Real Time Fuel Adulteration Detection System for preventing Health Hazards

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Abstract

Adulteration of automobile fuel is a prevailing problem because of the financial incentives it entails. It results in sub-optimal performance of engines and increased tailpipe emissions. Better detection techniques are required to weaken the fuel adulteration market. This paper is based on an electronic system to detect adulteration in hydrocarbon-based fuels. High-Speed-Diesel Oil (HSDO) was selected as the testing fuel of which Kerosene is a major adulterant. The proposed system incorporates a 3D-printed polylactide channel, Microchip Technologies' ATmega328p microcontroller and Espressif Systems' ESP8266 Wi-Fi module. The testing mechanism is based on fluid capacitance. The capacitance varies directly as the percentage of Adulteration while voltage varies inversely with it. The detection technique proposed in this paper offers portability, rapid testing with quantized results.

Keywords : *Health Hazard; Adulteration; Hydrocarbons; portable; Rapid Testing;*

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1 Introduction

The illegal and unlicensed mixing of inferior petroleum distillates into desired commercial petroleum fuels to enhance the overall volume of the desired product is known as fuel adulteration. Adulterants are substandard substances that decrease the product's quality. If Petrol and Diesel fail to meet the requirements set by Bureau of Indian Standards - IS 2796 and IS no.1460, it is then regarded as adulterated and unfit for distribution, according to the National Institute of Criminology and Forensic Science (NICFS) in India (NIFSC). The main effects of adulterated fuel distribution and consumption are increased tailpipe emissions of hydrocarbons (HC), carbon monoxide (CO), and particulate matter, a change in the octane number of the fuel results in shorter engine life, and finally, it adds value to revenue losses for the government. [Boadu et al, 2019, Eric et al].

According to empirical data from India's Petroleum and Natural Gas Regulatory Board, the country's petroleum business is becoming increasingly immoral. According to the Minister of Petroleum and Natural Gas, a total of 4375 occurrences of fuel adulteration were reported between 2016-19. As a result, 33 retail stores were permanently closed. From an executive director of the Oil Coordination Committee (OCC), fuel adulteration is responsible for a 40,000-crore annual scam in the country. In the petroleum business, turpentine is the most commonly utilized adulterant. In India, there is a subsidy on the PDS. The addition of turpentine made it a profitable adulterant for the practitioners. The subsidy was meant for low-income families who use turpentine for a variety of activities. The government was forced to eliminate these subsidies in the 2020-21 fiscal year due to the revenue loss. [4]. The massive consumption of these fuels creates economic opportunities for the adulteration industry.

The American Society for Testing Materials (ASTM) recommends a number of tests for monitoring gasoline adulteration. Density (ASTM D1298), Cetane Number (ASTM D613), Kinematic Viscosity (ASTM D445), and Distillation (ASTM D86) are a few of them [5]. These tests are widely acknowledged around the world. In India, Oil Marketing Companies (OMCs) have a system in place to monitor and supervise retail outlets. They are followed by the Calibrated Density Equipment test and the Filter paper test. Because of their high time consumption and vulnerability to human error, these tests should be replaced with more recent approaches to adulteration detection. Microfluidics, image processing, metamaterials, and optical fibers are only a few of the techniques that have been implemented [6,7,8,9] and reviewed [10,11].

However, in this study, we discuss an approach that is based on the fuel's capacitance and compares the results to those of pure fluid using computational tools. Capacitance is an excellent testing measure, as described in [12,10]. It can be utilized with a wide variety of adulterant concentrations, ranging from 0% to 100% by volume of turpentine in Diesel. The samples are collected using a 3D-printed channel manufactured of Polylactide (PLA). [13] looked into the properties of PLA and proposed that it could be used in industries.

