (High Turbulence), and the instability of the flame is very high. At high fuel flow rate the ring flame was established, ring flames are plate stabilised. There is no combustion in the stagnation zone, and hence the centre part of the plate is relatively cool. Combustion, therefore, occurs only at a position where the radial wall jet velocity (radial velocity) is reduced to an appropriate level. As a result the stabilised ring flame is not able to propagate towards the stagnation region, because; of the region of high radial velocity, which is higher than the flame propagation velocity to prevent the flame propagate towards the stagnation point. In these conditions, analyses of flame dynamic just before the flame blowout have been measured by the same techniques and analysed in the next section of results.

In this section of the results, two signals have been measured simultaneously in an impingement diffusion flame at different configuration of setup. The measured signals include acoustic pressure and Chemiluminescence emission. The measurements were taken at flow rate just before the flame blowout. This study makes available very detailed spectra of each channel, and phase-space diagrams between channels have been presented, which provides information on the phase difference between two channels. The method of cross-correlation had also been applied.

Figures (10 to 15) show the time series, power spectrum, cross-correlation between Chemiluminescence and acoustic signals ($R_{chemil.\ -\ acoustic}$), and phase space diagram of different burner diameter of 0.7 mm, 1.2 mm, and 1.7 mm, at H/D = 0.5 and 1.The sampling rate is 8000 samples per second and the duration of each sampling is 2.5 seconds.

In this configurations of setup, subfigures(B) of results show that the dominant frequencies of the acoustic emission are varied from 125 to 138Hz, on the other hand for a chemiluminescence emissions the dominant frequencies are varied from 20 to 29Hz, in all experiments results, for the smaller burner diameter d=0.7mm, for free jet without impingement plate the maximum frequency before flame blowout was less than 19 Hz, compared with impinging flame at H/D = 0.5 is 29 Hz, and at H/D =1 is 23 Hz. The dominant frequencies of the acoustic emission are much higher than for chemiluminescence emissions. It seems that fluctuation of the Chemiluminescence emissions does not directly couple to the dominant acoustic frequency. This is perhaps not surprising since the combustion process does not radiate strongly in the visible spectrum and while for high turbulent flows, this is agree with Arthur [14] says that the shear layer develops instability waves in its initial regions, when the amplified waves reach a certain level, they roll up into vortices that will generate the noise, the radiated sound power covers a broad spectrum of frequencies from 100 to 2000 Hz

Subfigures C of this section of the results show the cross-correlation. It can be seen also that the cross-correlation of the two signals are strongly correlated. This strong correlation because due to the strong interaction between the chemiluminescent and acoustic emissions. Subfigures D illustrate the phase space diagram of the chemiluminescence emission and acoustic pressure of normalized signals. The simplest way to illustrate the phase difference between two signals is to plot the values of the normalized chemiluminescence at time (t), versus the normalized acoustic pressure values at the same time (t) into a phase space diagram. The results shown in the subfigures D correspond to the same data shown in the power spectrum sub-figures of these signals. The phase-space diagrams indicate that the two signals are out of the phase with approximate 90 degree.

Figure (16) shows the relation between the frequency mode of the impinging flame and the burner diameters, at H/D = 0.5 and 1.It is clear from the figure that the chemiluminescence emissions and the acoustic pressure have similar trends for all conditions of rig conflagrations, both channels; the frequency mode increases with the decreases of the burner diameter, at the condition just before the flame blowout, and also the figure shows that the frequency mode of the burner is increased by decreasing the distance between the burner and the impingement flat plate (H/D). From the results, it is clear that the burner diameter and H/D have strong effect on the chemiluminescent emissions and the acoustic noise frequency mode.

