JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

SPRAY ANGLE OF PORT FUEL INJECTOR AT DIFFERENT PRESSURES FOR GASOLINE-ETHANOL BLENDS

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Abstract: This work reports the Spray angle of gasoline-ethanol blend at varying pressures for an 10-hole Port Fuel Injector. At 1 bar and 2 bar injection pressures, the spray angle is measured using Digital Image Processing Technique. Researched here are the spray behaviour of gasoline-ethanol blend with 1:1 ratio. The injector's necessary square pulse is produced using an Arduino UNO micro controller. Photos of the spray are taken using a fast shutter speed camera and then analysed in MATLAB to determine spray angle. Canon 5D is the camera model utilized. Spray angles and penetration depths improved as pressures rose. Even though there is a large gap between the viscosities of gasoline and Ethanol. The spray characters look the same at divergent pressures. For a given surface tension this goes against the usual expectation that spray angles would decrease with increasing viscosity. Spray angle is found to be 12.1 and 15.2 degrees for gasoline and 12.1, 15.3 degrees for 1:1 ratio of Gasoline-Ethanol blend at 1 bar and 2 bar pressures.

IndexTerms - **Gasoline-Ethanol blends, Port Fuel Injector, Injection Pressure, Digital Image Processing, Spray Angle.**

I. Introduction

Humans need stable energy sources in order to live their basic lives. The majority of the world's energy needs are met by non-renewable fossil fuels such crude oil, natural gas, coal, and their derivatives. About 90% or more of the world's energy requirement for transportation is met by crude oil-based petroleum products like gasoline and diesel, among others. In many facets of civilization, such as in agriculture, manufacturing, transportation, and many other fields as well, fossil fuels are widely employed. Energy has thus evolved over the previous several centuries into a "essential commodity," and any disruption in its delivery or production has had a significant impact on everyone's way of living. A nation's ability to function depends on having enough energy to meet everyone's demands. Since roughly 250 years ago, heat engines, particularly internal combustion engines, have helped humanity transform the energy found in fossil fuels into mechanical power. The recent increase in oil prices has placed an excessive burden on the government and the populace because the price of oil directly influences the cost of all vital items available on the market. India, like many other developing nations, is going through a serious energy crisis as a result of the enormous gap between the demand for and supply of conventional fuel sources. Because India spends hundreds of crores annually buying oil from nations that own and control substantial oil reserves, the Indian economy suffers.

It is unavoidable to effectively use the depleting non-renewable fossil fuels with fine combustion in IC engines to accomplish more efficiency. To achieve this the world is leaning towards using Port Feel Injector replacing Carburetors. A. Madan Modan et. al reported the Spray characterization of gasoline-ethanol blends from a multi-hole port fuel injector at different pressures. Observed that due to the interaction of fuel jets from each nozzle, there have a steep decrease in droplets size which contributes to fine atomization for better combustion [1]. There have always been researches to find a way to aid fossil fuels to use in IC Engines to decrease fossil fuels usage. [2,3].

Since it may be made from non-renewable sources, ethanol is a hopeful alternative fuel. Since ethanol is less likely to knock than gasoline, it could be used in IC engines with high compression ratios. This might compensate for the food's lower calorie content and enable improved performance. [4]. Studies have also linked this increase in efficiency to lower emissions of carbon monoxide and unburned hydrocarbons. Because it is less likely to knock than gasoline, ethanol can be burnt in engines with higher compression ratios. This could offset the lower calorific value and increase efficiency. [5]. Because ethanol has a higher octane rating than gasoline, it blends better. Gasoline must meet minimum octane number requirements to avoid engine knocking and maintain driveability. To get the normal 87 octane, lower-octane numbered gasoline is combined with 10% ethanol. Regardless of whether it is produced from starch- or sugar-based feedstocks, such as corn grain (as it primarily is in the United States), sugar cane (as it primarily is in Brazil), or from cellulosic feedstocks (such as wood chips or crop residues) ethanol has the same chemical formula.

