REFRACTOMETRIC FIBER OPTIC ADULTERATION LEVEL DETECTOR FOR DIESEL

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ABSTRACT

Adulteration of diesel with kerosene is common malpractice since kerosene is cheaper than diesel. Such adulteration results in increased pollution, reduced lifetime of components, decrease in engine or machine performance etc. This paper presents a simple, extrinsic intensity modulated fiber optic sensor for determining adulteration of diesel by kerosene. The sensing principle is based on variation in reflected light intensity due to change in the refractive index of adulterated diesel. A parallel two fiber sensor probe consisting transmitting fiber and receiving fiber with a reflector is used as a sensor. An adulterated diesel is considered as a medium between sensor probe and reflector. A prototype is fabricated and tested in laboratory for different levels of adulteration of diesel by kerosene.. The sensor is useful due to its simple construction, operation, safety with inflammable fuels and the possibility of making it compact and portable for in-situ measurements. Micro-controller is used for incorporating totally automatic and adding further sophistication in final display so that it is more useful to layman i.e. society. Thus inexpensive and portable adulteration level detector is proposed.

KEYWORDS: *fiber optic sensor, fuel adulteration, adulteration level detector, refractometeric sensor, fiber optic sensor probe.*

I. INTRODUCTION

The blending of kerosene with automotive diesel is generally practiced by oil industry worldwide as a means of adjusting the low temperature operability of the fuel [1]. This practice is not harmful or detrimental to tailpipe emissions, provided the resulting fuel continues to meet engine manufacturer's specifications [2]. High level adulteration causes increase in emissions, as kerosene is more difficult to burn than gasoline. Adulterating of diesel with kerosene is common malpractice since kerosene is cheaper than diesel. Such adulteration results in increased pollution, reduced lifetime of components, decrease in engine or machine performance etc. There are number of techniques used to detect adulteration like use of markers, gas chromatography etc. However, for in-situ measurement of level of adulteration these techniques fall short.

Fiber optic sensors (FOS) have received considerable attention in the recent years because of their inherent immunity to electromagnetic interference, safety in hazardous and explosive environment, high sensitivity and long distance remote measurements. The miniature size, low cost, intrinsic safety and ease of installation of FOS makes this system ideal for applications in various engineering areas including numerous in line chemical, food, beverages or medical analysis and monitoring system.

Languease presented an optical fiber refractometer for liquids which eliminates the influence of attenuation due to the liquids [3]. L.S.M. Wiedemann etal proposes a method to detect adulteration by using physico-chemical properties of gasoline samples and performing statistical analysis [4]. Sukhdev Roy proposes a method of changing the refractive index of cladding of fiber for detecting adulteration of fuel which is based on the modulation of intensity of light guided in the fiber due to change in the refractive index of the cladding formed by adulterated fuel and the phenomenon of evanescent wave absorption [5]. L. M. Bali et al has developed an optical sensor for determining the proportional composition of two liquids in a mixture [6]. It is based on changes in the reflected light intensity at the glass-mixture interface brought about by the changes in the proportion of one liquid over that of the other in the mixture. It uses a simple configuration consisting of the end separated fibers where T-R coupling is decided by medium filled in the gap. This configuration however is difficult to handle because of precision needed for alignment so as to get maximum sensitivity. This paper presents a simple, extrinsic intensity modulated fiber optic sensor probe for determining adulteration of diesel by kerosene. The sensing principle is based on variation in reflected light intensity due to change in the refractive index of adulterated fuel. A sensor probe consists of parallel transmitting fiber and receiving fiber and a reflector is placed at distance from the sensor probe. A gap between sensor probe and reflector is filled with adulterated fuel. The paper discuses and proposes parallel two fiber sensor probe and a reflector with liquid media whose refractive index in to be detected. An extrinsic FOS measures refractive index of adulterated diesel based on reflective intensity modulation.

In this paper, principle of operation for detecting adulteration in diesel by using the sensor probe is discussed in detail in section 2. Further section 3 discusses how the probe is designed and how it can be configured for measuring of adulteration in diesel by kerosene. It further discusses how to mount the sensor probe for in-situ measurement of adulteration of diesel in automobiles. Section 4 discusses block diagram of microcontroller based experimental set up for measuring the adulteration level. Flowcharts of the programs are explained in detail for two configurations. Next section 5 discusses results obtained after testing the probe for different values of percentage adulteration in diesel by kerosene. Finally the concluding section gives the important findings of the work.

