Spray Characterization of Port Fuel Injector at different Injection Pressures for Gasoline-Ethanol blends

[1] R AnandKishore, [2] Dr C Sreedhar, [3] S Sunil Kumar Reddy, [4] F Anand Raju, [5] P Jaya Prakash
[1] PG Student, [2] Professor , [3] Head & Professor , [4] Professor , [5] Assistant Professor
Department of Mechanical Engineering, Siddharth Institute of Engineering & Technology, Puttur-517583, A.P, INDIA

Corresponding author email address: anandkishore197@gmail.com

Abstract : Using an 8-hole Port Fuel Injector, this study describes the performance of gasoline-ethanol mix sprays at varying pressures. The perforations are positioned radially. At 1 bar, 2 bar, and 3 bar injection pressures, the spray characteristics are measured using Digital Image Processing Technique. Researched here are the spray behaviours of pure gasoline and gasoline-ethanol mixtures with 3:1 and 1:1 concentrations of Ethanol. The injector's necessary Pulse is produced using an Arduino UNO. Photos of the spray are taken using a fast shutter speed camera and then analyzed in MATLAB to determine its properties. Canon 5D Mark II 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 various pressures. This goes against the usual expectation that spray angles would decrease with increasing viscosity for a given surface tension.

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

I. INTRODUCTION

Humanity's basic life depends on access to reliable energy sources. Genuine, reasonably priced, and environmentally friendly energy sources are critical to a nation's economic development and people's quality of life generally. Nonrenewable fossil fuels, including crude oil, natural gas, coal, and other derivatives, provide a significant portion of the world's energy needs. Crude oil-based petroleum products, such as gasoline, diesel, etc., are responsible for meeting an estimated 90 percent or more of the transportation sector's global energy demand. Fossil fuels are used extensively in many areas of civilization, including agriculture, industry, power production, and transportation. As a result, energy has become an "essential commodity" over the last several centuries, and any disruptions in its production and delivery have had a profound impact on the standard of living of every person on Earth. Having enough energy to fulfill everyone's needs is crucial to a country's development as a whole. Heat engines especially Internal Combustion Engines have been assisting humanity for about two hundred and fifty years in converting the energy contained in fossil fuels into mechanical power. Since the price of oil directly affects the cost of all essential goods on the market, the recent spike in oil prices has imposed an undue burden on the government and on the people. India, like many other developing countries, is experiencing a severe energy crisis due to the vast imbalance between the demand for and availability of traditional fuel supplies. The Indian economy suffers because every year, the country spends hundreds of crores importing oil from other countries that possess and control significant oil resources.

It is inevitable 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. Observed due to the interaction of fuel jets from each nozzle, there have a steep decrease in droplets size which contributes to fine atomization for fine combustion [1]. There have always been researches to find a way to aid fossil fuels to use in IC Engines [2, 3].

Ethanol is a promising alternative fuel since it can be manufactured from non-renewable sources. While ethanol has gained popularity as a fuel additive, a 10% ethanol and 90% gasoline (E10) blend is not a suitable hardware substitute for spark-ignition engines. It's also common to find flex-fuel engines, which can function on a fuel combination of 85% ethanol and 15% gasoline (E85). Ethanol may be utilized in engines with a higher compression ratio since it is more resistant to knock than gasoline. It's possible that this might make up for the food's lower calorie count, allowing for increased performance [4]. Some studies also relate this efficiency improvement to reduced emissions of unburned hydrocarbons and carbon monoxide. Ethanol has higher resistance to knock than that of gasoline and hence can be burned in higher compression ratio engines. This might compensate lower calorific value and result in higher efficiency [5, 6]. Ethanol has a higher octane number than gasoline, providing premium blending properties. Minimum octane number requirements for gasoline prevent engine knocking and ensure drivability. Lower-octane gasoline is blended with 10% ethanol to attain the standard 87 octane. Ethanol has the same chemical formula 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).

With rising pollution levels, emission standards are becoming increasingly strict. Emission norms are forcing automobiles to provide accurate fuelling. Hence carburetor systems are being replaced with precise fuel injection systems as Port fuel Injector. In gasoline port fuel injection, the air-fuel mixture is prepared in the intake manifold and fed to the cylinder for combustion. Fuel injectors are essential for the mixture generation because they prepare the fuel for combustion in the engine. The fuel injectors counted on the fuel rail continuously dose the required fuel quantity into the intake manifold according to the spray pattern and with highest precision. Engine need not be tuned from time to time as in the case of a carbureted engine fuel supply system. The vapor lock problem does not occur, as EFI system uses an electric fuel feed pump. The pump maintains sufficient pressure in the fuel line to avoid vapor lock in hot weather. With Port fuel injector improved atomization can be achieved as fuel is forced into the intake manifold under pressure that helps break fuel droplets into a fine mist.

