IOP Conference Series: Earth and Environmental Science

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To cite this article: M A Ismael *et al* 2013 *IOP Conf. Ser.: Earth Environ. Sci.* **16** 012071

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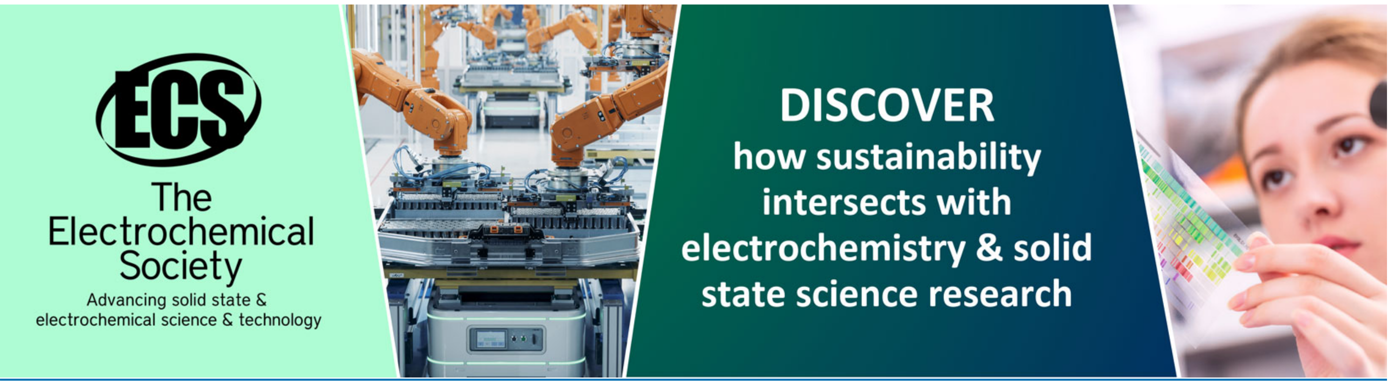

Characteristics of compressed natural gas jet and jet-wall impingement using the Schlieren imaging technique

M. A. Ismael[1], **M. R. Heikal**[2], **M. B. Baharom**[3]
Center for Automotive Reseach and Electric Mobility, Universiti Teknologi PETRONAS, Bander Seri Iskandar, 31750 Tronoh, Perak, Malaysia

E-mail: xmhadosx@yahoo.com

Abstract. An experimental study was performed to investigate the compressed natural gas jet characteristics and jet-wall impingement using the Schlieren imaging technique and image processing. An injector driver was used to drive the natural gas injector and synchronized with camera triggering. A constant-volume optical chamber was designed to facilitate maximum optical access for the study of the jet macroscopic characteristics and jet-wall impingement at different injection pressures and injectors-wall distances. Measurement of the jet tip penetration and cone angle at different conditions are presented in this paper together with temporal presentation of the jet radial travel along the wall.

1. Introduction

With increasing concerns about the energy crises and the harmful effects of conventional fossil fuel emissions such as those from diesel and gasoline fuels, alternative fuels have become attractive to power internal combustion engines. Compressed natural gas (CNG), and other gaseous fuels have been widely used as alternative fuels in internal combustion engines because of their potential to maintain engine performance and reduce the emissions of hydrocarbon [1]. Many researchers have used CNG in different engine types such as spark ignition engines, port injection lean burn engines, dual-fuel-pilot injection engines, and direct injection engines [2]. Significant research has been carried out on these engines, the most promising of these; the direct injection engine requires further development in order to investigate the injection full potential. There are two ways for direct injection natural gas engines: to start the injection at an early stage of the compression stroke and ignite it by a spark ignition system or to start the injection at a late stage of the compression stroke taking advantages of high compression ratio of diesel engines. Still many problems associated with the second method of direct injection compression ignition (DI CI) engines. For example, the characteristics of natural gas is differs considerably from those of the diesel fuel. Furthermore, previous studies focused on liquid fuel spray characteristics and wall impingement [3]. The results of these studies demonstrated the importance injection strategy as it plays an important role in the diesel fuel spray, atomization, droplet size and evaporation which in turn have a significant effect on the mixture formation inside the engine. Although the gas plays an equally important role in gas engines, its effect on the mixture preparation is different than liquid jets. Many studies on high pressures natural gas jet characteristics have been conducted using different techniques [4]. However, high injection pressures of the gas require high performance injectors and associated with high energy consumption in the production of such high pressures. One of the objectives of this study is to examine the effect of low gas injection pressure on the characteristics of the jet, wall impingement and hence mixture formation.

