Int. J. Mech. Eng. & Rob. Res. 2013
International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 2, No. 4, October 2013

Research Paper

LOCAL MEAN AND RMS VELOCITY MEASUREMENTS OF THE EXCITED AIR JET AT THREE REGIMES IN A RIJKE TUBE

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This paper presents the results of experimental studies that have been performed on the confinement air jet flow at the exit of the burner, and further upstream inside the Rijke tube with and without excitation were quantified by CTA Anemometer. To understand more about three regimes (compression, high velocity fluctuating, and rarefaction (Farhat *et al.*, 2005)) a full mapping of the velocity field has been obtained for all non-reacting flow. The third mode of the Rijke tube has been selected for detail investigations, since this is the lowest mode which has three regimes. A very important observation of the velocity close to the fuel nozzle is much higher than expected when under acoustic excitation. Comparisons and investigations of the velocity characteristics with and without excitation at different positions above the nozzle exit have been carried out. The results show that the axial local velocity was observed to increase by three times at the rarefaction regime, compared with the other regimes the local mean velocity is approximately remain the same as for flow without excitation. It seems to be that the surrounding air is mixed with the air jet exiting from the nozzle resulting in an accelerated jet of air. At similar condition of excitation, and with the air jet replaced by a propane fuel flame, the laminar propane diffusion flame becomes completely blue in colour, shorter in height, and also lifts off in the rarefaction regime, and a mushroom like flames and flame necking are observed in the high velocity fluctuating regime (Farhat *et al.*, 2005). This indicates that the acoustic excitation may have enhanced the mixing of the air and fuel in a rarefaction regime.

Keywords: Rijke tube, Acoustic excitation, Local RMS and mean velocity

INTRODUCTION

Combustion processes are encountered in many applications such as power generation, heating and propulsion. Continuous combustion processes exhibit a wide range of dynamics and in some conditions which

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promote coupling with the acoustic field. The combustion chambers can be viewed as organ pipes in which acoustic pressure and velocity oscillations can be sustained. To understand the flame dynamics a Rijke has been taken as a test rig. A loudspeaker is often used as an acoustic driver or actuator to provide the required acoustic power for flame instability control or for the understanding of flame and acoustic wave interactions. A loudspeaker is mounted at one end of a Rijke tube or both of ends with two loudspeakers. Many researchers have used this configuration, (Lang *et al.*, 1987; Mcmanus *et al.*, 1993; Erickson *et al.*, 1997; and Ng *et al.*, 2003).

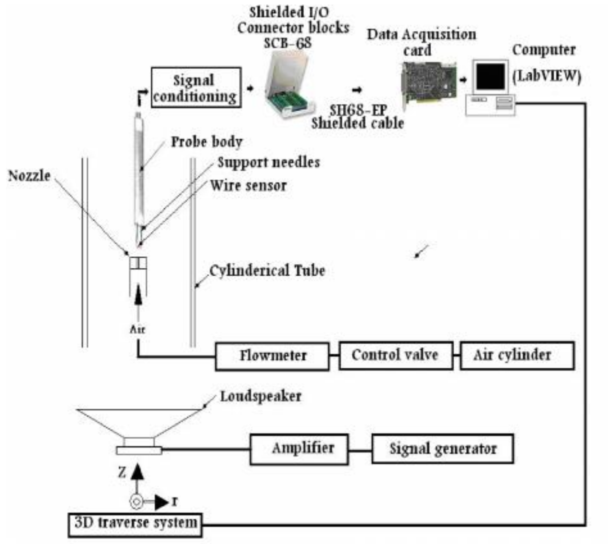
In the process of producing sound it is unavoidable that the surrounding air or fuel/air mixture will be disturbed. Therefore there is a need to know the velocity field induced by a loudspeaker. Unfortunately not much work can be found on this aspect. Mcquay *et al.* (2000) have investigated the acoustic velocity amplitude as a function of the position inside a Rijke tube. Values that are one order of magnitude higher than the average flow velocity have been observed, which increases the mass and momentum transport in the radial direction and produces improved mixing between the oxidizer and fuel and decreasing the combustion time. The oscillating flames were mostly blue, significantly shorter in length, and wider compared with cases without acoustic excitation.

