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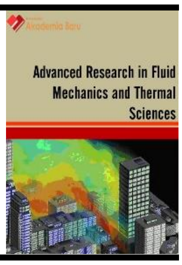

Effect of Acoustic Excitation toward Jet Flame: An Experimental Design

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ABSTRACT

Direct imaging technique is always used to obtain correlation of flame height or any other parameter of the visible portions of the flame. This is one of the important methods used in the combustion community to determine the characteristic of flame. Recently, the imaging technique has been developed and enhanced to provide more accurate data. However the utilization of the technology, such as the used of laser-based technique and acquiring sensor, increased the complexity of the process and also increased the amount of cost practically. This paper presents the results of an acoustic excitation towards a Liquid petroleum gaseous flame by using the direct visualizing technique. The direct visualizing technique is used to acquire the flame image and the images will be analyzed by using image analysis software. Results show the flame length at the flame core decreases when the amount of acoustic gradually increases. The effect of excitation towards the flame core is being investigated due to its significant influence toward the overall flame characteristic.

1. Introduction

Direct imaging technique is always used for obtaining a correlation of flame height or any other parameter of the visible portions of the flame. This is one of the important methods used in the combustion community to determine the characteristic of flame. Being able to quantify the parameter will improve the understanding of the flame characteristic. It is known that exciting acoustic could affect the flame dynamic [1-3]. Some of the perturbation may induce unstable flame behavior while at certain range of frequency, it can improve the burning efficiency and reducing the amount of produced carbon [4-5].

Recently, imaging technique has been developed and improved so that the information gather will be significant and can be processed into meaning full information. However the utilization of the

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technology such as the used of laser-based technique and other acquiring sensor increased the complexity of the process and also increased the amount of cost practically. Direct imaging or photography has always been a recording medium that helps to document flame throughout the year and its development had led to improvise on method of the image being acquired and due to its varsity the cost are much reasonable compare to other technique i.e.; laser based and other sensor acquiring method.

The objective of this paper is to integrate the used of direct imaging technique with the image analysis software (imageJ) to determine the measurement around the flame core. Usage of the software to analyze are excellent in making masses of measurement swiftly. Most of the measurement gather are properly interpreted and the most important aspect needed is the understanding of the limitations of the image software. Otherwise, not significance phenomena will be quantified during experiments [6].

2. Experimental Setup

This section is divided into three subsections, the first topic will focus onto jet flame systems, then the discussion will shift towards acoustic excitation system and finally will described about how the flame will be visualized.

The experimental apparatus is schematically depicted in Figure 1. The jet flame burner consisted of a well-contoured central nozzle that has a diameter size hole about 3mm and a length of 6cm attaches to a square burner frame. The length of a burner frame is 116 mm with a total size of 51 x 51 mm, which helped in the process of mixing air and fuel while making a fully developed laminar velocity profile at the exit. Total, the burner had a 2.5 m long fuel line. The fuel used in this study is supplied from the LPG tank. LPG has a composition of propane (C3H8, 30wt. %) and butane (C4H10, 70wt. %). LPG is colorless and odorless liquid which readily evaporates into gas and commonly used in Malaysia, residential and commercial application [7]. For safety measurement, an odorant, Ethanethiol commonly known as ethyl mercaptan (C2H6S) has been added to help detect any sign of leakage. LPG flows through a control valve with a constant pressure of 25psi and then through a rotameter, a measurement device used to measure the flow rate of gas (a constant flow rate of 2LPM being used for this experiment). LPG than pass through the pressure gauge to confirm the amount of pressure used, which is 25psi. Before entering the burner, LPG must pass through a one way control valve that functions as a meant to prevent any backflow happen. Fuel (LPG) and air (oxidizer) is mixed in the burner and spark is used to ignite the gas at the burner exit. The whole jet system was mounted on an AISI 1035 steel table and placed in a laboratory. To ensure the sound level and lightning exposure in the laboratory is controlled, the room is exhausted with a low-noise exhaust system and a black cloth was used as a curtain.