In the present study, the characteristics of a natural-gas jet (12-20 bar) and its wall-impingement into a constant-volume chamber were extensively investigated under different injection pressures and injector-wall distance using the Schlieren system and the obtain images were processed using Matalb software.

2. Experimental methods

2.1. Experimental test rig

Spray research has been performed in a number of test rigs: special research engines, high pressure, high temperature (bombs), flow rigs and constant volume chambers. a constant volume test rig was considered as the best option for fundamental research as it combine good optical access, large observation areas and good control of scavenging before injection. The chamber was 90mm high and 94mm wide was designed and built to allow for optical analysis of both the jets and wall impingement. The bottom plate of the test rig was from aluminum (piston material). Different methods have been used in previous studies for achieving representative temperature conditions in the rig e.g. some used direct heating of the walls (bottom) of the test rig [5]. While others used an electric heater [6]. In this study, a controlled electric heater was used to heat the bottom plate up to 200^{o}C and a thermocouple was inserted in the plate to measure the wall temperature. The variation of the injector-wall distance, a holder of the CNG injector was mounted in the center of test rig top plate. The injector-wall-distance was changed in the range 10-80mm by moving this top plate up and dawn.

2.2. Experimental Procedure

The experimental conditions are listed in Table 1. The natural gas found in Malaysia which consists mainly of mainly methane, ethane and propane was used in this project. Typical composition of this natural gas found in Malaysia is shown in the Table 2. the CNG injection system consisted of a CNG cylinder (the pressure inside the cylinder was up to 200 bar), two pressure regulators (double stage), pressure gage, pressure regulating valve, and a CNG injector (solenoid-valve injector with maximum pressure of 20bar). A National Instrument driver and a power supply (12V) were used to drive the injector with injection duration10 ms. The gas flow meters was calibrated using the positive displacement method described in [7]. The injection duration (solenoid valve opening) against the mass flow rate with different injection pressures are shown in Figure 1. The images were captured using a Schlieren system which consists of a lamp, two concave mirrors, knife edge and a high speed video camera (Phorton, FASTCAM-APX) operated at speed of 4,000 frames per second with effective pixel size of 640x128. A Nikon 60 mm f/2.8D micro-Nikkor lens was used to accompany the camera.

Table 1. Experimental Condition

Fuel	Compressed Natural Gas
Injection pressure	12-20bar
Injection duration	10 ms
Ambient pressure	1 bar
Wall position	80-40 mm
Wall temperature	300-473 k

Table 2. CNG Composition

Items	Volume Fraction
CH_4	96.160
C_2H_6	1.096
C_3H_8	0.136
N_2	0.001
CO_2	2.540

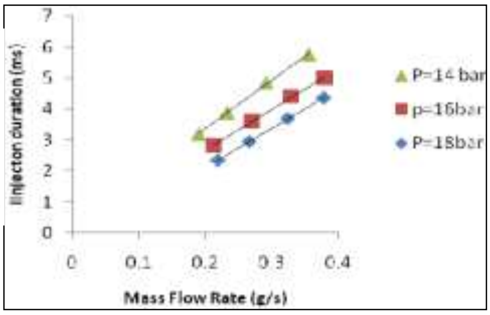

Figure 1. Effect of injection pressure on time-resolved injection rate

2.3. Image Processing

The captured images were processed in order to calculate a number spray characteristic such as the spray penetration, spray angle and impingement foot-print. The spray edges were detected using the canny image detection technique [8]. Several methods were presented in the literature for obtain a spray contour, but no consensus was found on the definition of a spray (cone) angle equivalent spray angle or standard angle. Figure 2 shows how the spray tip and the spray cone angle were defined. The spray angles were measured by drawing horizontal lines at 20 mm from the nozzle tip and measuring the angle between the edges of the spray [9]. The spray tip penetration was measured along the centerline axis of the spray as the distance between the injector nozzle tip and the furthest spray point. To convert pixels measurements to SI metric measurements a calibration image of a graduated scale was taken. Calibration of the gas jet dimensions was also achieved by taking an image of a scale attached to the fuel injection vertical plane. The value of the one pixel was found out to be equivalent to 0.27 mm.