The fuel injector acts as the fuel dispensing nozzle. It injects liquid fuel controlled by the Electronic Control Unit (ECU). Fuel injector’s valves remain closed until the ECU decides to send fuel into the Port. Usually, the injectors have two pins. The power supplied in pulses will provide current to the injector’s solenoid. The magnet on top of the plunger is attracted to the solenoids magnetic field, opening the valve. Hence the fuel is injected with high velocity into the port. Once the Power supply ends, automatically cuts the electromagnetism and thus the valve closes.

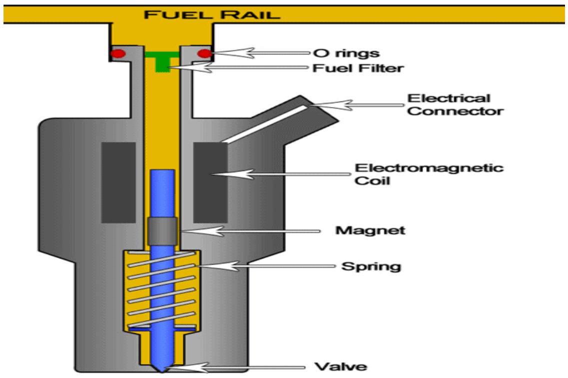

Fig.1. Electronic fuel injector

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 multi-hole injectors carried out fine atomization. By precisely selecting the appropriate number of injector holes, the correct droplet sizes and spray angles can be achieved. [7]. 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 vaporization 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 [8].

In this paper we have characterized the spray of the injector with 8 holes arranged in the circular pattern as shown in the figure2.

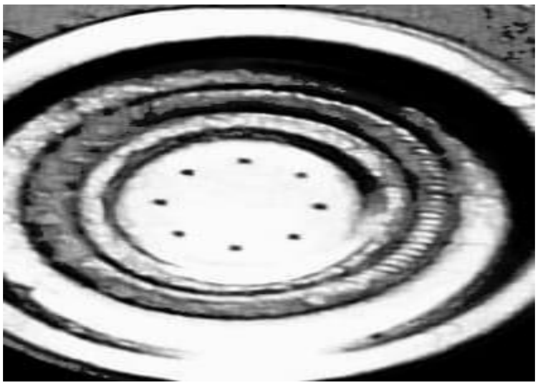

Fig.2. 8 hole fuel injector

The characteristics of a spray can be measured with Digital Image Processing (DIP) technique. Digital Image Processing has been applying many fields with technological advances, such as Geographical Information Technologies, Space Sciences, Military Applications, Security etc; MATLAB contains Image Processing toolbox which requires scripts. The Images captured with high shutter speed Cameras is processed in MATLAB to find the spray angles.

The injection spray time plays a crucial role in efficiency of the engine. The timing of the injection can be manipulated with the Arduino UNO microcontroller. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) 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), via a type B USB cable. It can be powered by 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 technique where we vary the width of a square pulse to control the power supplied to any connected device. Using this technique, we can simulate an analog output using a digital output. In the graphic below, the green lines represent a regular time period. This duration or period is the inverse of the PWM frequency. In other words, with Arduino's PWM frequency at about 500Hz, the green lines would measure 2 milliseconds each. The different duty cycles of PWM are shown in figure 3.