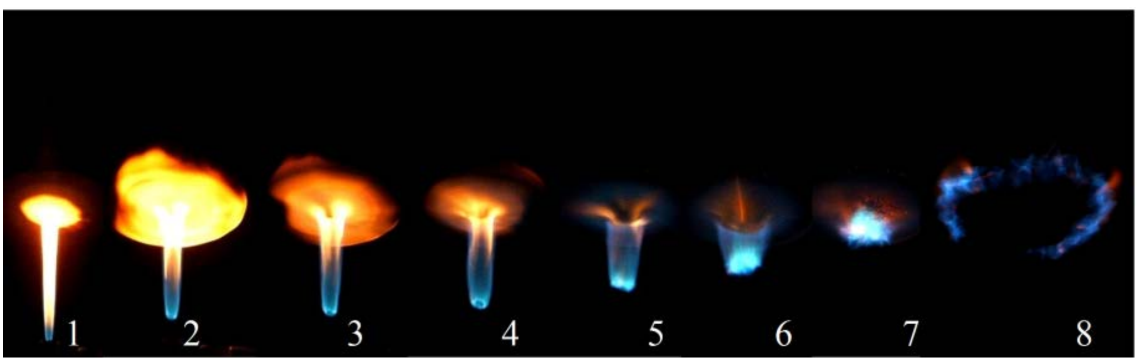

Figure 4: flame photography images during the increase of fuel flow rate from a laminar to the flame blowout conditions at H/D=1, and Burner diameter 0.7mm

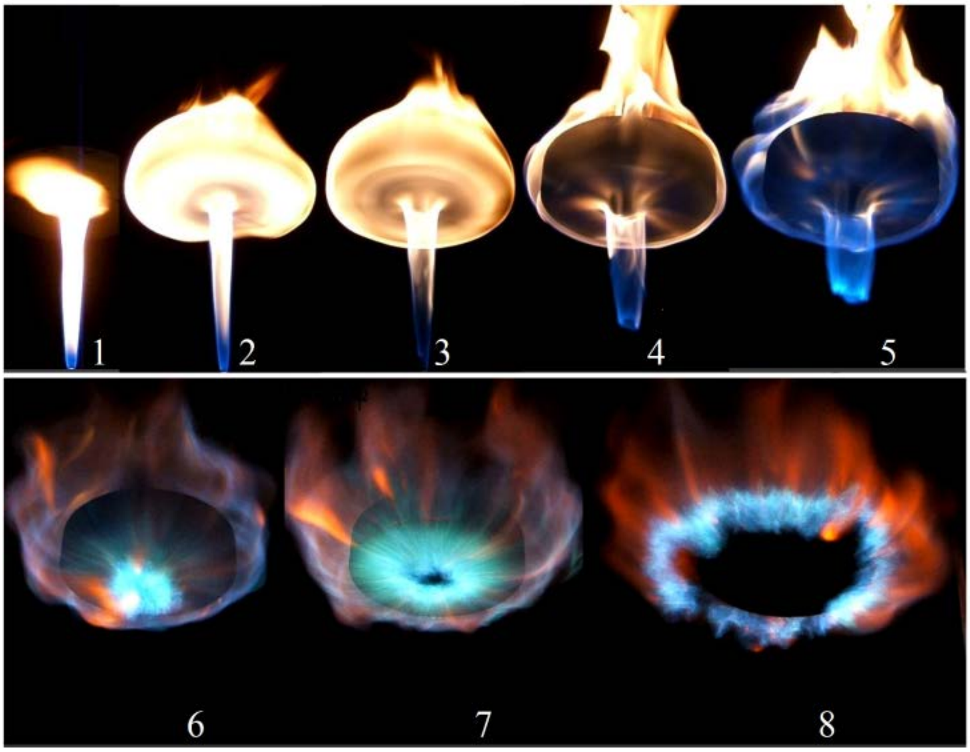

Figure 5: flame photography images during the increase of fuel flow rate from a laminar to the flame blowout conditions at H/D=1, and Burner diameter 1.2mm.