3. Results and Discussion

3.1. Effect of Injection Pressure

Figure 3 shows the Schlieren images of the CNG under ambient condition and injection pressure of 18, 16, and 14 bar at different time intervals from 0.25 to 2.75 ms at interval 0f of 0.25ms. As shown in the spray images, the injection pressure has a large influence on the spray structure as expected. However, for the case of low injection pressure 14 bar, a weak cone shape and lower tip penetration were observed.

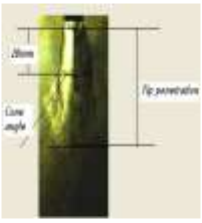

Figure 2. Definitions of jet penetration and jet cone angle

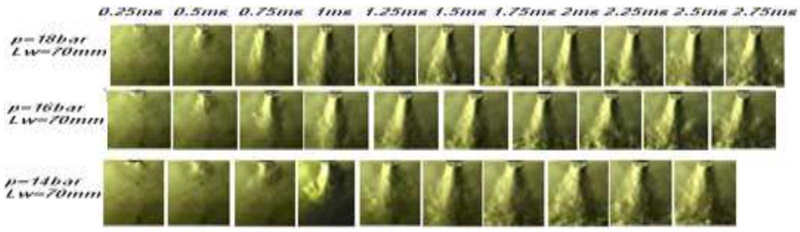

Figure 3. Schlieren images for CNG at 18, 16 and14 bar and injector-wall distance 700mm

With an increase of the injection pressure to 20 bar, a strong vortex in the spray tip plume was found to develop. Figure 5 shows is the spray cone angle measurement against the time after the start of injection. The spray cone angle was measured at a distance of 20mm from the end of injector nozzle was found to increase with increase of injection pressure.

Generally, both the penetration and cone angle (See Figure 4 and 5) have shown an increase with the increase of injection pressure. Figure 6 shows the effect of the wall distance from the injector on the tip penetration. It can be seen that the tip penetration rate decreases with the jet travel as the cone angle and hence the aerodynamic resistance increase and the loss of jet momentum due to air entrainment by the jet. The effect of injection pressure on the development of the impinged jet is shown in Figure 7. The results showed that as the injection pressure increased, both the radial penetration and the height increased due to the effect of the higher momentum of the moment of impingement.

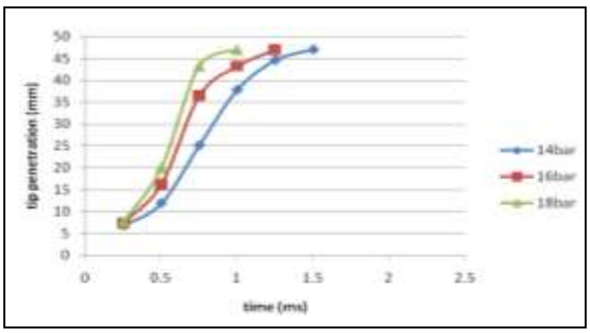

Figure 4. Spray tip penetration of CNG against time after start of injection (P= 18, 16 and 14 bar)