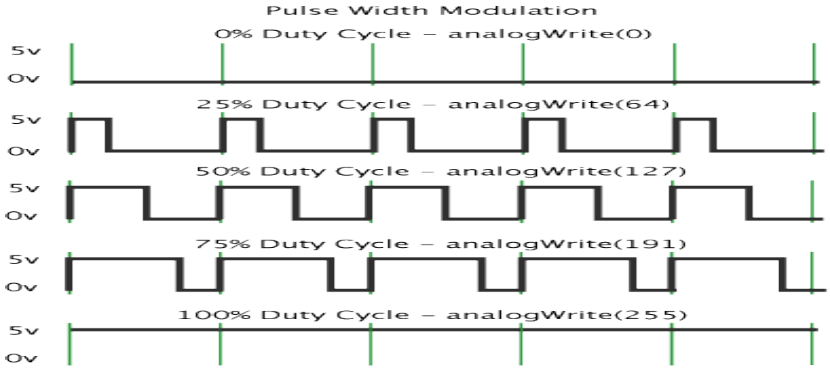

Fig.3. Pulse width modulation duty cycles

II. LITERATURE SURVEY

Kim et al. [9] studied the measurement of spray angles of PFI injectors by three different methods: digital image processing, shadowgraphy, and spray patternation. They observed that the International Journal of Spray and Combustion Dynamics 2 definition and measurement of the spray angle is difficult due to the curved boundaries of the spray caused by air interaction. The spray angle was found to vary both with time and with axial distance from the injector tip, and with the technique used. The Digital Image Processing technique been the most cost effective among others. Zhao et al. [10] obtained backlit images and PDA measurements on baseline and pressure modulated PFI injectors, and obtained SMD and droplet distribution and velocity data. For the baseline case, the SMD was found to be between 160 and 190 micron for different injectors. The velocity of the injections increased with increase in the Pressures.

Ishii et al. [11] reported SMDs for an air assisted M-jet low-pressure injector to be 120 micron without air assist, and 10 micron with air assist, though details about the location of the measurements are not available. The air assistance decreased the Sauter mean diameter of the droplets which implies the fine atomization compared without air assistance. Thus concluded that Port Fuel Injection can have more efficiency in real world. Kato et al. [12] at Yamaha motor company, Japan, studied the influence of PFI parameters on combustion stability by simulating the engine through computational fluid dynamics, and correlating the results with an experimentally determined coefficient of variance (COV) in the net mean effective pressure. They reported measured spray angles of around 5 degrees and SMDs in the range of 120 micron 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 [13].

A comprehensive study of the spray has been done with state-of-the-art techniques, with all the important parameters such as the spray angle, spray tip penetration, mass injected, droplet velocities, droplet distributions and SMDs, being measured. The spray was observed to be pencil-like with a low spread, and breakup lengths of several centimeters. The mass of fuel injected was found to be 12 mg per 8 ms pulse. Spray droplet size distributions were determined at three different locations 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 around 120 micron for the 4-hole injector. Thus, a large reduction in the SMD was observed when going from the two-hole to the four-hole injector. At the axial locations, the SMD was found to be initially high, followed by a near constant value after which it drops. The spray half cone angle was found to be around 6° for 2 and 4 hole injectors, and the injection velocity was found to be around 21 m/s [14].

Injectors were found to inject similar quantities at low pressures, while the 4-hole injector was found to inject a higher mass of fuel at higher pressures. From shadowgraph images of the sprays, the presence of large ligaments and also non-spherical droplets at several locations was observed. The streams injected through the nozzle orifices were also found to interact such that they cannot be recognized as separate streams away from the injector. The spray angle and spray tip penetrations were determined as functions of pressure: the spray was found to be wider at higher pressures, and the tip penetration at a given time after the start of injection was found to be higher at higher pressures. Droplet sizing by shadowgraphy was performed and the variation of droplet sizes with pressure and time was determined. The SMDs were found to be in the range of 120 micron at 500 kPa and 100 micron at 800 kPa for the 2-hole injector, and around 90 micron at 500 kPa and around 70 micron at 800 kPa for the 4-hole injector. Hence, based on the SMD, the 4-hole injector seems to be a better choice [15].

Jeonghyun Park et al [16] characterized the PFI sprays at high pressures using MATLAB. Raw spray images obtained through macroscopic spray visualization experiments were post-processed for quantitative data. The image post-processing process was performed using a program based on MATLAB with the following sequence: Background removal, black and white, binarization, and noise reduction. Using the post-processed image, it was possible to distinguish between areas where sprays were present and those that were not, and to quantify various spray characteristics. Because the PFI system operated at lower injection pressures than the injector with direct injection, the droplets of the spray were relatively large and clearly distinguishable from the background. Therefore, the threshold used for image processing in this study was used as a fixed value. Digital Image Processing Technique also is effective as PDA, PDIA and

Laser backlit Imaging Techniques.