The acoustic modulation system consisted of a DDS Signal Generator, a power amplifier and an acoustic exciter (a loudspeaker). Acoustic excitation is used to control the flame stabilization and perturb its flow. Two loudspeakers is installed (for this experiment only 1 speaker will be active) and located 3.5cm from the center of nozzle for both sides. The speaker has a total power of 6 watts (3 watt each) and able to withstand a frequency range from 120 Hz to 20 kHz. It is a cone-type loudspeaker with a size of 75 mm x 90 mm x 70 mm and driven by a California Electronic AV-238 amplifier with a frequency response between 10 Hz to 50 kHz and an input sensitivity larger than 95 dB (A- rating). The source of the acoustic excitation generates from a DDS Signal Generator MHS-5200A, this device generally has a five different type of output waveform to choose from, which is a sine wave (0 Hz to 25 MHz), a square wave (0 Hz to 6 MHz), a triangle wave (0 Hz to 6 MHz), a sawtooth wave (0 Hz to 6 MHz) and a TTL digital signal wave (0 Hz to 6 MHz) with a total of 1024 points of waveform length and a 8 bit amplitude resolution. The acoustic amplitude and frequency are well controlled by the signal generator and the power amplifier. Amplitude is directly related to the intensity of sound or acoustic energy, it is adjustable, but is kept constant 6 W throughout the experiment. The excitation frequency could be tuned or varied to produce an effect toward jet flame. For this experiment the flame is observed as the value of excited frequency been varied between 0 kHz to 20 kHz. The resulting acoustic waveform intensity and the uniformity at the nozzle exit are carefully examined with a sound level meter TES-1358. The sound level meter is used to measure the frequency response of the loudspeaker and its sound pressure level (SPL) at a distance of 5 cm along the nozzle line of sight. This device has a measurement frequency range between 25 Hz to 10 KHz, configuration setting for this device is as follows, the frequency weighting used is A-rating with a 'fast' time constant weighting and the measurement mode used was 1/1 – octave analysis. A 100 sample averaging process is used throughout the experiment to obtain stable results. The loudspeaker output waveform is properly maintained and the excitation amplitude is limited to avoid any kind of distortion to the waveform.

Propagation image of flame is visualized by using a digital single-lens camera (DSLR), Canon EOS 70D and analyst using an open-source image analysis software, ImageJ (version 1.51n). The camera is placed on the same axis as the burner and at 90° to the flow direction, the distance between the imaging plane and the camera lens is set at 50cm. The determined distance will capture the entire image of a flame. The camera shutter speed was set-up to 1/100 s, shutter speed influence the brightness image, faster shutter speed will decrease the intensity or brightness while prolong it will smear the image, due to the movement of the flame. ISO and aperture (f-stop) for the camera being configured to 2000 and 36. The ISO importance of reducing the noise ratio that can cause random pixels to falsify colored while aperture has two important effects, focusing on the flame and control the amount of light let into the camera.

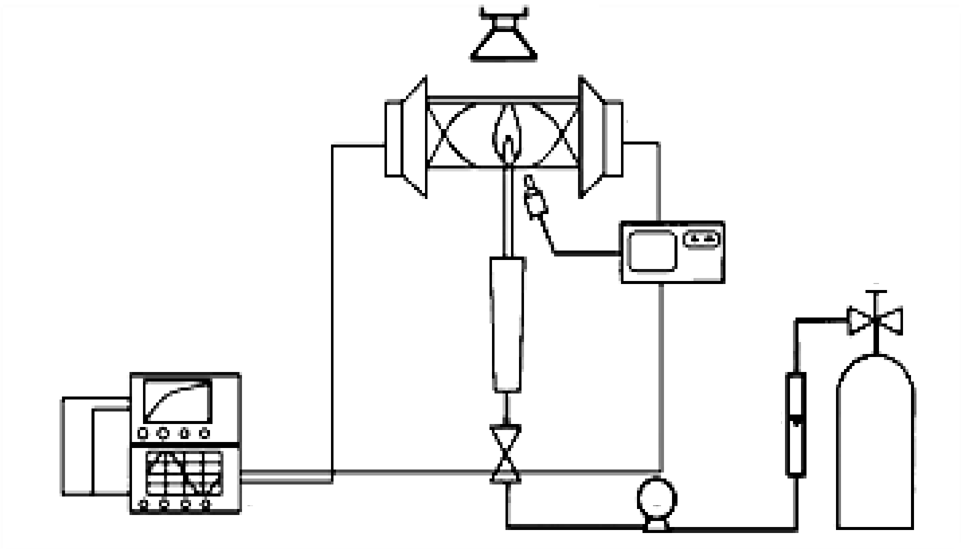

Fig. 1. Schematic diagram of the experimental configuration

3. Result and Discussion

A schematic representation of the step performed for this analysis is shown in Figure 2. The original images in Figure 2 (a) represent each part of the flame. The flame divided into three parts first the outer flame, then the reduction zone and lastly the flame core. The part is described as in

Figure 2 (a).The original images are first pre-processed, this is to achieve the optimal uniformity of illumination and contrast from the original images. This process being achieved by subtracting or eliminating the background image, this is done by reducing the noise or artifacts that generate during the acquisition process. This background subtraction is one of the built-in process in ImageJ, this function is implemented using Rolling ball algorithm. According to D.S Martin *et al.,* this algorithm is a gray scale morphological process with “rolling ball” being a circular structuring element far more convenient as a single command dedicated to the background subtraction [8]. Next the following pre-processing images are converted into 8-bit grayscale images as shown in Figure 2 (b). This conversion process defines the bit depth of an image by using “8-bit” meaning that the grayscale of the images has 256 steps, in other words the value of the grayness between black and white is divided by that number of steps. This conversion process, simplify the intensity of the image to a grayscale image ranging to a value from 0 to 256. The importance of this conversion is best described by Kota Miura [9]. Next the images are converted to threshold as in Figure 2 (c). This process helps to identify and distinguish light object over a constant, dark background, in a way where the flame light and the background color are grouped into two dominant modes that allow the light of the flame being enhanced. Thresholding the images help to identify the flame parameters visibly, the outer part and the reduction zone of the flame are being highlighted by the green color while the dark-cone like image represent the flame core. This analysis will focus towards the characteristic of the flame core itself. In Figure 2 (d), the length of the flame core will be measured and label using x-y coordinate. To ensure the measurement credibility, 50 points will be taken from the dark-cone and the average value will be used as the desired value.