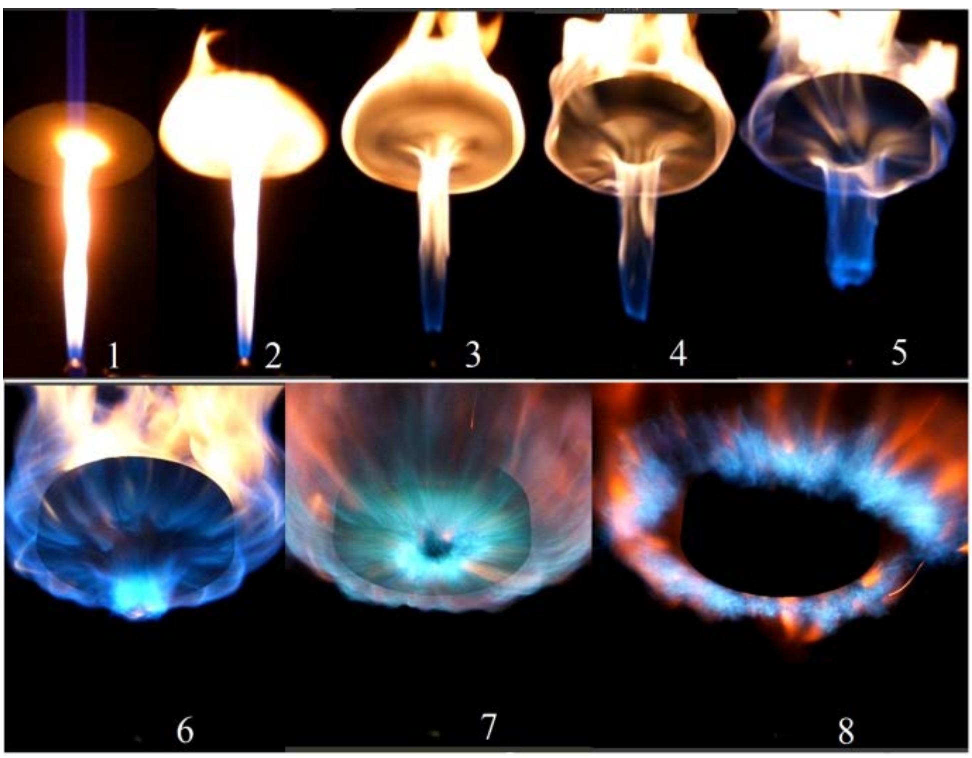

Figure 6: flame photography images during the increase of fuel flow rate from a laminar to the flame blowout conditions at H/D=1, and Burner diameter 1.7mm.

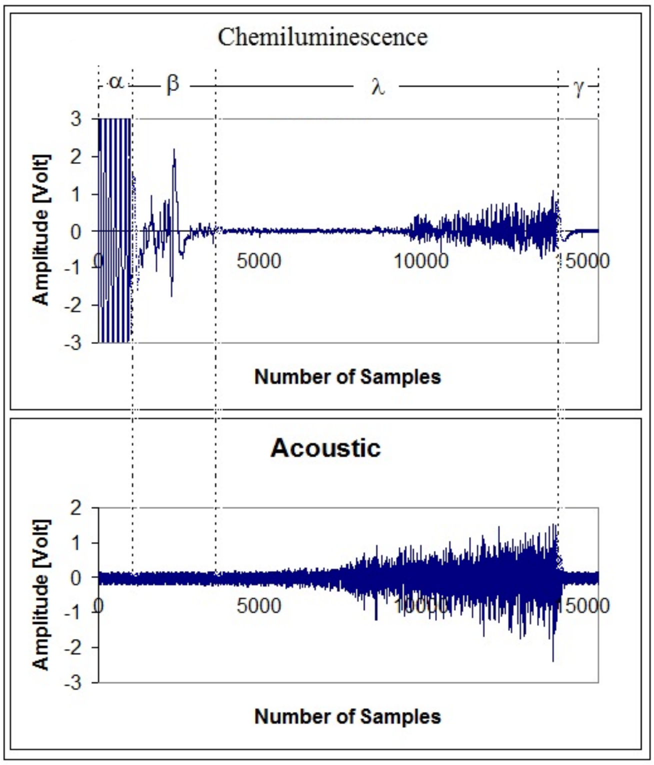

Figure 7: Time history of Chemiluminescence emission and acoustic pressure signals at H/D=1, Burner diameter 0.7mm.