For a cylindrical tube with relative small diameter (say, small than the quarter wave length of the excitation acoustic wave) one would expect the acoustic properties to be 1D in nature. However the field of interest is not far away from the loudspeaker and the hydrodynamic near field effect could not be ignored. As a result, complex flow patterns inside the tube may be induced. Three acoustic zones have been looked in detail. In the rarefaction zone, it has been observed that the yellowish diffusion jet flame change colours to blue completely in some regions of the tube, which imply the significant change in chemical reaction and the importance of burner nozzle position relative to the combustion chamber. In the high velocity fluctuation zone, mushroom like flame shape and flame necking are present. The velocity fluctuation seems only affects the bulk movement of the flame. In the compression zone, no obvious flame change could be observed directly (Farhat *et al.*, 2005). Farhat and Zhang (2007), reports some important features of the flow characteristics of laminar air jet in a loudspeaker induced standing wave, this paper showed that the local mean velocity close to the air nozzle excited with the second mode has increased to about 7 times, this paper only studied the flow structure at the rarefaction zone. In current paper the acoustic velocity fields in a loudspeaker driven cylindrical tube are investigated experimentally at three regimes, compression, high velocity fluctuating, and rarefaction. In most of published literature, the burner nozzle position is often fixed at one particular position relative to the Rijke tube or moved to very limited positions. Facilitated by a computer controlled traverse system, the change of the flow velocity measurements (Local RMS and mean velocity) by using CTA Anemometer of air jet inside a Rijke tube without excitation and with excitation of the third mode of this tube at the various positions along the standing wave generated by a loudspeaker at the one end of a Rijke tube have been investigated.

EXPERIMENTAL SETUP

The overview of the experimental setup of this test rig is shown in Figure 1. It consists of an air jet system, a signal generation and data collection system, a Constant Temperature Anemometer (CTA) and a computer controlled 3D traverse system. The air jet system consists of an air supply system. The Nozzle is a single copper fuel pipe of 0.5 cm inner diameter. There is an orifice at the end of the pipe which reduces the overall inner diameter to 1.75 mm. The pipe is connected to a compressed air gas cylinder. The air is regulated by a control valve and measured by a flow-meter. The cylindrical tube is made of transparent material with a wall thickness of 0.25 cm. The cylindrical tube has a length and inner diameter of 0.75 m and 0.125 m respectively. The air nozzle position relative to the cylinder could be adjusted automatically by using a computer controlled traverse system as shown in Figure 1. It has been arranged in such a way that the air nozzle position was fixed and the cylindrical tube and the loudspeaker unit were moved relative to the air nozzle. Therefore the disturbance to the nozzle and the measurement probes is reduced.

Figure 1: Schematic of the Experimental Configuration of the Velocity Measurements System

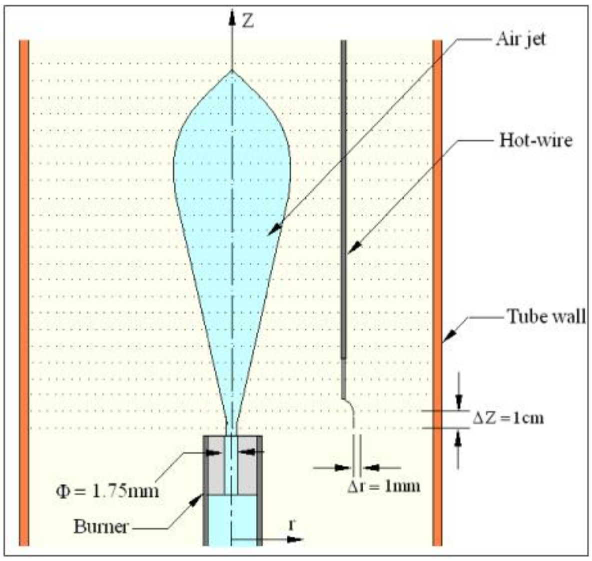


The signal generating system includes a signal generator, an amplifier with impedance of 10 Ω and a loudspeaker (maximum power of 350 W and a frequency range from 20 to 4000 Hz).