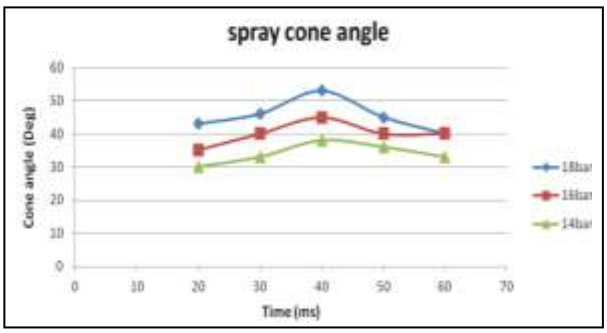

Figure 5.SFpary cone angle of CNG against time after start of injection

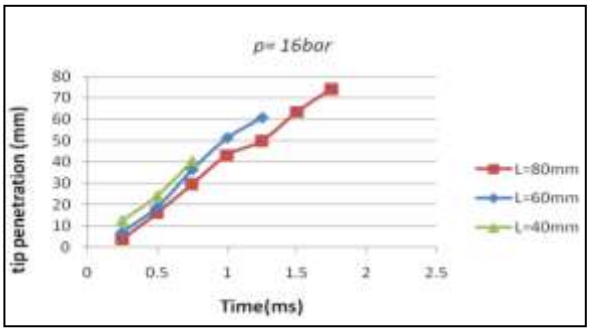

Figure 6. Effect of injector-wall distance on and tip pentaration against time.

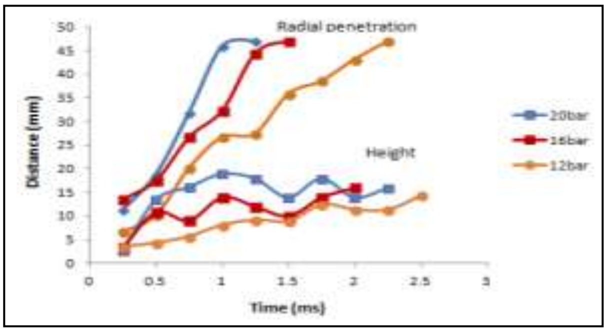

Figure 7. Effect of injection pressure on the radial penetration and the height of the jet impinged on the wall.

4. Conclusion

As expected the Schlieren images of natural gas jet showed, the jet structure is largly influnced by the injection pressure. Generally, the tip penetration, cone angle and radial penetration all increased with the increase of the injection pressure. However, the rate of jet penetration decreased with the jet travel as a result of the increase in the cone angle and hence the aerodynamic resistance as well as the loss of jet momentum due to air entrainment. The radial spraed of the impinged jet on the wall was also found to increase with the increase in injection pressure while the hight of the jet plume on the wall was not significantly affected.

Refferences

[1] S. H. Schneider the Greenhouse Effect : Science and Policy 1989 *Science* **243** 771 - 781

[2] Semin, Rosli A. B. A Technical Review of Compressed Natural Gas as an Alternative Fuel for Internal Combustion Engines 2008 *American J. of Engineering and Applied Since* **1** 302 - 311

[3] Kennaird D., Crua C., Lacoste J., M. R. Heikal, M. R. Gold, and N. S. Jackson In-Cylinder Penetration and Break-Up of Diesel Sprays Using a Common-Rail Injection System 2002 *SAE Technical Paper* **1** 1626

[4] T. Senoo, M. Sasaki, and M. Shioji, Spark-Ignition Stability of Natural-Gas Jets with Impinggement on Cavity Wall 2010 *FISITA World Automotive Congress*

[5] Y. S. Shim, G. M. Choi, and D. J. Kim Numerical Modeling of Hollow-Cone Fuel Atomization, Vaporization and Wall Impingement Processes under High Ambient Temperatures 2008 *International Journal of Automotive Technology* **9** 267-275

[6] M. Mbarawa, B. Edward, and R. Thomas Experiments and Modelling of Natural Gas Combustion Ignited by a Pilot Diesel Fuel Spray 2001 *International Journal of Therma Sciences* **40** 927 - 936

[7] C. Pinho, "The Positive Displacement Method for Calibration of Gas Flow Meters. The Influence Of Gas Compressibility 2012 *Applied Thermal Engineering* **41** 111-115

[8] J. Canny A Computational Approach to Edge Detection 1986 *IEEE Transactions on Pattern Analysis and Machine Intelligence* **8** 679-98

[9] Chengli, Zhang Application Research on Digital Image Technology in the Measurement of Nozzle Spray Cone Angle 2011 IEEE *Instrumentation and Measurement Technology Conference* 1-5