Finding the spray angle requires the use of digital image processing. Black and white photography only allows for the measurement of one variable: light intensity. More information may be gleaned from a picture, however, if the correlation between light-intensity and other characteristics is understood. Such an endeavor necessitates the development of novel methods that have seen little use so far in engine study. In the 1920s [17], when journalists sought a method of transmitting photographs from one location to another via standard telephone lines, the groundwork was laid for the modern field of digital image processing (DIP). The techniques have seen widespread usage in the military, space exploration, and the medical field since the 1960s. In addition, digital image processing has been used in some capacity in engine research since the 1980s. Some of the potential applications of DIP are similar to those of conventional dark-room methods, with the primary distinction being that the outcome may be seen instantly on the monitor. There are a lot of other options that go well beyond what can be done with film cameras. For the purposes of DIP, an image may be seen of as a data matrix that describes some aspect of the picture in minute detail. In this context, the term "pixel" is often used to refer to each individual cell in the matrix. Additionally, in a black-and-white picture, the information contained in each pixel is the fighting intensity, and in a color image, it is the intensity of the main hues (red, green, and blue). Pixel values are often limited to what can be stored in a single Byte on the machine being utilized (or one byte each for red, green and blue for color images). This limits the possible color palette to 16.7 million colors, or just 256 different degrees of gray. It's sufficient for the most conventional applications of pictures since it exceeds the range of human visual acuity. Segmentation, the process of correctly separating the foreground from the background of a spray picture, is a crucial first step in any study of a spray image, regardless of the optical approach used. There are many other segmentation strategies described in the literature, each with their own advantages and disadvantages [18]. Several 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 the 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 [19].

T.N.C Anand et al. reported spray structure, droplet size and velocity measurements for various gasoline-ethanol blends from a 4-hole port fuel injector. Specifically the spray structure and the planar drop size measurements were performed using laser-backlit imaging and PDA technique at injection pressures of 0.25 MPa and 0,65 Mpa. Data has been generated for gasoline, ethanol and gasoline-ethanol blends containing 10%, 20% and 50% ethanol. Despite difference in the viscosity of fuel injected, the droplet sizes and the cone angles are found to be similar. This is against the expected trend of higher drop sizes with increasing viscosity for a relatively constant surface tension value. It is believed that design of injector wherein four streams of liquid emerge from the nozzle almost parallel to the axis, and interact with each other resulting in break could be the main reason for the effect of viscosity not being strongly manifested.

III. EXPERIMENTAL SETUP

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

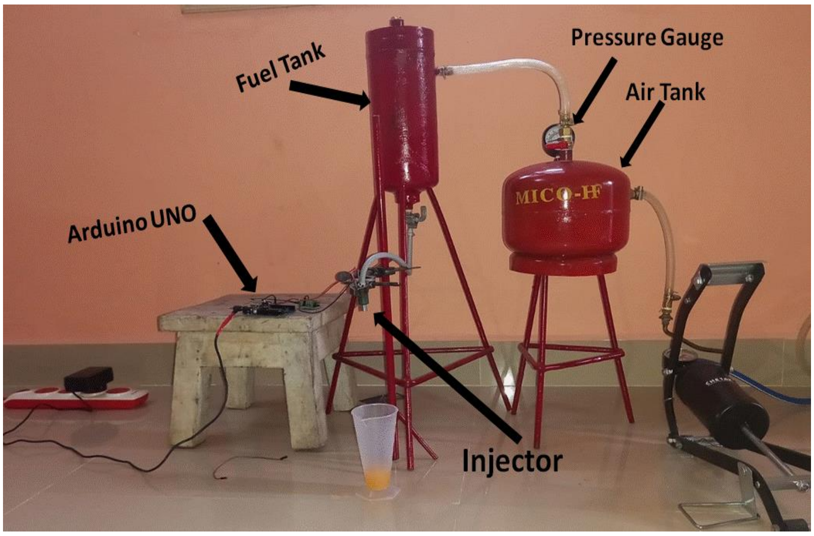

Fig.4. Experimental setup

Components

1. Air tank
2. Fuel tank
3. Multi-hole Injector
4. Electric circuit
5. Canon 5d Camera
6. MATLAB for Image Analysis

1. Air Tank

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.

2. Fuel Tank

This 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. The fuel used in the experiment is pure gasoline and gasoline-ethanol mixtures with 3:1 and 1:1 concentrations of Ethanol.

3. Multi-hole Injector

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 required PWM are provided to the injector from an electric circuit built with Arduino UNO.

4. Electric circuit

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.

5. Canon 5d MARK II Camera

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

6. MATLAB for Image Analysis

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

IV. METHODOLOGY

1. Spray Images captured are processed in MATLAB. Images should be taken many steps to calculate the spray angles and are said below.
2. Read the image in python code.
3. Convert image to grayscale image.
4. Convert grayscale image to black-and-white image after setting desired threshold.
5. Use canny edge detection to detect edges.
6. Use convex hull command to obtain a closing curve on the detected edges.
7. Find out 4 corners of trapezoidal shape of nozzle.
8. Calculate slope of left and right side lines using the corner points.
9. Calculate angle of each line using slope angle relation.
10. Subtract both the slope angles to get the included angle of the nozzle.