II. PRINCIPLE OF OPERATION

The proposed probe is based on the fiber optic sensor reported by Choudhari etal[7,8,9]. The fiber optic probe consists of two fibers: one fiber as transmitting fiber (T) and other is used as receiving fiber(R) .Both the fibers are of same type and same dimension. The fiber optic sensor (FOS) used is extrinsic type. So the light is carried up to the modulating zone by transmitting fiber where the properties of the incident light are modulated by modulator. The modulated light is carried out to the detector by receiving fiber. The modulating zone is between the fiber probe and a reflector kept at distance Z from transmitter.

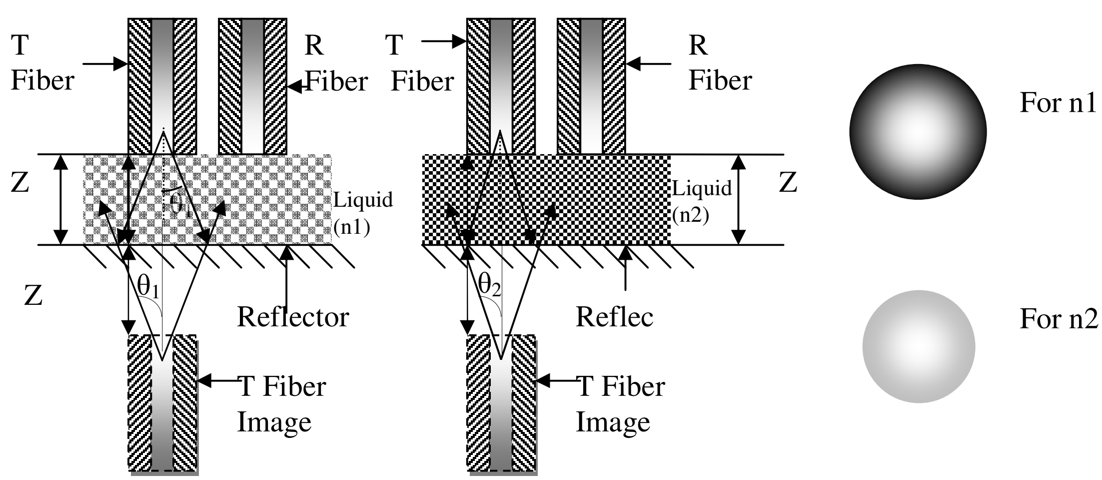

Fig. 1(a) Model of fiber optic Refractive index sensor

Fig. 1(b) Cross sections of Reflected cone for different refractive indices

An adulterated fuel is used as medium. As shown in Figure 1(a) the incident light in the form of cone of emission from transmitting fiber gets reflected back in the form of expanding cone of light towards the receiving fiber. The cone of emission depends upon the refractive index of the medium filled between the fiber probe and reflector. The medium having refractive index n1 is filled between the gap in sensor probe and reflector. The angle of emission is θ_1. It is given by equation

$$\theta_1 = \sin^{-1} (NA/n_1) \qquad (1)$$

where NA is numerical aperture of transmitting fiber and n_1 is refractive index of liquid filled between sensor probe and reflector. The output power is determined by the amount of light reflected by reflector. It is calculated by considering overlap area between the receiving fiber cone and reflected cone emitted by image of transmitting fiber. The receiver collects the optical power that falls in its cone of acceptance and guides it up to the detector.

Consider the gap is filled with liquid having refractive index n_2 as shown in Figure 1. Since $n_2 > n_1$ the cone of emission is $\theta_2 < \theta_1$. θ_2 is given by

$$\theta_2 = \sin^{-1} (NA/n_2) \qquad (2)$$

where NA is numerical aperture of transmitting fiber and n_2 is refractive index of liquid filled between sensor probe and reflector. The light rays are concentrated in smaller cone thus concentrating more intensity in the receiving fiber. Hence received output power increases. Figure 1(b) shows light received by the receiving fiber for refractive indices n_1 and n_2 respectively. Keeping Z fixed, the output thus depends on the variation in adulteration level of diesel by kerosene i.e. refractive index of liquid filled between sensor probe and reflector.