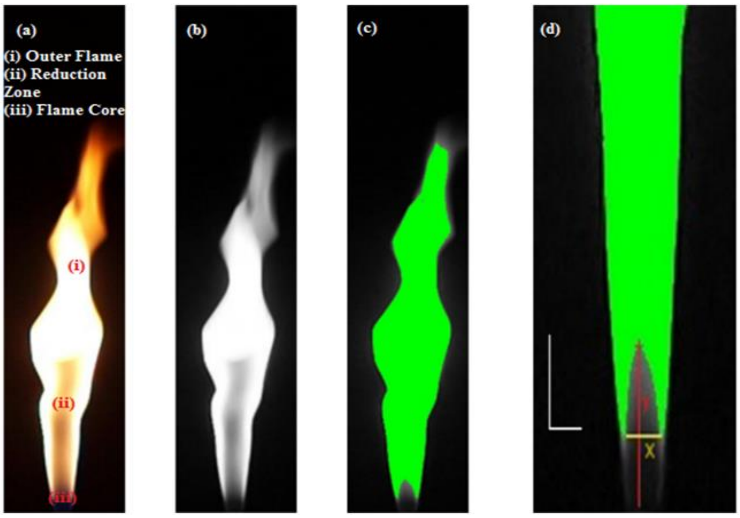

Fig. 2. Image analyze process (a) original Image (b) 8-bit grayscale image (c) threshold image (d) enlarge image used for measurements

Figure 3 represents the comparison of a flame core length when being excited by frequency (5 and 10 Hz) and without excitation (0 Hz). From the bar chart, it is noticed that for length (x) and (y) the flame length of the flame core decreases as the acoustic excitation increases. Flame core is important because it represents the overall value of a flame length. If the flame core is smaller in size (comparison make with no excitation) the flame length becomes shorter. The decrease in length when being excited by acoustic has also been reported by Delabroy *et al.,* [10], Rocha *et al.,* [11], Zhou *et al.,* [12], Tangirala *et al.,* [13] and Chao *et al.,* [14]. Flame length decreases as the acoustic excitation gradually increases for both (x) and (y) indicates that higher rates of air are diffused into the fuel by the perturbation [11]. The reduction in flame length represents the increase in turbulence mixing as suggested by Schadow *et al.,* [15]. The author also suggested that forcing promotes early transition to fine scale turbulence which definitely improves mixing faster. When the rate of mixing increased the following flame will be stabilized closer to the nozzle meaning that by direct visualization, it can be seen the change of flame length becomes shorter due to excitation.

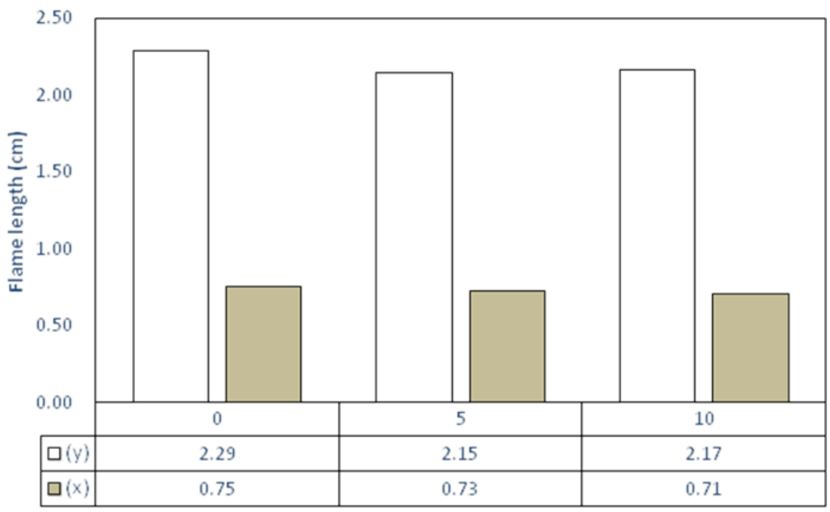

Fig. 3. Flame length (y) and (x) at flame core excited by various frequency (1 speaker), for LPG

4. Conclusions

Acoustic excitation has been tested on a premix jet flame for frequencies of 5 Hz and 10 Hz sourcing from one speaker. Results show a decrease in the flame length of the flame core.

The result shows that the flame length decreases as increasing the amount of excitation (frequency). This is because acoustic excitation promotes and affects the mixing characteristic as shown by the shortening of flame core. The flame core represents the overall change of a flame characteristic, smaller the flame core is shorter the flame length. This acoustic excitation has the potential of promoting good mixing characteristic allowing a better temperature distribution.

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