V. RESULTS

1 – 100% Gasoline

1.a 1 bar

Fuel injector spray pattern at 1 bar pressure and a cone angle of 10.2 degrees for 100% gasoline is shown in Fig.5.

Fig.5

1.b 2 bar

Fuel injector spray pattern at 2 bar pressure and a cone angle of 14.3 degrees for 100% gasoline is shown in Fig.6.

Fig.6.

1.c 3 bar

Fuel injector spray pattern at 3 bar pressure and a cone angle of 19.1 degrees for 100% gasoline is shown in Fig.7.

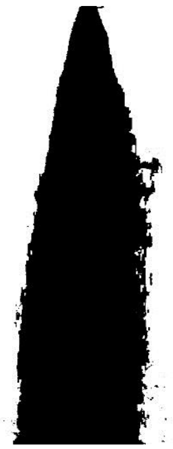

Fig.7.

2 – 75 %Gasoline and 25%Ethanol blend

2.a 1 bar

Fuel injector spray pattern at 1 bar pressure and a cone angle of 10.3 degrees for 75% gasoline and 25% Ethanol blend is shown in Fig.8.

Fig.8.

2.b 2 bar

Fuel injector spray pattern at 2 bar pressure and a cone angle of 14.3 degrees for 75% gasoline and 25% Ethanol blend is shown in Fig.9.

Fig.9.

2.c 3 bar

Fuel injector spray pattern at 3 bar pressure and a cone angle of 19.2 degrees for 75% gasoline and 25% Ethanol blend is shown in Fig.10.

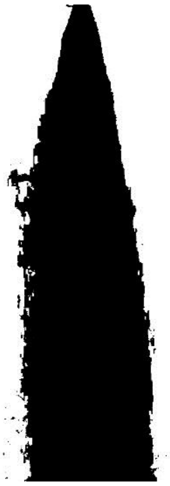

Fig.10.

3 – 50 %Gasoline and 50%Ethanol blend

3.a 1 bar

Fuel injector spray pattern at 1 bar pressure and a cone angle of 10.1 degrees for 50% gasoline and 50% Ethanol blend is shown in Fig.11.

Fig.11.

3.b 2 bar

Fuel injector spray pattern at 2 bar pressure and a cone angle of 14.3 degrees for 50% gasoline and 50% Ethanol blend is shown in Fig.12.

Fig.12.

3.c 3 bar

Fuel injector spray pattern at 3 bar pressure and a cone angle of 19.2 degrees for 50% gasoline and 50% Ethanol blend is shown in Fig.13.

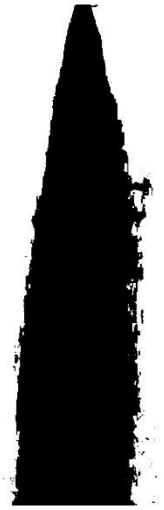

Fig.13.

Fig.14. shows the spray angles of Port fuel injector at different Pressures with different proportions of Gasoline-Ethanol blends.

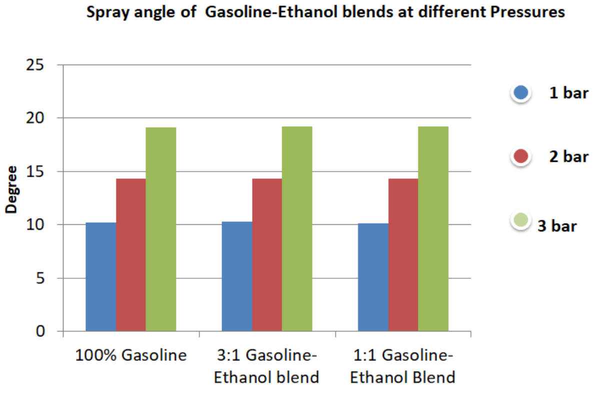

Fig.14.

VI. CONCLUSION

The Spray Angle for various gasoline-ethanol blends from a 8-hole injector are reported. Data has been generated for gasoline, gasoline-ethanol blends containing 25% and 50% ethanol. The spray angles are found to be around 10º, 14º and 19º at 1 bar, 2 bar and 3 bar pressures for different proportions of ethanol blends. This imply that spray angles of fuel injected at each pressure are found to be similar. This is contrary to the expected trend of lower spray angles with increasing viscosity for a relatively constant surface tension value. It is believed that the design of injector wherein eight streams of liquid emerge from the nozzle almost parallel to the axis, and interact with each other resulting in a unique mode of breakup could be the main reason for the effect of viscosity not being strongly manifested. This observation has interesting ramifications for the utilization of this mode of atomization for other high viscosity fuels in low pressure injection applications with ethanol blends.

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