2 Materials and Methods

To test the feasibility of capacitance as a testing parameter, physical experiments were conducted. The idea was to observe the trend followed by capacitance with increase in %Adulteration in the test samples. The experimental setup consisted of a Poly-Lactide (PLA) channel, fitted with two copper electrodes along the length of the channel. The setup acted as a parallel plate capacitor. Using a standard LCR meter, change in capacitance was studied. The samples were prepared by adding turpentine in Diesel with adulteration ranging from 0% to 50% (V/V). The below figure demonstrates the experimental setup used for taking readings. On carrying out numerous sets of readings for fuel samples from different vendors, we observed a trend in readings as depicted in fig. 2 (Line Graph). We observed that capacitance varies almost linearly with %Adulteration i.e. % Adulteration increases, Capacitance increases, similar relationships can be found in [12]. From this we came to the conclusion that capacitance can be an effective parameter for adulteration detection.

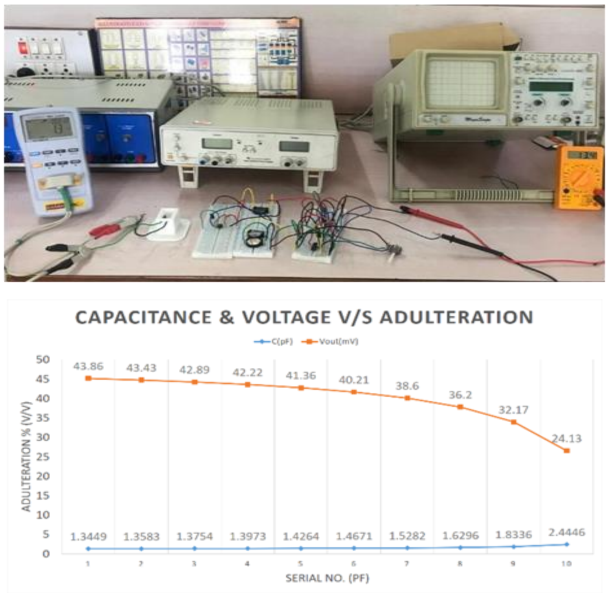


Figure 1. a) Experimental Setup for Look-up Table Development, b) Line Graph – Variation of Capacitance and Voltage with Adulteration

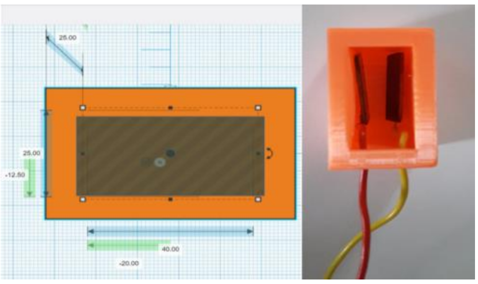
Channel

The proposed channel has been created using Poly lactic Acid or Polylactide (PLA) material. The channel design was made using Onshape CAD software. 3-D printing was employed for fabricating the channel. We used the Ultimaker 3D printer for the purpose. The steps involved in 3D printing can be found below.

Step 1: - Creation of 3D model of channel – There are many software tools available for creating 3D models but we chose Onshape on account of its interactivity and precision. The .stl file created from Onshape was then sent for slicing.

Step 2: - Slicing – Once the printable file was ready, we started preparing it for 3D printing. Basically, slicing is a process of slicing a 3D model into hundreds or thousands of layers. For this purpose, we require slicing software. We used Ultimaker's slicing software to employ the process. The resolution of the channel was set using the software to make it water tight. The sliced file is ready for 3D printing.

Step 3: - 3D printing – The slice file is sent to the 3D printer via USB, SD card or Wi-Fi. The sliced file is printed layer-by-layer. The internal cavity dimensions of the 3D printed channel are – (30mm X 15mm X 20mm). The copper plates of dimension (23mm X 9mm X 1mm) acting as parallel plates are attached to opposing inside edges of the cavity. The testing sample acts as a dielectric for the capacitor. The designed cavity can hold 9mL of test fluid. The system thus becomes efficient in decreasing the sampling volume by 95.5% of what is used in standard density tests.