Because of its great performance advantages, port fuel injectors have replaced carburetors in the world of IC engines. The dispensing nozzle for fuel injection is the fuel injector. The Electronic Control Unit directs the injection of liquid fuel (ECU). Until the ECU decides to inject gasoline into the Port, the fuel injectors' valves are closed. The injectors typically have two pins. The solenoid of the injector will receive current from the electricity delivered in square pulses. The valve opens when the magnet on top of the plunger is drawn to the magnetic field of the solenoid. As a result, the gasoline is pumped into the port at a fast rate of speed. Once the Power supply ends, automatically electromagnetism get ends and thus the valve closes. Fuel injector and its parts are mentioned in the Figure.1.

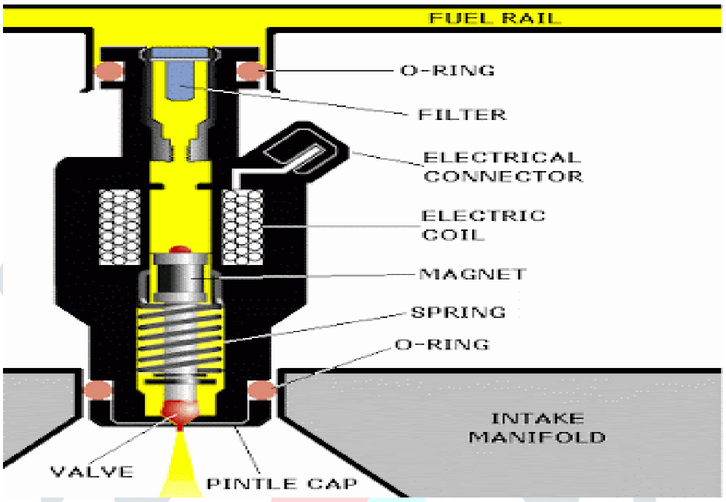

Figure.1 Electronic fuel injector

The quantity of holes and their widths have a significant impact on the amount of fuel sprayed as well as the degree of atomization. The interaction of the jets emitted from each injector hole is evidence that multihole injectors carried out fine atomization. By precisely selecting the appropriate number of injector holes, the correct droplet sizes and spray angles can be achieved. [6]. When fuel and air are combined, fuel pressure has a direct impact on how the fuel atomizes. Higher pressure results in faster fuel exiting the injector's nozzle, which interacts with the jets. When fuel departs the orifice at a rapid rate due to high injection pressure, the fluid flow separates into ligaments and then into droplets. The spray figure demonstrates how the spray takes the shape of a cone at a particular angle and how the liquid droplets occupy a sizeable fraction of the chamber's gas volume. It is thought that higher ambient pressure will result in greater vaporisation because numerous studies have demonstrated that fuel injection pressure has a stronger impact on the angle of spray. Angle of the spray may also be affected by other factors, such as the concentration of ethanol in gasoline [7].

In this paper we have characterized the spray of the injector with 10 holes arranged in the circular pattern as shown in the Figure.2.

Figure.2. 10 hole fuel injector

The injection spray time plays a critical role in efficiency of IC engine. The timing of the injection can be manipulated with the Arduino microcontroller with processor ATmega328P. The board is equipped with sets of digital and analog input/output pins that may be interfaced to various expansion boards and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), through a type B USB cable. It can be powered with the USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts. The fixed interval power supply cab be achieved with PWM generated by Arduino board. Pulse width modulation (PWM) or pulse duration modulation is a method where we vary the width of a square pulse to control the power supplied to any of the connected device. Green lines in the figure below represent a regular time period. This period or duration is the inverse of the PWM frequency. In other words, with Arduino's PWM frequency at about 500Hz, the green lines would be measured upto 2 milliseconds each. The different duty cycles of PWM are shown in Figure.3.