The velocity measurements are conducted with a Constant Temperature Anemometer. CTA anemometer equipment constitutes a measuring chain. It consists of a probe with probe support and cabling, a CTA anemometer (servo bridge loop), a signal conditioner, an analogue to digital converter, a data acquisition system, and a traverse system (see Figure 1).

For these experiments a boundary layer probe with offset prongs and with the sensor perpendicular to the probe axis has been selected see Figure 2. The CTA anemometer has a built-in signal conditioner for high-pass and low-pass filtering. The 3D traverse system is used to control the position of the probe. The traverse system should be rigid to avoid any probe vibrations effecting the velocity measurements. The traversing speed could be varied from 1 mm/sec to 10 mm/sec along the tube, with an increment of less than 0.1 mm in radial and axial directions. A National Instrument DAQ card and LabVIEW software has been used for the data acquisition, monitoring and analysis. A CTA anemometer is calibrated before use.

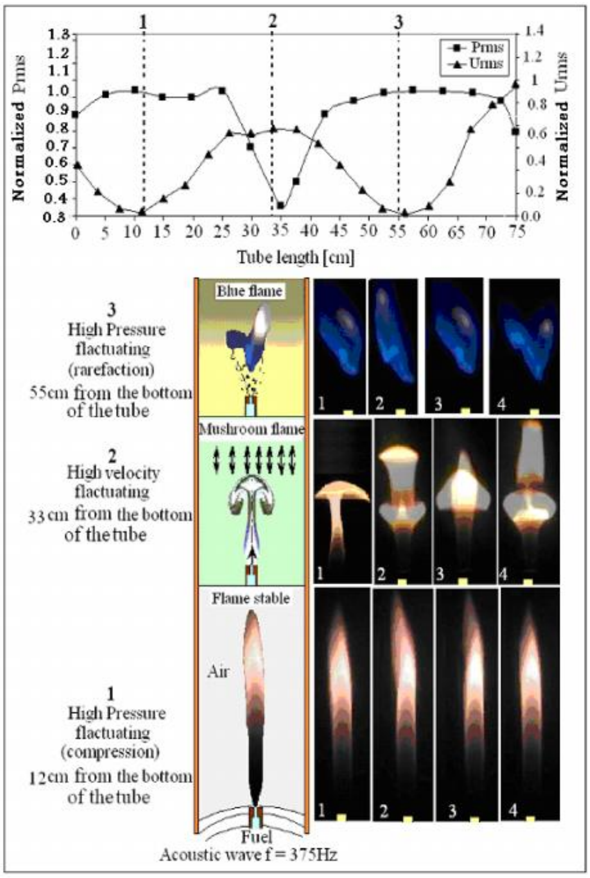
Figure 2: Schematic Diagram of Nozzle and Hot-Wire Probe Arrangement



RESULTS AND DISCUSSION

To understand more about three regimes a full mapping of the velocity field has been obtained for non-reacting flow of the air jets. The air is supplied from a compressed air cylinder at initial flow rate of 183 ml/min, regulated by a control valve through the burner with inner diameter of 1.75 mm (Re number = 148). The burner nozzle position relative to the cylinder could be adjusted automatically by using a computer controlled traverse system as explained in detail in experimental setup. Three regimes have been scanned by using the traverse system in two directions, radial and axial directions. In this experiment the traverse system is used to move the probe with increment of 1mm in radial direction and three levels above the nozzle in axial direction, the size of the scanning area of each regime above the burner is 8 cm in radial direction and three different positions of the nozzle inside the tube (12 cm, 33 cm, and 55 cm from the lower open end of the tube), these size of scanning areas are covered all the lower part of the jet at distance of 5 mm, 15 mm, and 25 mm above the nozzle. The data acquisition sampling rate is 5000 samples per second and the duration of each sampling is two seconds (number of the samples is 10000). A plane acoustic wave (generated by loudspeaker at the centerline downstream of the test section) with excitation frequencies of 375 Hz have been selected to scan the velocity field. The third mode of the rig (375 Hz) has been