The Capacitance of the channel is realized using a bridge configuration. The channel is attached to one of the arms of the bridge. The output voltage obtained from the bridge varies as the channel capacitance. The voltage obtained from the bridge arrangement was in nV range and it was brought to a measurable range by passing it through an OPAMP. We used OPAMP 741 due to its high open loop gain which met our requirement of measuring the voltage. The voltages corresponding to the channel capacitance were noted and an average value was obtained from them. This value was used as a basis of comparison of the measured voltage. We used LM339 ICs to create a differential amplifier circuit to compare the voltage obtained from the OPAMP with the standard value. The difference of the two values was amplified as discussed in [14] and sent to the Readout part of the system.

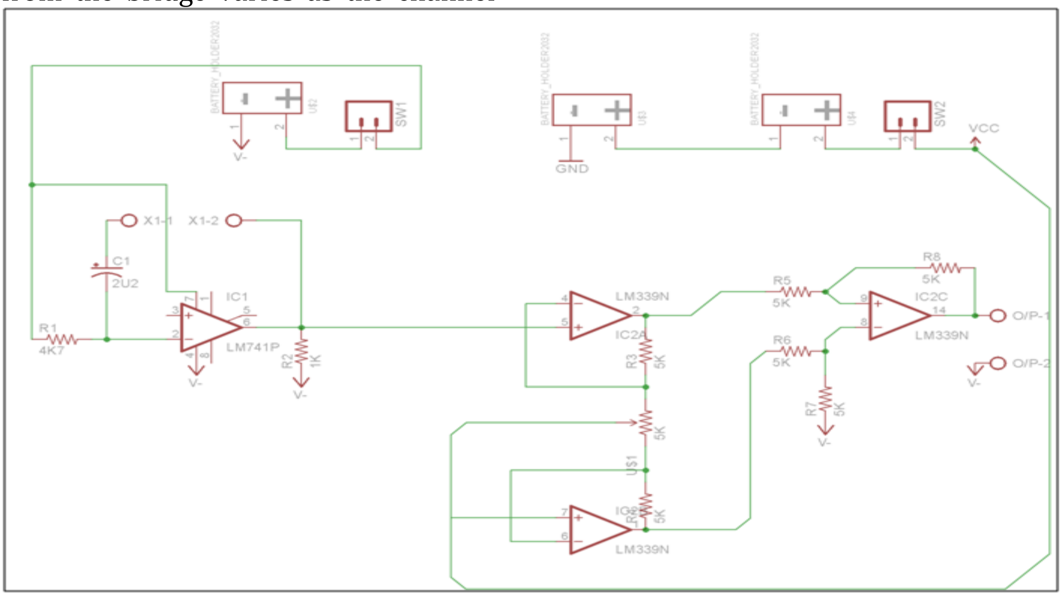


Figure 2. Schematic - Sensing Circuit (Integrator and Instrumentation Amplifier)

The function is the digitization of the analog values obtained from the sensing circuit. The display circuit consists of the ATmega328p IC and LCD primarily. We also interface ESP8266 module along with the MCU to send data to the Dweet cloud platform. The cloud platform acts as a secondary screen in case the onboard LCD malfunctions. We apply the analog signal obtained from the sensing circuit on pin28/AIN5 (Analog Input 5) of ATmega328p IC. Using the on-chip ADC (Analog-to-Digital Converter) the analog input is converted into its corresponding digital value. This digital value is mapped into the corresponding range of adulteration observed through the MCU. We use Embedded C programming to program the MCU as suggested in [15]. The comparison of the observed value is done with the pre-defined LUT (Look-Up Table) stored in the MCU. If the observed value lies between the range defined then the % Adulteration corresponding to that value is displayed on the LCD. The same value is sent as a string through the ESP8266 Wi-Fi module to dweet.io IOT platform. There we can observe the % Adulteration observed in the fuel sample.