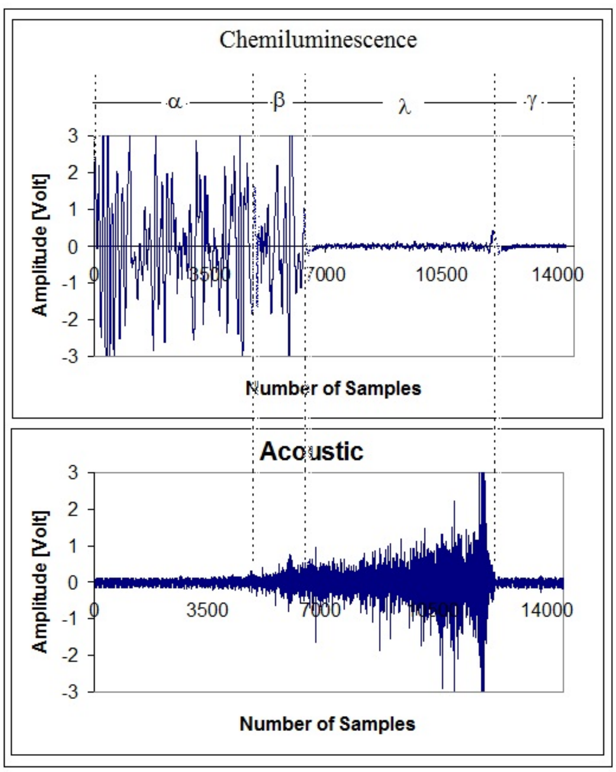

Figure 8: Time history of Chemiluminescence emission and acoustic pressure signals at H/D=1, Burner diameter 1.2mm.

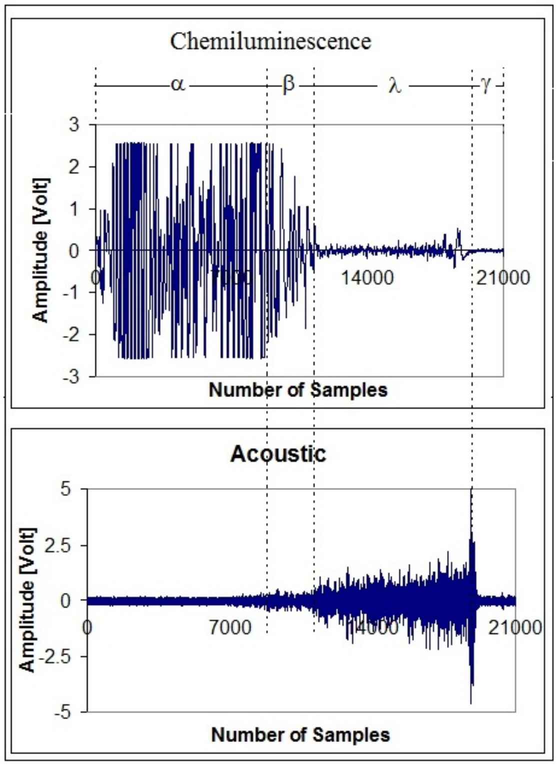

Figure 9: Time history of Chemiluminescence emission and acoustic pressure signals at H/D=1, Burner diameter 1.7mm.

