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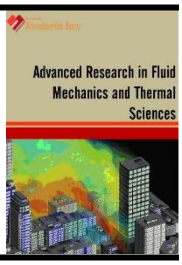

Acoustic Perturbation Toward Jet Flame – Variation of Flame Shapes Mode

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ABSTRACT

Effect of acoustic excitation on jet diffusion flames caused by an energy transfer delivered by the source (speaker) to the receiver (jet flame) through a medium of air. Using the first law of thermodynamics, which is the expression of the conservation of energy principle. Energy cannot be created nor be destroyed during a process; it can only change from one form to another. From this principle, the energy transfer from the sound waves to the jet flames causing the flames to change in both macroscopics and microscopic. The macroscopic effects related to the motion and the flame of shapes cause by the acoustic disturbance. This paper shows the macroscopics effects can clearly been seen when the flame shapes start to split in two branches during the transfer of energy. This effects clearly correspond with the periodically changes of acoustic frequency. By using ImageJ, a Java-based image processing program to detailed out the changes of structure correspond by the increase of acoustic frequencies.

1. Introduction

Sound or pressure waves have the capabilities to influence flames in macroscopic and microscopic in a form of energy of a system. The changes are related to the molecular structure and the degree of molecular activity and can be viewed as the sum of the kinetic and potential energies of the molecules [1]. By utilizing these effects, there are possibilities to improve combustion control of such phenomena as high-load combustion [2-5], soot suppression [6], NOx reduction [7], noise

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control [8] and the mixture formation of fuel [9-14]. The effects of an acoustic perturbation deal directly and indirectly towards flame. For a direct interaction, it mainly occurs in the flame zone. The wave occurrences upon the flame zone is scattered and potentially amplified because of the steep gradients in gas properties at the flame front and by the response of the flame to the disturbances. The effect has been examined both for premixed and diffusion flames.

A variation of flame shape record by [15-20], when laminar jet flames being exposed with a resonant frequency, the laminar flame decreased in length. A vortex likes flame shape formation caused by increase of acoustic excitation can be seen from the. The increase of excitation amplitude causes the position of flame to move upstream due to the spreading rate that changed however, the longer the exposure in high amplitude perturbation will extinguished the flame.

Another research done by [21] stated that when a laminar flame being excited by forcing frequency, the change of flame shape can be grouped into four; a flame of feeble forcing (Mode I), a fat flame (Mode II), an elongated flame (Mode III) and in-burning flame (Mode IV). Each of the flame shape is recorded using direct imaging technique. The change of mode shape correlate with the increase of excitation due to higher local strain.

Based on [22] observations, a flame shape of a laminar flame can somehow turn into a ‘’Y’’ shape like during the perturbation of sound frequency. It was also noted that the “Y” shape flame is a product of flame when it diverges into two branches; this branching behavior is caused by the acoustic excitation toward the flame. The goal of this paper is to investigate the variation of flame shape mode for a premixed flame under the effect of acoustic excitation using direct imaging technique.

2. Methodology

Detail for this experiment can be refer to [23], a schematic diagram for this experiment apparatus as shown in Figure 1. The jet flame burner used are a well-contoured central nozzle that has a diameter size hole of 3mm and a length of 6cm attached to a square burner frame. The length of a burner frame is 116 mm with a total size of 51 x 51 mm. 51 x 51 mm. the burner had a 2.5 m long fuel line. The fuel used in this study is a composition of propane (C_3H_8, 30wt. %) and butane (C_4H_{10}, 70wt. %) supplied from the LPG tank.