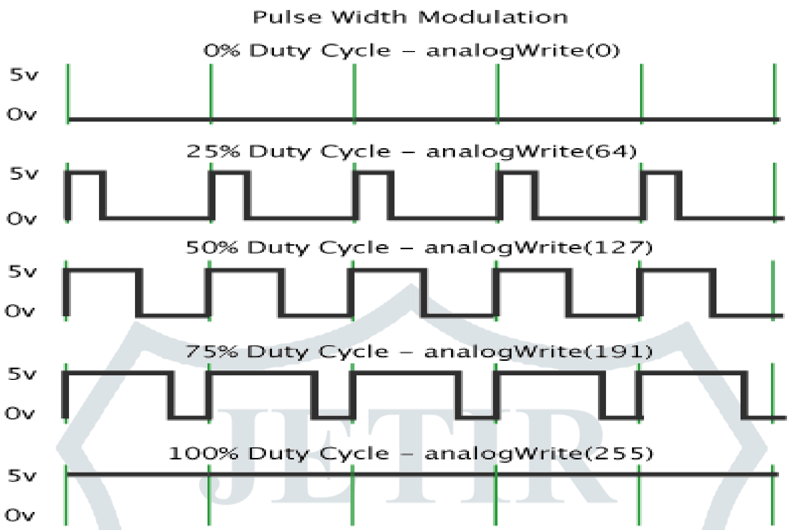

Figure.3. Pulse Width Modulation duty cycles

II. LITERATURE SURVEY

Zhao et al. [8] acquired backlit images and PDA measurements on baseline and pressure modulated PFI injectors and obtained SMD, droplet distribution and velocity data. For the baseline case, the SMD was found to be between 160 and 190 micron for different types of injectors. The velocity and distribution of the injections increased with increase in the Pressures.

Kato et al. [9] at Yamaha motor company in Japan, By simulating the engine studied the impact of PFI parameters on combustion stability through computational fluid dynamics (CFD) and correlating the results with an experimentally determined coefficient of variance (COV) in net mean effective pressure. They reported that measured SMDs in the range of 120 micron and spray angles of around 5 degrees for injectors operating at 3 bar pressure. The Spray angle increased with increase in pressure. This is good sign of spray distribution in the control volume of the engine. Thus fine Combustion increases the efficiency of the engine [10].

At low pressures, Injectors were found to inject similar fuel quantities, At higher pressures whereas the 4-hole injector was found to inject a higher mass of fuel. It is observed, from shadowgraph images of the sprays, the presence of non-spherical droplets and also large ligaments at several locations. The streams of fuel injected through the nozzle orifices were also found to interact with each other jets such that they cannot be admitted as separate streams away from the injector. The spray tip penetrations and spray angles were determined as functions of pressure. At higher pressures the spray was found to be wider and at a given time the tip penetration after the start of injection was found to be higher. With shadowgraphy technique droplet sizing was performed and the variation of droplet sizes with pressure changes and time was determined. At 500 kPa the SMDs were found to be in the range of 120 micron and 100 micron at 800 kPa for 2-hole injector, and around 90 micron at 500 kPa and 70 micron at 800 kPa for the 4-hole injector. Thus, based on the SMD of sprays the 4-hole injector is a better choice [11].

Jeonghyun Park et al [12] characterized the PFI sprays at high pressures using MATLAB. Raw spray images acquired through macroscopic method spray visualization experiments were post-processed for quantitative data. The image post-processing process was performed using a program based on MATLAB with the mentioned sequence: Background removal, black and white, binarization, and noise reduction. Using the post-processed images, it is able to distinguish between areas where the sprays were present and those that were not, and to quantify different spray characteristics. Because the PFI system operated at lower injection pressures than the direct injection, the droplets of the spray were relatively sizeable and clearly distinguishable from the background. As a result, the image processing threshold used in this study was set at a fixed value. Digital Image Processing Technique is as effective as PDA, PDIA and Laser backlit Imaging Techniques. In this study Images captured are processed in MATLAB for characterizing the spray.

Diverse methods have been developed so far for identifying the correct intensity threshold value that can identify all the picture pixels relating to the spray, whether it is in liquid or the vapor phase, in the case of automobile sprays, both diesel and GDI. Because of the fleeting nature of sprays and the wide variety of experimental settings, it is well knowledge in this area how difficult it is to discover the "best" segmentation approach. For instance, if the image's intensity histogram conforms to the conditions of correct bimodal distribution, the well-known Otsu's technique [13].