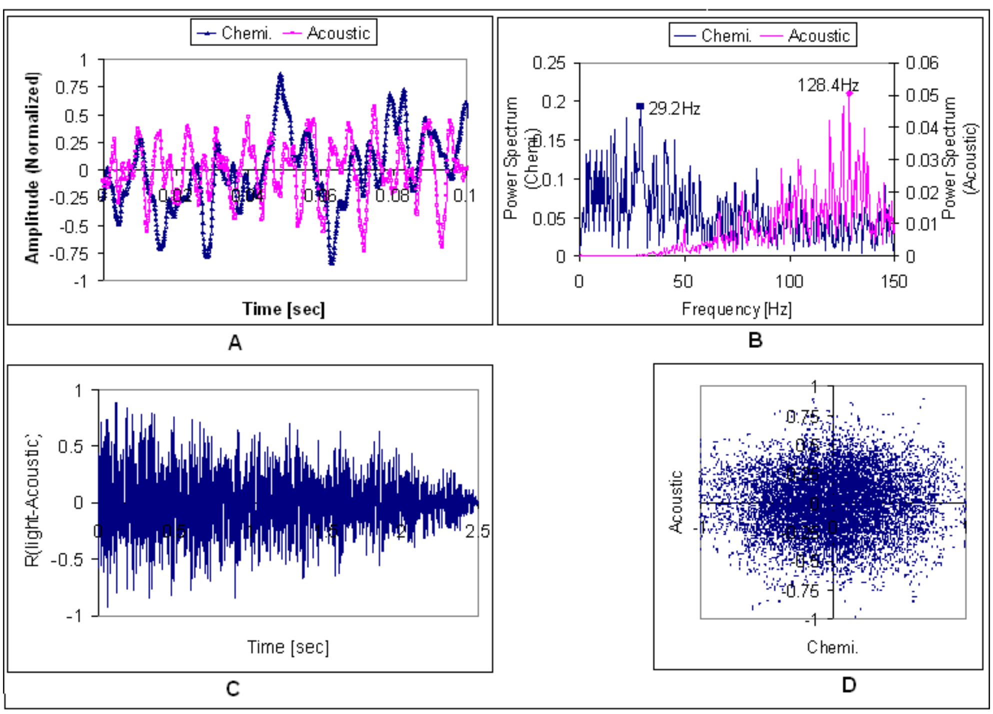

Figure 10: Time series (A), power spectrum (B), cross-correlation of ($R_{chemil. - acoustic}$) (C), and phase space diagram (D)(d_1=0.7mmand H/D=0.5).

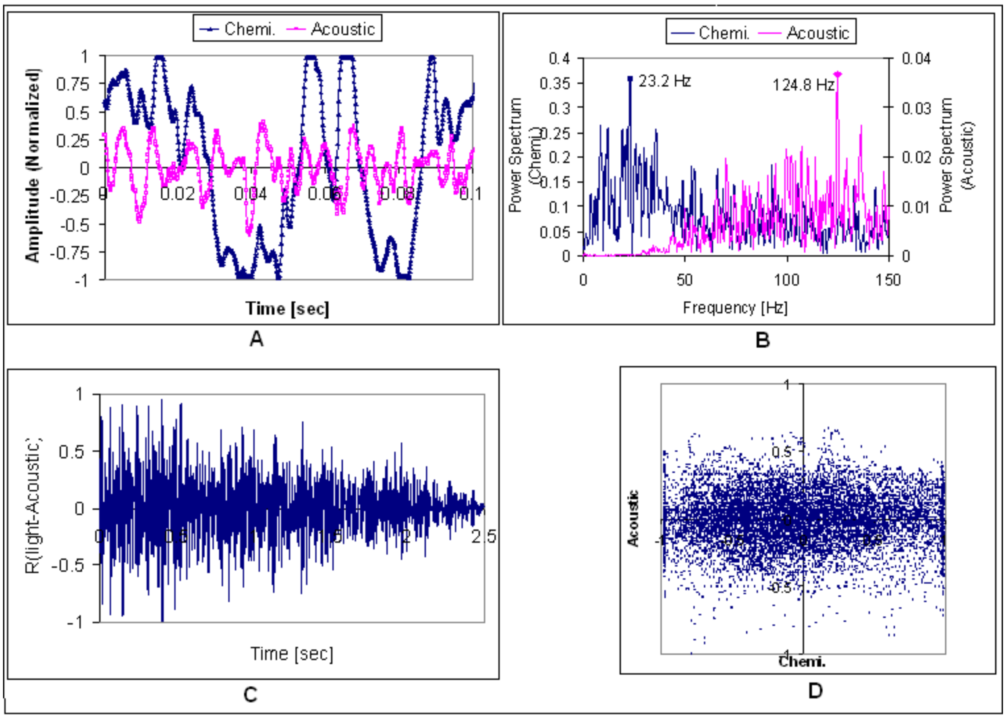

Figure 11: Time series (A), power spectrum (B), ($R_{chemil.\,-\,acoustic}$) (C), and phase space diagram (D), (d_1= 0.7mm and H/D=1).