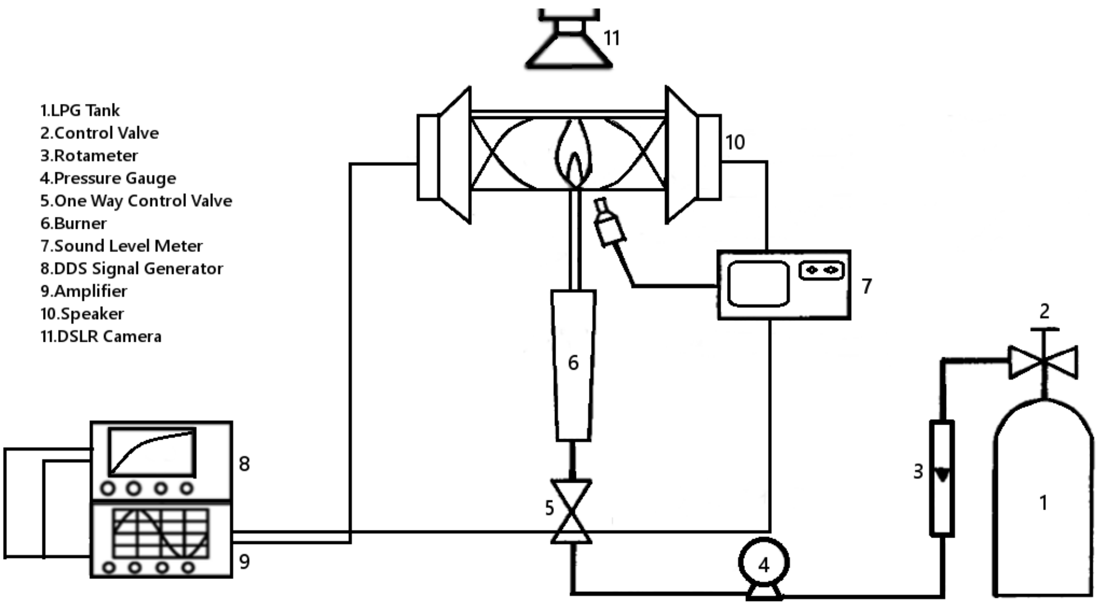

Fig. 1. A schematic diagram for the experiment configuration [9]

The flow rate of the gas measured using a measurement device (The value of the flow rate is set constant to 5LPM). An odorant, Ethanethiol commonly known as ethyl mercaptan (C2H6S) being add to help detect any sign of leakage. For acoustic perturbation, a system consisted of a DDS Signal Generator, a power amplifier and acoustic exciters (a loudspeaker) are used.

Two loudspeakers are installed (single and dual experiment comparison) and located 3.5cm from the center of nozzle for both sides. The excitation frequency for this experiment will be tuned or varied from 0 kHz to 20 kHz. The flame is then photograph as the value of excited frequency being varied. The flame image is then photographed using digital single-lens camera (DSLR), Canon EOS 70D and analyst using open-source image analysis software, ImageJ (version 1.51n).

3. Results

Figure 2 shows five-(5) difference variation of flames shapes with increasing excitation of frequencies recorded during the experiments. For (Figure 2 (1)), the flame without any influenced of acoustic excitation (unforced flame) has a symmetrical and cone- like shape, it can be assumed that an axis of symmetry line to be exist along the vertical centerline of the flame. The dotted line in the picture represent that the length of flame is supposedly to be constant due to the controlled fuel flow rate used during the experiments. From Figure 2 disturbance resulted from the acoustic excitation generated by the DDS Signal Generator can be categorized to four-(4) types of mode disturbances; fat-flame, in – burning flame, elongated flame and Y- shape flame. Overall, acoustic excitation forced dramatically influence the flame length by reducing and increasing it such like a turbulent-like flow shape.

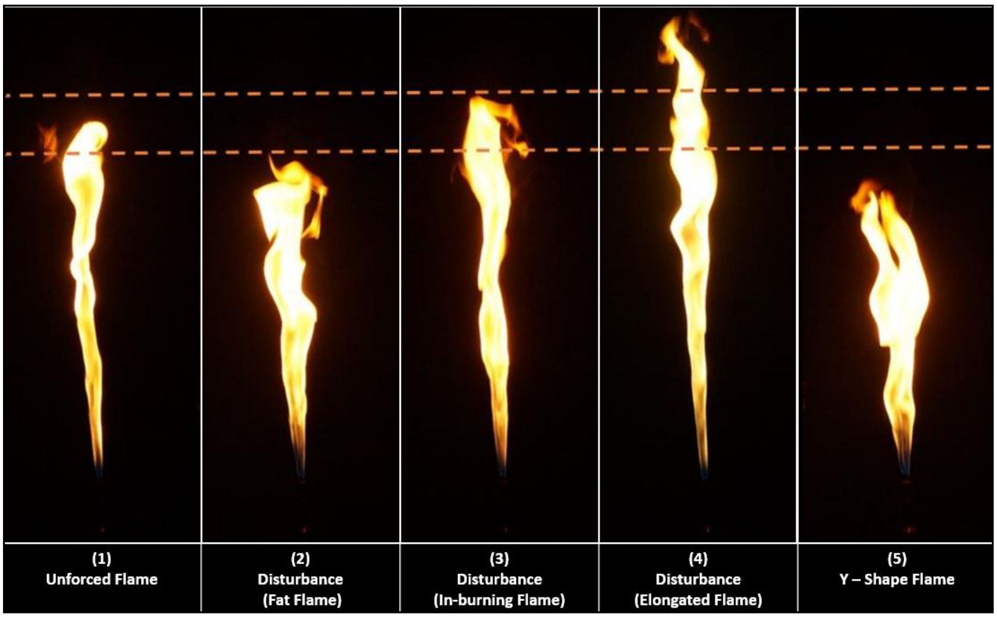

Fig. 2. Variation of flame shapes mode (1) Unforced flame; (2) Disturbance -Fat Flame; (3) Disturbance – In-burning Flame; (4) Disturbance – Elongated Flame; (5) Y-Shape Flame