The spray was thoroughly studied using cutting-edge techniques, with all important parameters such as spray angle, spray tip penetration, mass injected, droplet velocities, droplet distributions, and SMDs are measured. The spray was observed to be pencil-like with a low spread, and several centimeters of breakup lengths. 8 mg of mass of fuel was injected per 8 ms pulse. Spray droplet size distributions were determined along the axis of the spray at 2 ms intervals in time, and found to be in the range of 200-250 micron for the 2-hole injector and 120 micron for the 4-hole injector at three different locations. Thus, a large decrease in the SMD was observed when going from the two-hole to the four-hole injector. The SMD was discovered to be initially more, followed by a near constant value and then drops. The injection velocity was found to be around 21 m/s and the spray cone angle was found to be around 6° for 2 and 4 hole injectors [14].

III. EXPERIMENTAL SETUP

In this section, we provide a summary of the experimental setup that was used to carry out the studies described in the paper shown in the Figure4.

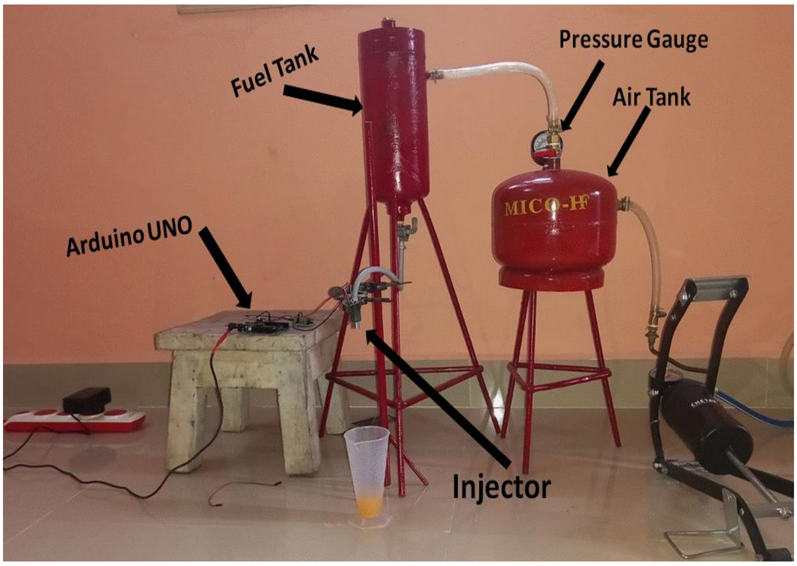

Figure.4. Experimental Setup

3.1 COMPONENTS

Air tank
Fuel tank
Multi-hole Injector
Electric circuit
Canon 5d Camera
Software used for Image Analysis

With the aid of a compressor, the air is pumped into the storage tank. A pressure gauge is mounted on the tank so that you can keep track on the air pressure. The Pressures maintained for this study are I bar, 2 bar and 3 bar.

Fuel Tank is where the various fuel mixtures are kept before being pumped into the injector. Fuel is pressurized to the required level by pumping compressed air into the fuel tank from the air tank. Fuel gets injected once the solenoid is magnetised with the pressure applied. The fuel used in the experiment is gasoline-ethanol mixtures with 1:1 concentrations.

Multi hole injector shown in figure(2) is used for characterizing spray of gasoline-ethanol blends. The pressurized fuel is fed into the injector from fuel tank. Power supply of 5v and with desired pulses are provided to the injector from an electric circuit built with Arduino microcontroller.

Alternating pulses of 500 per minute is generated using Arduino microcontroller. A Python readable code blocks are loaded to the board for PWM generation through Arduino IDE Software. The pulses generated are square pulses.

Enormously fast injection images are captured with 150mm Lens used in Canon 5d camera. Images of the spray are captured with high shutter speeds. The device has a 12.3-megapixel feature. Cam's lens has a wide f/1.8-f/3.4 range with a maximum exposure of 1/10000.

Images are read in Python code and converted to grayscale images at desired threshold to calculate the Spray angles in MATLAB.

3.2 METHODOLOGY

Spray Images captured are processed in MATLAB. Images should be taken through many steps to calculate the spray angles and are as detailed step wise below.

Read the image in python code.

Convert image into grayscale image.

Convert grayscale image to the black-and-white image after setting desired threshold.

Use canny edge detection to detect edges.

Use convex hull command to obtain a closing curve on the detected edges.