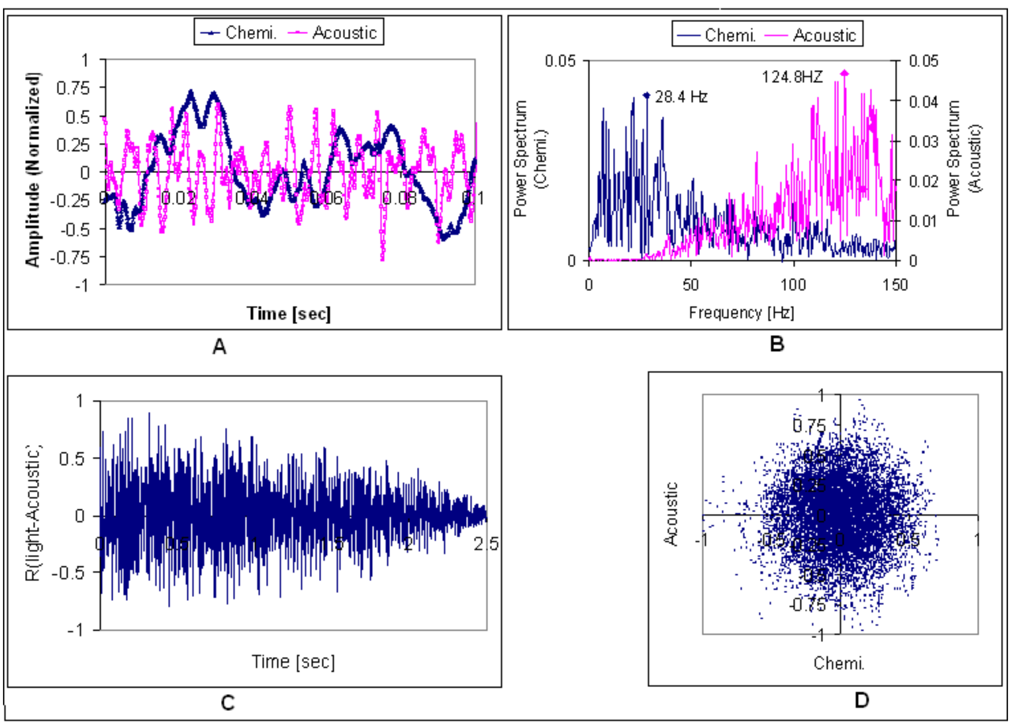

Figure 12: Time series (A), power spectrum (B), ($R_{chemil.\,-\,acoustic}$) (C), and phase space diagram (D), (d_2=1.2mm and H/D=0.5).

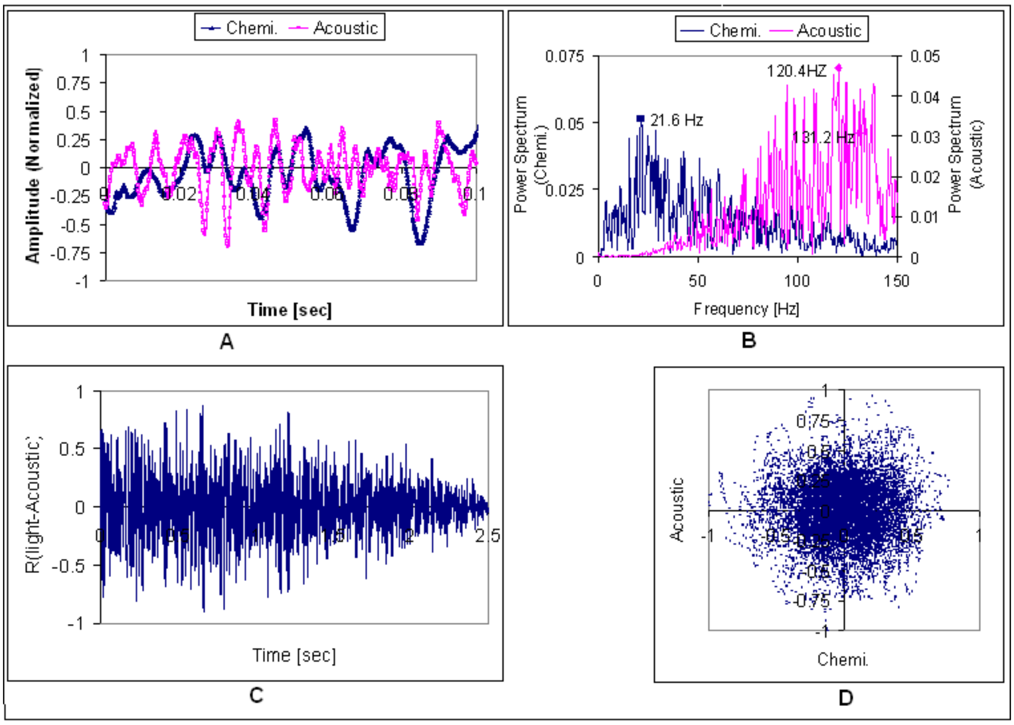

Figure 13: Time series (A), power spectrum (B), ($R_{chemil.-acoustic}$) (C), and phase space diagram (D), (d_2=1.2mm and H/D=1).