Referring to the graph in Figure 3 (Variation of Flame Shape) for a single speaker, when frequency perturbation being increase from 100Hz to 500Hz the flame mode shape become (Figure 2(2)) – A Fat Flame shape mode. The fat flame shape decreases in length dramatically and the width of flame became larger making the shape of flame become shorter and wider, according to [24] this phenomena associated with the declined of axial diffusion, and enhanced radial diffusion of the fuel mainly caused by the acoustic perturbation. From 900 Hz to 1400 Hz, the shape mode turn to (Figure 2 (3)) – In burning flame. The In- burning flame refers to the occurrence of burning inside the flame. Disturbance excited by the acoustic create a moment of entrainment, the influence is strong enough making the side of the flame be more dominant and help mixing the air around it. Moreover, the lift of flame from the nozzle refer to the increase of local flame stretch according to [25].

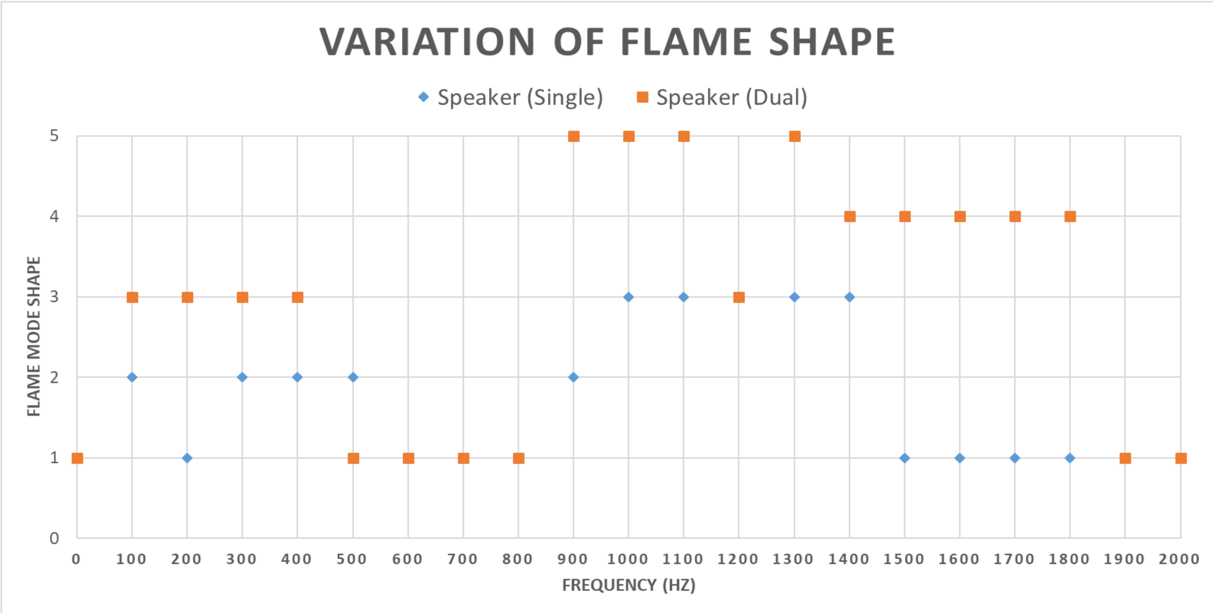

Fig. 3. Variation of flame shapes mode - Flame Mode Shape versus Frequency (Hz)

For a dual speaker, the effect of acoustic with a constant flow rate is shown at start of low frequency (100 Hz to 400 Hz) when the flame mode shape as in (Figure 2 (3)) – burning flame mode. As the excitation start to increase the flame, revert to its normal shape as in (Figure 2 (1)). further the excitation the flame starts to show sign of branching (800 Hz), the flame clearly branches (900Hz to 1200Hz) into (Figure 2(5)) – Y shape flame, at (1300Hz) the flame start to decreases its branching angle and the shape finally changes to (Figure 2(4))- elongated flame. The formation of Y- shape flame can be arrange into four sub processes [22], first is due to its constant flow rate then the meandering process, where the direction of excitation propagates. Next the transition process of the jet flame where the flame start to twisted into two branch arms causes by the use of dual speaker and final the branching or Y-shape flame happen, where the acoustic excitation direct through the middle and separates into two flows.