III. FOS PROBE FOR ADULTERATION DETECTION:

Fiber optic sensor probe consists of light source, detector, and chemical cell with holes and a reflector as shown. The light from source is launched in to optical fiber and guided to a region between sensor probe and reflector. Light is reflected from reflector through sample solution. It is then collected by the receiving fiber. The other end of this fiber probe is connected to a detection and measuring system. The fiber used for the experimentation is a plastic fiber of 488 μm core diameter with numerical aperture of 0.47. Cladding thickness (cl) = 0.612mm. T-R separation with jacket(s) = 0.0mm, angle between T-R fibers = 0^0. The length of the fiber = 85mm. Both transmitting and receiving fibers are of same type. A round cut transparent glass is press fitted to the sensing tip end of the fibers in order to avoid damage of polished tip due to the interaction with any chemical/fuel under test. Fiber sensor probe consists of a RED bright LED and photodiode (L14G3) enclosed in a brass assembly as shown in Figure 2(a). A chemical cell is fabricated having holes on the side walls and reflector is press fitted at the bottom. Mirror is used as a reflector. This chemical cell is fitted to the fiber sensor tip assembly. The sensing distance between the senor probe and reflector in chemical cell is adjusted so as to sense the variation in refractive index of adulterated fuel.

3.1 Configuration Description:

Fig 2. (a) shows configuration for detecting in situ measurement of adulteration level of diesel by kerosene. It has three indicator LEDs showing different adulteration levels such as no adulteration, adulteration within limits and over adulteration. This probe consists of transmitting and receiving fiber (sensor probe) and a reflector. A light is launched in the transmitting fiber and receiving fiber received the light reflected from reflector which is further detected by photo-detector. A reflector is fitted at the base of chemical cell with holes as shown in Figure 2(a). If the probe is immersed in the fuel (diesel) then depending upon the adulteration of diesel by kerosene RED, Yellow or Green LED glows. Green LED indicates that there is no adulteration of diesel by kerosene (0%). Yellow LED indicates that there is adulteration of diesel by kerosene but it is within the tolerance limits (up to 30%).