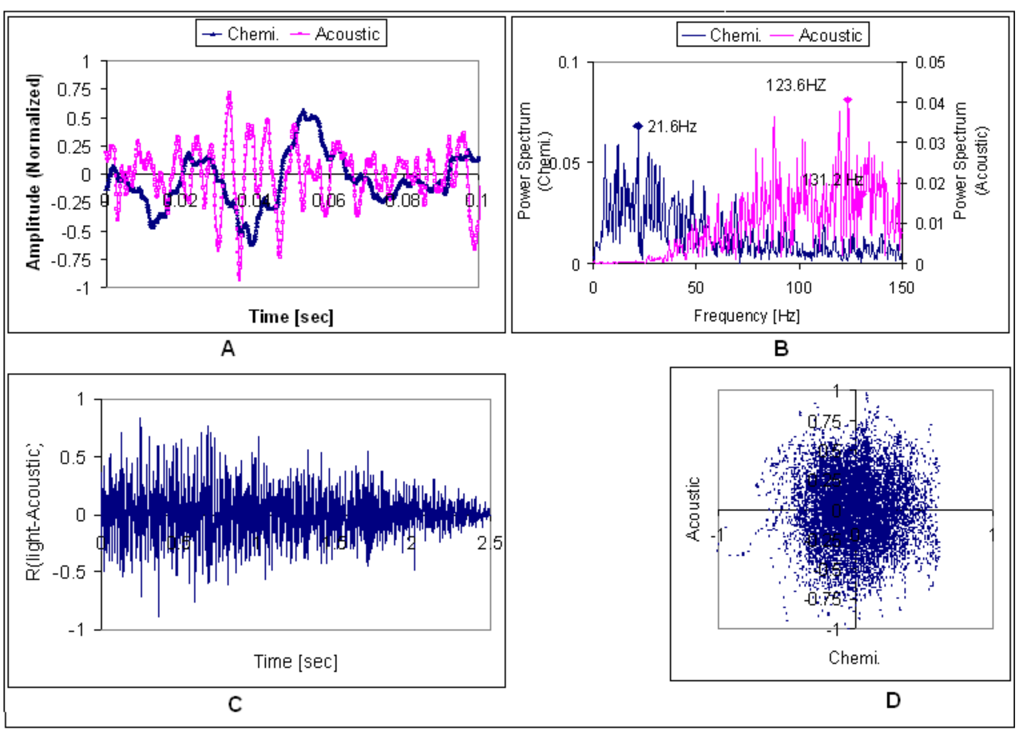

Figure 14: Time series (A), power spectrum (B), ($R_{chemil.-acoustic}$) (C), and phase space diagram (D), (d_2=1.7mm and H/D=0.5).