4. Conclusions

The variation of flame shape for a laminar jet flame under acoustic perturbation has been examined by means of direct imaging techniques and the used of image analysis software. The changes of flame shape are directly proportional to the increase of frequency. There are five variation of mode shape resulted by the acoustic perturbation. These results will help further understand the effect of acoustic perturbation toward jet flame.

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References

[1] Cangel, Y. A., and Michael A. Boles. "Thermodynamics: An Engineering Approach 4th Edition in SI Units." *Singapore (SI): McGraw-Hill* (2002).
[2] Yoshida, H., M. Koda, Y. Ooishi, K. P. Kobayashi, and M. Saito. "Super-mixing combustion enhanced by resonance between micro-shear layer and acoustic excitation." *International journal of heat and fluid flow* 22, no. 3 (2001): 372-379.
https://doi.org/10.1016/S0142-727X(01)00103-5
[3] Khalid, Amir, Adiba Rhaodah Andsaler, Bukhari Manshoor, and Norrizam Jaat. "Effect of high pressure on the flow characteristics of injector using computational fluid dynamics (CFD)." *ARPN Journal of Engineering and Applied Sciences* 11, no. 12 (2016): 7503-7506.
[4] Azahari, Bin Razali Mohd, Masayuki Mori, Masataro Suzuki, and Wataru Masuda. "Measurement of thermophoretic parameters for binary gas mixtures." *Journal of aerosol science* 63 (2013): 60-68.
https://doi.org/10.1016/j.jaerosci.2013.05.003
[5] Azahari, Bin Razali Mohd, Masayuki Mori, Masataro Suzuki, and Wataru Masuda. "Effects of gas species on pressure dependence of thermophoretic velocity." *Journal of aerosol science* 54 (2012): 77-87.
https://doi.org/10.1016/j.jaerosci.2012.07.002
[6] Saito, Masahiro, Masayuki Sato, and Akira Nishimura. "Soot suppression by acoustic oscillated combustion." *Fuel* 77, no. 9-10 (1998): 973-978.
https://doi.org/10.1016/S0016-2361(97)00286-X
[7] Pun, W., S. L. Palm, and F. E. C. Culick. "Combustion dynamics of an acoustically forced flame." *Combustion Science and Technology* 175, no. 3 (2003): 499-521.
https://doi.org/10.1080/00102200302384
[8] Samsubaha, Muhammad Fauzi. "Performance of Flexible Polyurethane Foam Reinforce with Coconut Coir and Tyre Particle as Package Cushioning Materals." PhD diss., Universiti Tun Hussein Onn Malaysia, 2012.
[9] Nursal, Ridwan Saputra, Amir Khalid, Ahmad Tajuddin, Ahmad Syukri, and Syahrunniza Abd Hadi. "Performance and emissions characteristics of alternative biodiesel fuel on small diesel engine." *Energy Procedia* 18 (2015): 1317-34.
[10] Khalid, A., A. S. A. Tajuddin, N. Jaat, B. Manshoor, I. Zaman, S. A. A. Hadi, and R. S. Nursal. "Performance and emissions of diesel engine fuelled with preheated biodiesel fuel derived from crude palm, jatropha, and waste cooking oils." *International Journal of Automotive and Mechanical Engineering* 14 (2017): 4273-4284.
[11] Khalid, Amir, Azim Mudin, M. Jaat, Norrizal Mustaffa, Bukhari Manshoor, Mas Fawzi, Mohd Azahari Razali, and Mohd Zamani Ngali. "Effects of biodiesel derived by waste cooking oil on fuel consumption and performance of diesel engine." In *Applied Mechanics and Materials*, vol. 554, pp. 520-525. Trans Tech Publications Ltd, 2014.
https://doi.org/10.4028/www.scientific.net/AMM.554.520
[12] Khalid, Amir, and Bukhari Manshoor. "Effect of high swirl velocity on mixture formation and combustion process of diesel spray." In *Applied Mechanics and Materials*, vol. 229, pp. 695-699. Trans Tech Publications, 2012.
https://doi.org/10.4028/www.scientific.net/AMM.229-231.695
[13] Khalid, Amir, Norrizal Mustaffa, Bukhari Manshoor, Hanis Zakaria, Ahmad Jais Alimin, Abdul Mutalib Leman, and Azmahani Sadikin. "The comparison of preheat fuel characteristics of biodiesel and straight vegetable oil." In *Applied Mechanics and Materials*, vol. 465, pp. 161-166. Trans Tech Publications Ltd, 2014.
https://doi.org/10.4028/www.scientific.net/AMM.465-466.161
[14] Khalid, Amir, Norazwan Azman, Hanis Zakaria, Bukhari Manshoor, Izzuddin Bin Zaman, Azwan Sapit, and Abdul Mutalib Leman. "Effects of storage duration on biodiesel properties derived from waste cooking oil." In *Applied Mechanics and Materials*, vol. 554, pp. 494-499. Trans Tech Publications Ltd, 2014.
https://doi.org/10.4028/www.scientific.net/AMM.554.494
[15] Smyth, Kermit C., Joel E. Harrington, Erik L. Johnsson, and William M. Pitts. "Greatly enhanced soot scattering in flickering CH4/air diffusion flames." *Combustion and flame* 95, no. 1-2 (1993): 229-239.
https://doi.org/10.1016/0010-2180(93)90064-A
[16] Razali, Mohd Azahari, Azwan Sapit, Mohd Faisal Hushim, Amir Khalid, Suzuki Masataro, and Masuda Wataru. "Flame spread behavior over combined fabric of cotton/polyester." (2015).