Figure 3: Flame Patterns at (1) High Positive Pressure Fluctuating (Compression), (2) High Velocity Fluctuating and (3) High Pressure Fluctuating (Rarefaction, the Pressure is Lower than Atmospheric Pressure) Regions

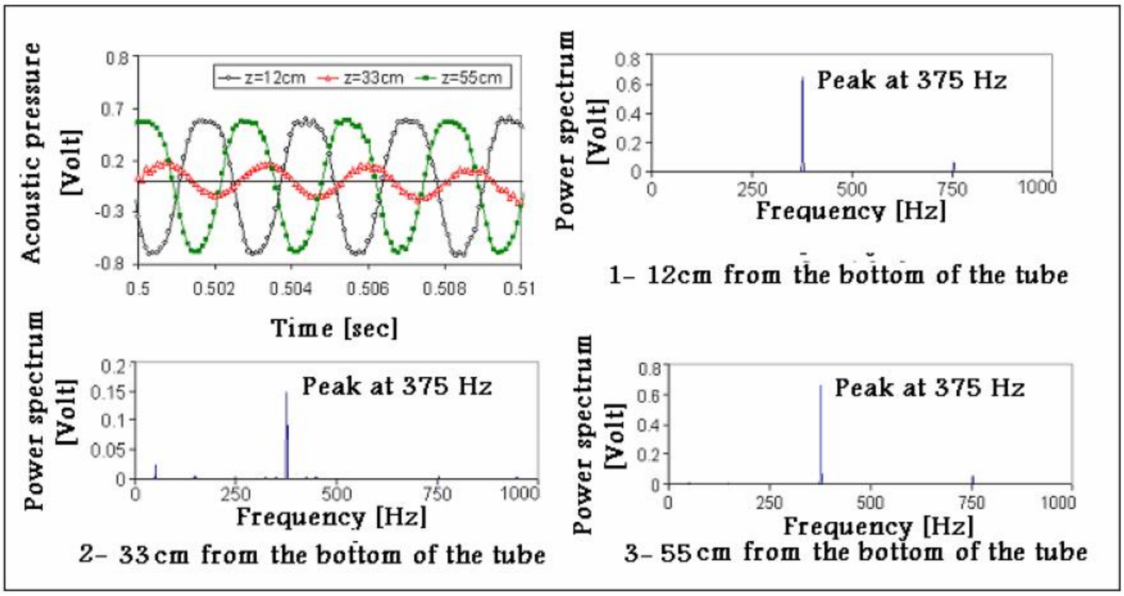


Source: *Farhat et al.* (2005)

selected for detail investigations; since this is the lowest mode which has three regimes of compression, high velocity fluctuating and rarefaction as shown in Figure 3 (Farhat *et al.*, 2005). In the compression regime (1), the velocity fluctuation is at its minimum. It can be seen that the flame shape is almost the same as the case of without excitation. In the high velocity fluctuating regime (2), the pressure fluctuation is the minimum. The flame is yellowish in colour, but the flame shape and dynamics are dramatically different. Mushroom like shape is dominant, Flame necking is also observed, it seems that the velocity fluctuation only induced the bulk movement of the flame but did not affect much on the mixing of the fuel and air. In the rarefaction regime (3), the velocity fluctuation is at its minimum. The pressure fluctuation prms is at its maximum. It can be seen that the flame colour has changed to blue; which indicates that the mixing of fuel and air has changed significantly; it's similar to the rarefaction regime in second mode (220 Hz) (Farhat *et al.*, 2005). Blue flame could mean lean premixed combustion. When the flame colour turns blue, the flame length shortens significantly. The flame shape was observed to be highly three dimensional and flame rotating around the fuel nozzle was seen in some of the testing conditions, and also the flame would lift off and finally blow out if the excitation level increased to certain limit.

Figure 4 shows the acoustic signals at the three regimes and the power spectrum of each signal. It's clear from the figure that the measured signals are very close to the pure sine wave, high amplitudes are observed at the rarefaction and compression regimes, but the acoustic signal in the high velocity fluctuation zone is very low. The peak frequencies are the same for all the three positions and they are equal to the excitation frequency (375 Hz).