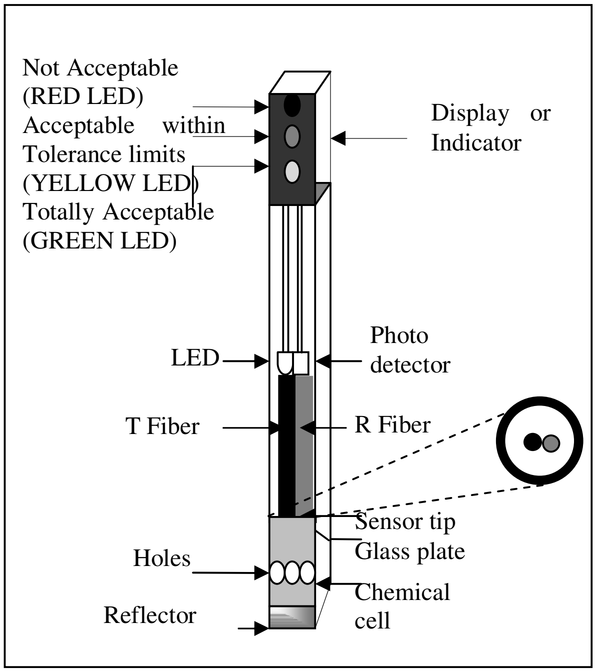

Fig.2 (a) Configuration indicating level of adulteration

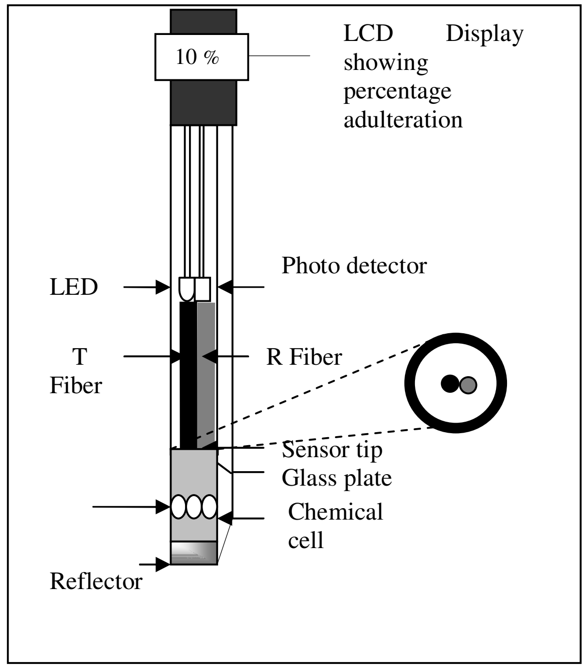

Fig.2 (b) Configuration showing level of adulteration numerically

If Red LED glows then diesel is highly adulterated by kerosene i.e. not acceptable (>30%). Such a probe is very much useful for in situ measurements. This probe can be fitted directly to the diesel tank of the vehicle. Fig 2(b) shows configuration used for detecting percentage adulteration in laboratory. In this configuration instead of indicating the adulteration level, its numerical value is actually displayed on the LCD display.

3.2 Probe Mounting:

A cup is designed with perforated upper part on side wall and opaque lower part and fitted at the mouth of the fuel tank as shown in Figure 3(a). Initially small quantity of diesel is to be filled and then depending upon the level of adulteration RED, GREEN or YELLOW LED will glow. Figure 3(a) , Figure 3(b) and Figure 3(c) shows how the sensor actually works for detecting adulteration in diesel by kerosene. . If RED indicator glows showing adulteration then diesel should not be filled in the vehicle. If GREEN or YELLOW indicator glows this indicates no adulteration or adulteration within limits. Then diesel should be filled in vehicle.

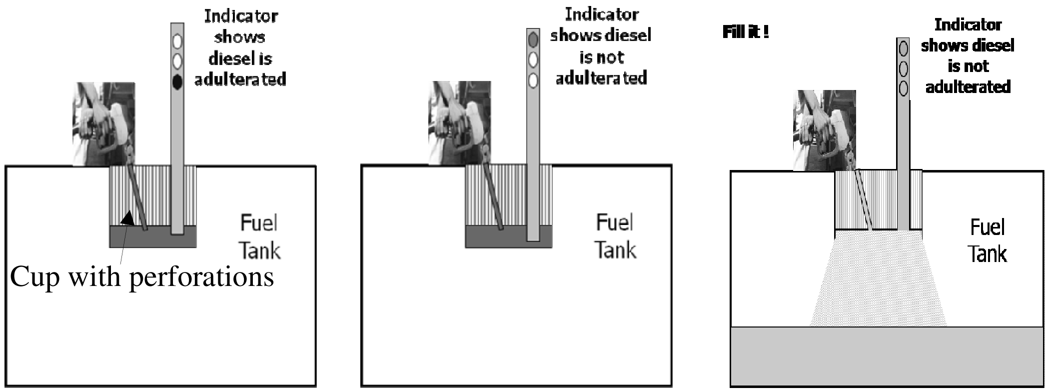

Figure 3(a) Indicator showing Adulteration Figure 3(b) Indicator showing no adulteration Figure 3(c) No adulteration results in filling the tank

IV. EXPERIMENTATION:

Adulteration level detector consists of a sensor probe and electronic components, ADC, Micro-controller and LCD display or LEDs. Fig 4 shows block diagram of instrument along with sensor probe.