[17] Razali, Mohd Azahari bin, Azwan bin Sapit, Akmal Nizam Mohammed, Mohd Faisal Bin Hushim, Hamidon bin Salleh, and Hazahir bin Peraman. "Effect of thread angle on flame spread behaviour over combined fabric of kenaf/polyester." In *AIP Conference Proceedings*, vol. 1831, no. 1, p. 020016. AIP Publishing LLC, 2017. https://doi.org/10.1063/1.4981157

[18] Ramli, Afifah, Mohd Azahari Razali, Azwan Sapit, Mohd Faisal Hushim, Normayati Nordin, Amir Khalid, and Md Nor Anuar Mohammad. "Flame Spread Behaviour over Combustible Solid of Paper, Bagasse and Paper/Bagasse." In *MATEC Web of Conferences*, vol. 135, p. 00012. EDP Sciences, 2017. https://doi.org/10.1051/matecconf/201713500012

[19] Razali, Mohd Azahari, Azwan Sapit, Akmal Nizam Mohammed, Mohd Faisal Hushim, Azmahani Sadikin, Md Norrizam Mohmad Ja'at, Hazahir Peraman, and Mirnah Suardi. "Flame Spread Behavior over Kenaf Fabric, Polyester Fabric, and Kenaf/Polyester Combined Fabric." In *Engineering Applications for New Materials and Technologies*, pp. 67-75. Springer, Cham, 2018. https://doi.org/10.1007/978-3-319-72697-7_5

[20] Ramli, Afifah, Mohd Azahari Razali, Azwan Sapit, Mohd Faisal Hushim, Normayati Nordin, Amir Khalid, and Md Nor Anuar Mohammad. "Flame Spread Behaviour over Combustible Solid of Paper, Bagasse and Paper/Bagasse." In *MATEC Web of Conferences*, vol. 135, p. 00012. EDP Sciences, 2017. https://doi.org/10.1051/matecconf/201713500012

[21] Lee, Kee Man, Tae Kwon Kim, Won Jin Kim, Seung Gon Kim, Jeong Park, and Sang In Keel. "A visual study on flame behavior in tone-excited non-premixed jet flames." *Fuel* 81, no. 17 (2002): 2249-2255. https://doi.org/10.1016/S0016-2361(02)00150-3

[22] SUZUKI∗, Masataro., Takao Atarashi, and Wataru Masuda. "Behavior and structure of internal fuel-jet in diffusion flame under transverse acoustic excitation." *Combustion science and technology* 179, no. 12 (2007): 2581-2597. https://doi.org/10.1080/00102200701487012

[23] Sapit, Azwan, Mohd Azahari Razali, Mohd Faisal Hushim, Amir Khalid, and Md Norrizam Mohmad. "Effect of Acoustic Excitation toward Jet Flame: An Experimental Design." *technology* 53, no. 1 (2019): 69-74.

[24] Xi, Zhongya, Zhongguang Fu, Xiaotian Hu, Syed Waqas Sabir, and Yibo Jiang. "An investigation on flame shape and size for a high-pressure turbulent non-premixed swirl combustion." *Energies* 11, no. 4 (2018): 930. https://doi.org/10.3390/en11040930

[25] Samsubaha, Muhammad Fauzi. "Study on the Performance of Biodiesel Blend Jathropa Oil in a Combustion System." PhD diss., Universiti Teknologi Malaysia, 2015.