Find out 4 corners of trapezoidal shape of nozzle.

Calculate slope of left and right side lines using the corner points.

Calculate angle of each line using slope angle relation.

Subtract both the slope angles to get the included angle of the nozzle.

IV. RESULTS

4.1 100% GASOLINE

4.1.1 1 BAR

The spray angle is 12.1 degrees for 100% gasoline is shown in Figure.5. The spray is measured at origin of the spray.

Figure.5. 12.1^{O}

4.1.2 2 BAR

The spray angle is 15.1 degrees for 100% gasoline is shown in Figure.6. The spray is measured at origin of the spray.

Figure.6. 15.1^{O}

4.2 50% Gasoline - 50% Ethanol

4.2.1 1 bar

The spray angle is 12.1 degrees for gasoline-ethanol blend is shown in Figure.7.

Figure.7. 12.1^{O}

4.2.2 2 bar

The spray angle is 15.2 degrees for gasoline-ethanol blend is shown in Figure.8.

Figure.8. 15.1^{O}

Figure.9. shows the spray angles of Port fuel injector at different Pressures with different proportions of Gasoline-Ethanol blends. The spray angle is same for ethanol blend irrespective of the difference in viscosity. The chart below represents fuel proportions on x-axis and Pressure on y-axis in degrees and legends says the pressures considered in bars.

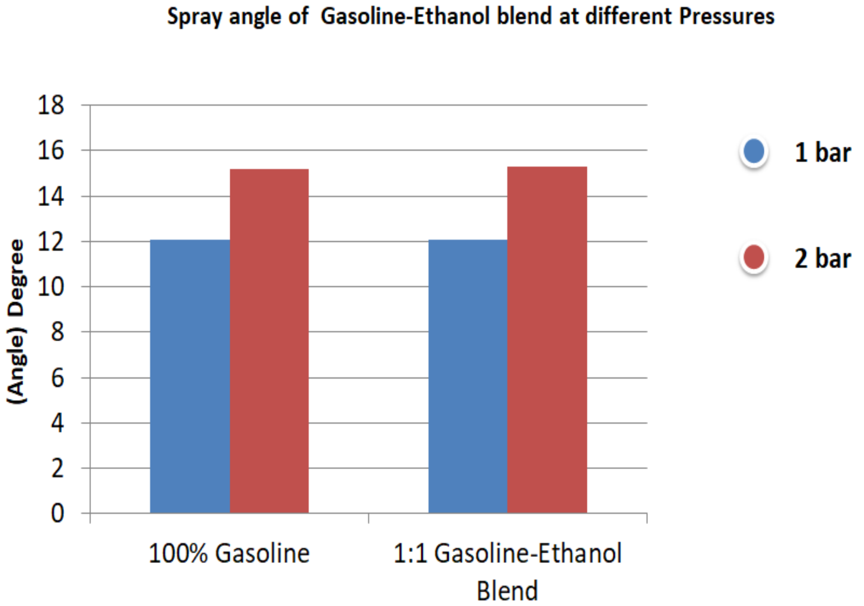

Figure.9. Spray angle of gasoline and blend of ethanol at different pressure.

V. CONCLUSION

Spray Angle for gasoline and 1:1 gasoline-ethanol blends from a 10-hole injector are reported. Data has been generated for gasoline and a gasoline-ethanol blend. The spray angle is found to be 12.1^{O}, 15.2^{O} at 1 bar pressure and 12.1^{O}, 15.3^{O} at 2 bar pressures. The spray angles are higher than the expected due to the interactivity of multiple jets of fuel. This is opposite to the expected trend of decreasing spray angles with increasing viscosity for a relatively persistent surface tension values. At 1 bar pressure ligaments can be seen at the origin of spray. Whereas at 2 bar pressure no sign of ligaments as the spray breakage was happening at very origin of the spray. So, higher pressures can result in improved fuel atomization. The fundamental reason that the viscosity character does not prominently develop is thought to be the injector design, in which 10 streams of liquid emerge as jets from the nozzle practically parallel to the axis and interact with each other to produce a certain form of breakage. This study's adaptation of this form of atomization for other high viscosity fuel injection applications using ethanol blends has several intriguing implications.

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