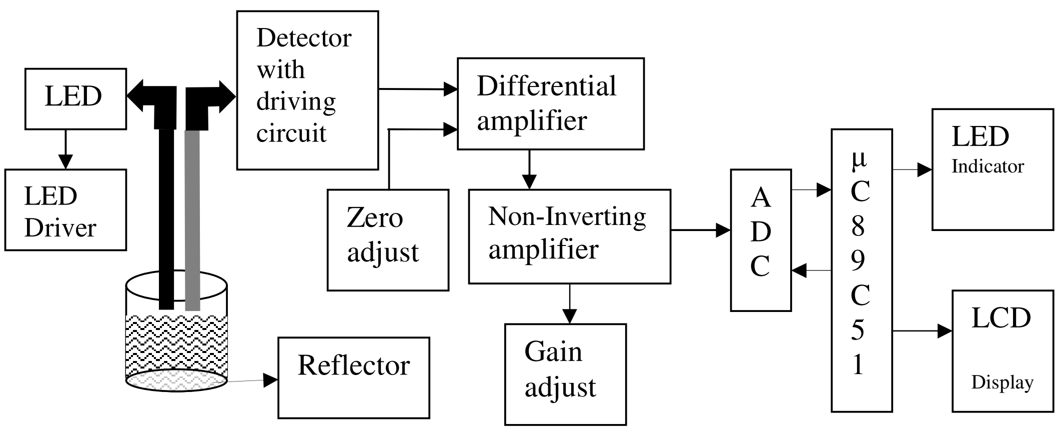

Fig 4. Block diagram of adulteration detector instrument

It consists of light source and its driving circuit, photo- detector and its driving circuit, sensor probe and chemical cell. The experiment was carried out for fixed distance between probe and reflector. The sensor probe consists of two multimode plastic fibers each of diameter 488 micrometer. Photo detector is a phototransistor and its driving circuit which consists of buffer. Differential amplifier is used to amplify difference between detector output and the reference voltage. This reference voltage is meant for zero-adjust of instrument for no adulteration. Non-inverting amplifier is used to further amplify the difference with adjustable gain (span adjustment). Output of amplifier is applied to ADC (AD 0809) which gives binary equivalent of the input analog voltage. Micro-controller is used to calculate the adulteration level and depending upon the binary input it will turn ON respective LEDs which are connected to the port pins. For LCD display the calculated adulteration level is first converted to ASCII code and then displayed on the LCD.

Chemical cell with holes at the side walls is used to test adulterated fuel. The chemical cell is cylindrical in shape with a mirror fitted at a centre of bottom. The mirror is used as a reflector. The experiment was carried out for 0% adulteration (pure diesel) up to 100% adulteration in pure diesel in interval 10% adulteration level. Sensor probe is dipped into sample of fuel under test. The amount of reflected light received by receiving fiber depends on the refractive index of the fuel and distance between sensor probe and reflector. Keeping the distance constant, we get output proportional to refractive index of fuel depending upon its adulteration level by kerosene. The experimental measurements were carried out with variation in adulteration level of diesel by kerosene. Different quantities of kerosene such as 0%(10ml pure diesel), 10%(9ml diesel+1ml kerosene),20%(8 ml diesel + 2 ml kerosene) up to 100%(pure kerosene) are added in diesel to create different adulteration levels. The ZERO adjust potentiometer is adjusted for pure diesel thus making the output voltage zero, indicating 0% adulteration. The span adjustment is done for 100% adulteration i.e only kerosene.

Purpose of using micro-controller is to collect and store the data from different fuel pumping stations and compare them with the standard values. Analytical methods are very tedious and may take hours to conduct different tests in the laboratories for detecting adulteration levels and also these methods are not in-situ. Hence such adulteration detector is not only useful for keeping health of the society but also useful for technical persons which are interested in data analysis.

For configuration indicating level of adulteration, the microcontroller initializes the ADC and output of the sensor is applied to the input channel of ADC. Digital data at the output of ADC is compared with the preset threshold values and accordingly RED, GREEN or YELLOW LED glows indicating over adulteration, no adulteration and adulteration within limits respectively. For configuration showing numerical value of adulteration, the microcontroller initializes ADC and data from the sensor is converted to proper form so that adulteration level is displayed on LCD display unit. Figure 5(a) shows flowchart for LED indicator (configuration 1) and figure 5(b) shows flowchart for LCD display (configuration 2).

V. RESULTS AND DISCUSSION:

The fiber optic sensor used is extrinsic type. Light is carried up to modulating zone by T (Transmitting) fiber and R(Receiving) fiber which collects it after reflection from reflector fitted at the bottom of the chemical cell at a distance Z from sensor probe. The cone of emission of the T fiber gets reflected back in the form of expanding cone of light towards the R fiber. The cone of emission depends on the refractive index of liquid as given by equation (1) and (2). The output power of R fiber depends upon the overlap area and cross section of reflected cone emitted by image of T fiber. This is given by the cross section of overlap area of reflected cone and the core of receiving fiber. A refractive index increases, angle of emission decrease, but energy density increase. Hence even if overlap area decreases output of the receiving fiber increases which in turn increase the output power. For Z up to 4mm effect of overlap area is dominant on the output power while as refractive index increases effect of energy density within the small cone of emission increase showing increase in output power.