Figure 4: Acoustic Signals (Top Left Sub-Figure) and Spectra at Different Position Along the Tube. All the Three Measurements have the Same Data Acquisition Conditions



1- 12cm from the bottom of the tube

2- 33cm from the bottom of the tube

3- 55cm from the bottom of the tube

Figures 5, 7, 9 and 11 show the local mean axial velocity at each location above the nozzle, without and with excitation of 375 Hz. It can be seen that; the mean axial velocity at 5 mm above the fuel nozzle (rarefaction regime) is more than 2.3 m/s. In comparison, the jet-velocity without excitation is only 0.7 m/sec, although the volume flow rate through the fuel nozzle was kept constant in all the cases. These results confirm the observations of Erickson *et al.* (1997) and Mcquay *et al.* (2000). The cases investigated here are cold flow only. Therefore it is not linked to the thermo-acoustic coupling phenomena. The very different RMS velocity and mean axial velocity imply that the acoustic wave not only enhances the mixing of fuel and ambient air

Figure 5: Mean Velocity Without Excitation

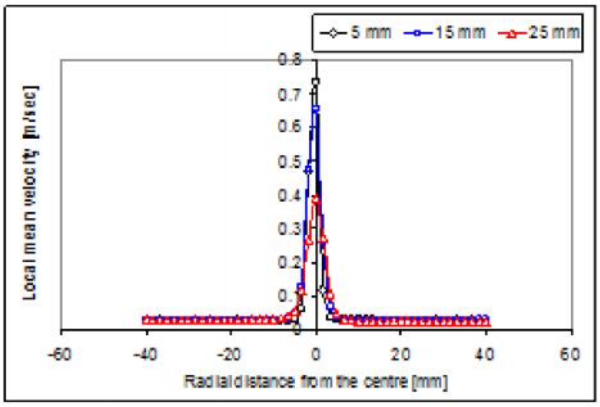


Figure 6: RMS Velocity Without Excitation

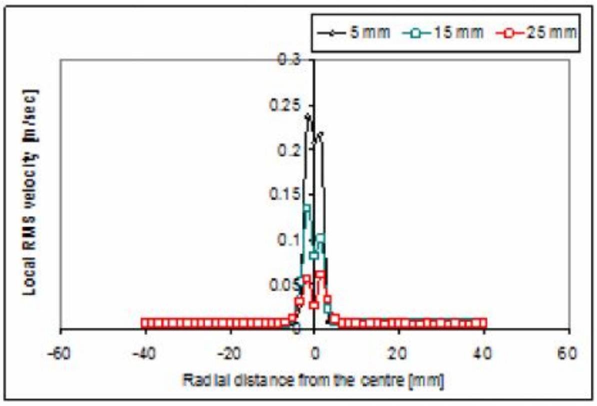


Figure 7: Mean Velocity with Excitation of 375 Hz, z = 12 cm

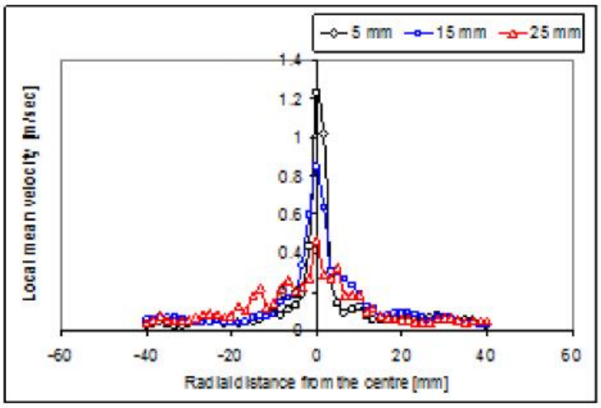


Figure 8: RMS Velocity with Excitation of 375 Hz, z = 12 cm

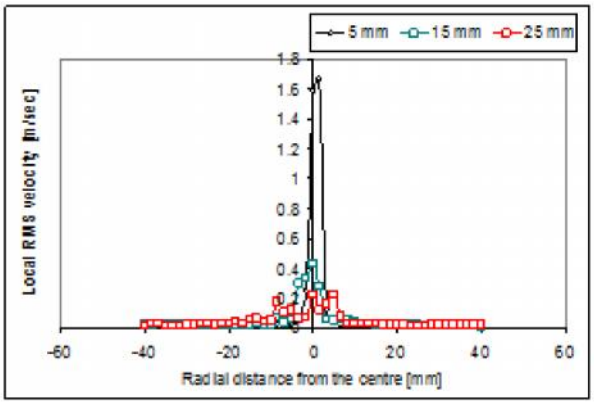


Figure 9: Mean Velocity with Excitation of 375 Hz, z = 33 cm

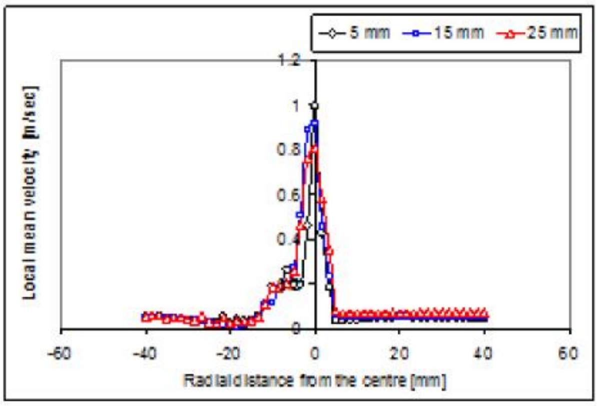


Figure 10: RMS Velocity with Excitation of 375 Hz, z = 33 cm

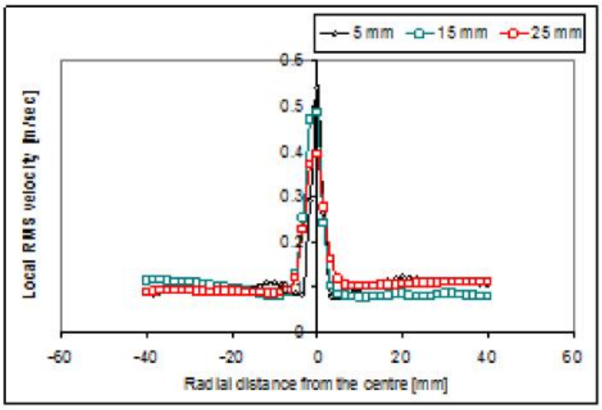
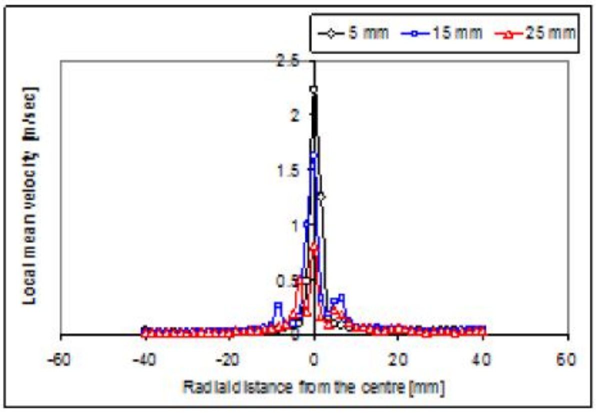


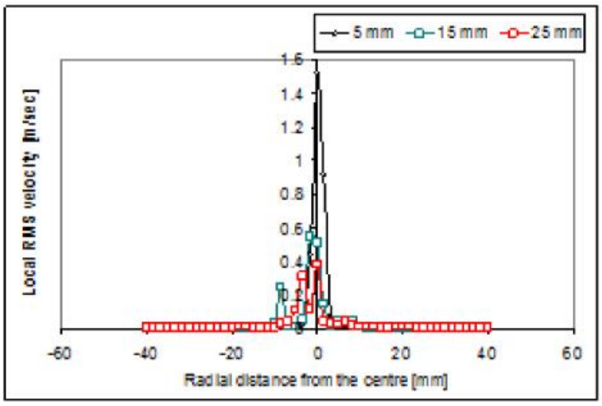
Figure 11: Mean Velocity with Excitation of 375 Hz, z = 55 cm



but also accelerates the jet flow. How the acoustic wave could work in this way is worth further investigation. Note that the volume flow rate out of the nozzle was kept constant.