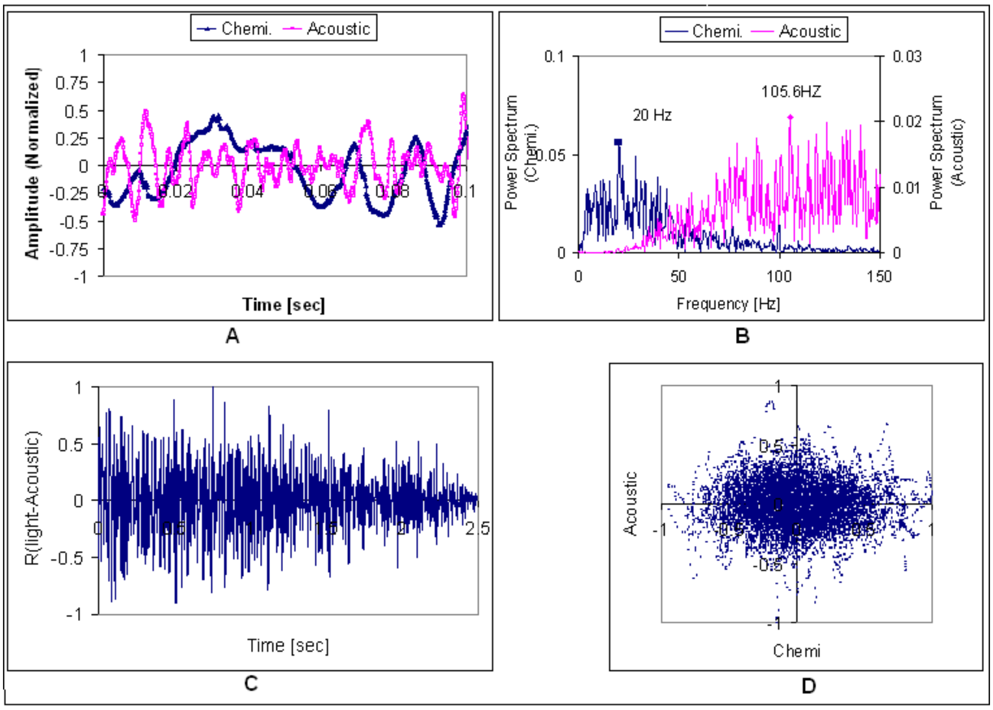

Figure15: Time series (A), power spectrum (B), ($R_{chemil.-acoustic}$) (C), and phase space diagram (D), (d_2=1.7mm and H/D=1).

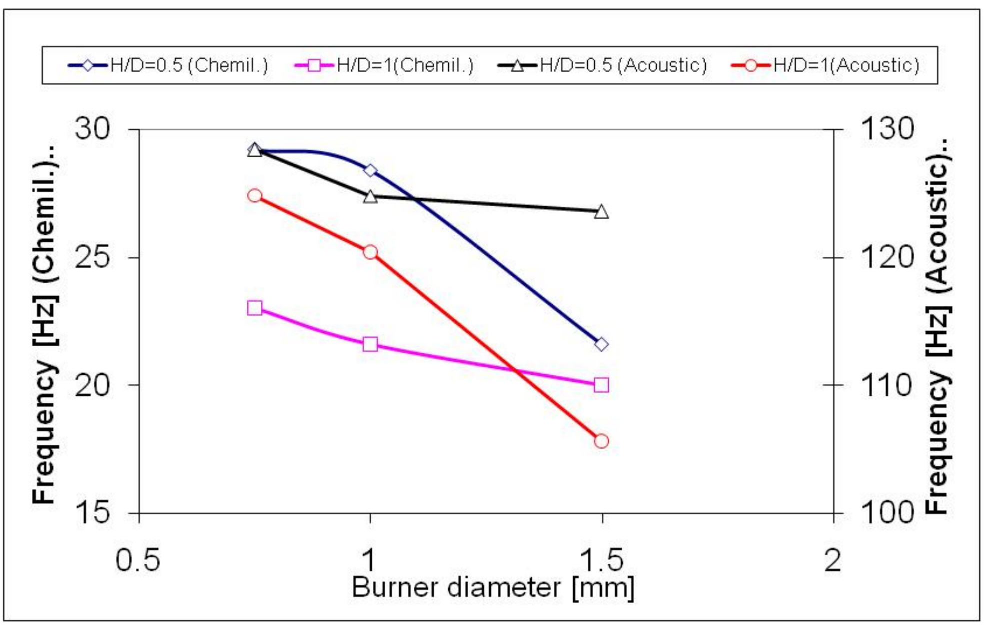

Figure 16: Burner diameter versus frequency mode of Chemiluminescence and acoustic emissions at H/D = 0.5 and 1.

CONCLUSION

An impinging flame is a flame impinging on a medium, such as a wall or an inert gas, the one presented here is a flame impinging normal to a circular plate with a diameter of 10 cm. The flame dynamics of an impinging diffusion flame at different diameters and different H/D have been investigated using global chemiluminescent and acoustic pressure emissions measurement. The results illustrate some important features of the impinging diffusion flame characteristics on a circular plate and showed that burner diameter has a strong effect on the frequency mode of the acoustic and chemiluminescence emission. A very important observation is that the H/D also has an effect on the frequency mode of combustion. Comparisons and detailed investigations of the acoustic characteristics with Chemiluminescence emission at different configurations of setup have been conducted with advantage of improving the combustion process. The simultaneously measured global Chemiluminescence emission and acoustic pressure emitted from an impinging diffusion flame provide further quantitative information on flame dynamics. The phase-space diagrams for the acoustic and Chemiluminescence emission indicate that the two signals are out of phase in the all cases with approximate 90^o. In addition, the collected data can be helpful in the development of modelling schemes that provide adequate prediction capabilities for the occurrence of flame instability or for the understanding of acoustic wave and chemiluminescence emission interactions of turbulence flame.

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