These results show good agreement with those reported by Choudhari et al [9]. Experiment is performed for different adulteration levels such as 0% (pure diesel), 10%, 20% up to 100 %(pure kerosene) at fixed probe reflector separation of 6.22 mm. It is repeated 60 times for same adulteration level. Figure 6 shows histograms for testing the repeatability of the sensor output for adulteration levels. It is observed that for each adulteration level the sensor output shows a spread around mean value. As the observations were made starting from 0% kerosene with adulteration interval of 10%, it is seen that the subsequent peaks are well separated. A statistical T test was used to confirm the non-overlapping of the consecutive distributions. Figure 7 shows mean output voltage variation with increasing adulteration of diesel by kerosene. Though the observations are performed for 0-100% range of kerosene the adulteration of diesel will have significance on lower (approximately upto 30%) kerosene concentration side. It is seen from Figure 7 that the output voltage of the probe almost shows linear variation in this range.

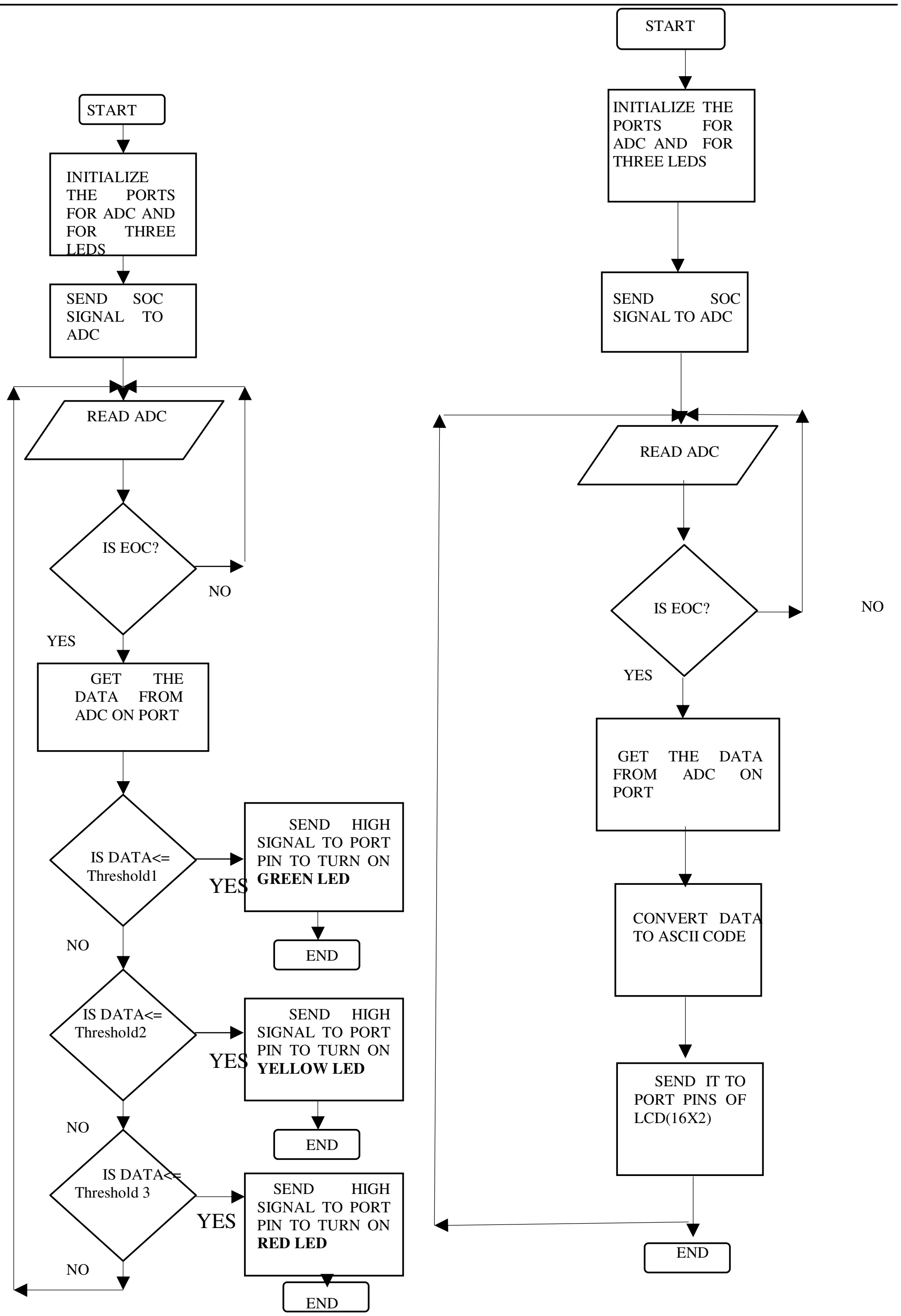

Figure 5(a) Flowchart for configuration 1 Figure5(b) Flowchart for configuration 2

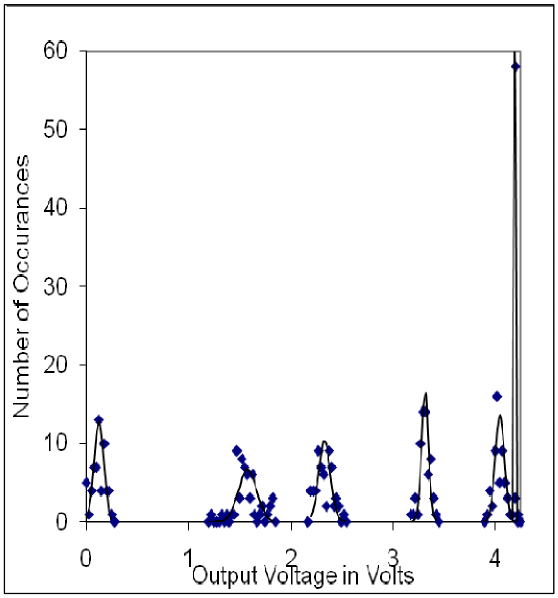

Figure 6 Repeatability of Measurement

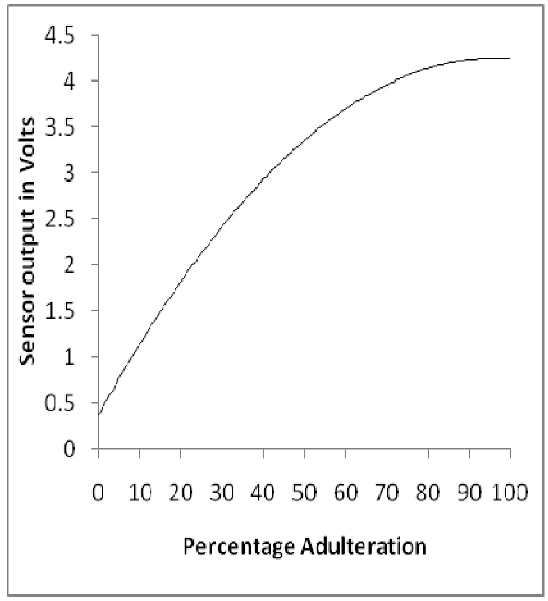

Figure 7 Experimental Results

VI. CONCLUSION:

Fiber optic sensor probe is designed using multimode fibers which detect adulteration level in diesel by kerosene. This sensor is based on principle of refractive index variation due to variation in adulteration level. It shows significant variation in output voltage for different values of percentage adulteration. It is further tested for repeatability using T-tests. Distinct detection of adulteration levels is observed. This probe is used in two configurations one for in-situ measurement and other for laboratory measurement of adulteration level. For in-situ measurement, RED, YELLOW and GREEN indicators are used for showing no adulteration, adulterated with acceptable level and over adulterated fuel respectively. The configuration 2, designed for laboratory use shows actual value of adulteration percentage on the display unit. Though the observations are performed for 0-100% range of kerosene the adulteration of diesel will have significance on lower (approximately up to 30%) kerosene concentration side. The instrument shows nearly linear behavior in this region. This sensor probe can be used with appropriate modifications for other adulteration detection applications where the adulteration alters the refractive index of the specimen and has definite commercialization potential.

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