It is of interest to compare the velocity profiles locations at different heights above the nozzle as a function of nozzle position in the tube. At each regime, three locations above the nozzle have been selected (5, 15 and 25 mm above the nozzle). The RMS velocity profiles of the air jet under various conditions are presented in Figures 6, 8, 10 and 12. The RMS velocity without acoustic excitation shows the typical feature of a simple jet. With excitation, the RMS velocity is generally higher. At higher locations above the fuel nozzle, the peaks move progressively away from the jet centerline. By comparing the profiles of RMS velocity at different regimes and at the same location above the fuel nozzle, it can be seen that the RMS velocity at high velocity fluctuation regime is lower close to the central axis, in comparison with the corresponding profiles in the compression and rarefaction regimes.

Figure 12: RMS Velocity with Excitation of 375 Hz, z = 55 cm



This observation may explain why the flame is blue in the rarefaction zone. The higher RMS velocity close to the nozzle may induce stronger air and fuel mixing before combustion commences. As a result the flame in the rarefaction zone is blue in colour. On the other hand, it seems that the higher RMS velocity away from the jet region does not help the jet mixing, which is observed in the high velocity fluctuation regime.

CONCLUSION

To further develop our understanding of the three acoustic regimes (Farhat *et al.*, 2005), the velocity measurement of a cold jet from the fuel nozzle has been carried out using a CTA. For safety reasons, air has been used as a substitute for propane fuel. The air was supplied from a compressed air cylinder at a volume flow rate of 183 ml/min. The three regimes had been scanned in both the radial and axial directions. The results illustrate some important features of the flow velocity characteristics of a laminar air jet (Re < 150, based on the fuel nozzle diameter) inside a loudspeaker induced standing wave. The third mode of the Rijke tube has been measured experimentally in detail. The results have shown that; the acoustic excitation has a strong effect on the jet flow structure. A very important observation is that the velocity close to the air nozzle is much higher than expected at the rarefaction regime. The results also show that the high velocity fluctuating has not effect on the air/fuel mixing, it can be seen that; the RMS velocity at this regime is lower close to the central axis, in comparison with the corresponding profiles in the compression and rarefaction regimes, the flame only change in shape (Mushroom like shape is dominant) and unsteady flame height.

Comparisons and detailed investigations of the velocity characteristics with and without excitation at different positions above the nozzle exit have been conducted. This phenomenon may take good advantage in improving the combustion process.

REFERENCES

1. Erickson P A, Mcquay M Q, Dubey R K and Sommerfeldt S C (1997), "An Active Control Mechanism to Enhance and Parametrically Study a Multi-Fuel, Rijke Type Combustor", *Noise Control Engineering*, Vol. 45, No. 4, pp. 147-156.
2. Farhat S A and Zhang Y (2007), "Laminar Jet Characteristics in a Loudspeaker Induced Standing Wave", *Journal of Engineering Research*, Vol. 8, pp. 25-37, University of Tripoli.
3. Farhat S A, Kleiner D and Zhang Y (2005), "Jet Diffusion Flame Characteristics in a Loudspeaker Induced Standing Wave", *Combustion and Flame*, Vol. 142, No. 3, pp. 317-323.
4. Lang W, Poinsot T and Candle S (1987), "Active Control of Combustion Instability", *Combustion and Flame*, Vol. 70, pp. 281-289.
5. Mcmanus K R, Poinsot T and Candle S M (1993), "A Review of Active Control of Combustion Instabilities", *Prog. Energy Combst. Inst. Sci.*, Vol. 19, pp. 1-29.
6. Mcquay M Q, Dubey R K and Carvalho J A (2000), "The Effect of Acoustic Mode on Time-Resolved Temperature Measurements in a Rijke-Tube Pulse Combustor", *Fuel*, Vol. 79, pp. 1645-1655.
7. Ng W B, Salem A F and Zhang Y (2003), "Three-Dimensional Visualization of the Diffusion Flame Shapes Under Acoustic Excitation Using Stereoscopic Imaging and Reconstruction Technique", *Visualisation*, Vol. 6, No. 4, pp. 329-336.