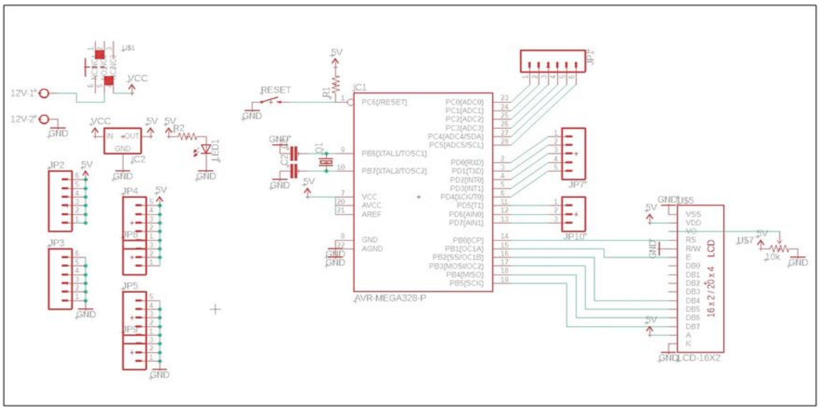


Figure 3. Schematic - Readout Circuit (ATmega328P interfaced with 16x2 LCD)

3. Working

The sensing circuit uses a bridge type arrangement of resistors and capacitors along with the channel as an unknown capacitance. Using the bridge balancing concept, we derive the channel capacitance. This capacitance is measured using the bridge arrangements voltage (which is in uV range). The underlying mathematics is as follows:

The channel capacitance is connected in series with Capacitor rated 1000uF. Thus, the effective capacitance of the combination can be calculated using the formula –

$C = \frac{\varepsilon^{13}\varepsilon_0 A}{d}$----Eq 1.

Where, c1 = 1000uF; C2 = channel capacitance; C = Effective capacitance

Table 1. Displaced Volume of testing sample with Volume of adulterant and diesel

Sr. No.	Volume of Adulterant, VT (mL)	Volume of Diesel, VD (mL)	Displaced Volume of testing sample, V2=VT/VD
1.	0	50	0
2.	5	45	0.1111
3.	10	40	0.25
4.	15	35	0.4285
5.	20	30	0.6667
6.	25	25	1
7.	30	20	1.5
8.	35	15	2.33
9.	40	10	4
10.	45	5	9
11.	50	0	∞

The relative dielectric constant of the sample fluid is calculated using the formula –

$\varepsilon_{13} = [v_2(\varepsilon_2 - \varepsilon_1)] + \varepsilon_3$ ----Eq 2.

Where, ε_{13}–Dielectric constant of sample; v_2 - Volume of displaced fluid; v_2- Dielectric constant of Adulterant; ε_1 - Dielectric constant of Diesel; ε_3 - Dielectric constant of air. We calculate the value of C using Eq 1.

Here, R = 10KΩ; Ceff = C – Cair

Where, Cair = 1.221pF and, f=1KHz

The output of the bridge is connected to an OP-AMP 741 IC to bring the output voltage to measurable value. The high gain of the OPAMP aids in this process (Gain =). This measured value is then compared with the standard voltage value obtained from experimentation. The comparator circuit is designed using LM339 IC. LM339 is a quad-comparator IC. It houses 4 differential amplifiers, of which 3 are used for our purpose. The first differential amplifier gets the output voltage from the 1st phase of the sensing circuit. The second differential amplifier uses voltage generated through the coin cells as the reference voltage. Both the inputs are applied on the negative terminals of the differential amplifiers. The resistors used in the comparator arrangement are of value 5K ohm. Effectively we get a gain factor of 10 through the arrangement.

Moreover, to validate the calculated values of parameters related to test fluid and the bridge type arrangement, Scilab was used. The above mentioned formulas were coded and used to find out the effective capacitance and the adjacent voltage.

Table 2

RC constant values with relative dielectric constants

Sr. no.	Relative dielectric constant, ε_{13}	C (pF)	Ceff (pF)	1/RCeff
1	2.1	2.5659	1.3449	7.435×10^8
2	2.111	2.5793	1.3583	7.362×10^8
3	2.125	2.5964	1.3754	7.27×10^8
4	2.14285	2.6183	1.3973	7.156×10^8
5	2.16667	2.6474	1.4264	7.01×10^8
6	2.2	2.6881	1.4671	6.816×10^8
7	2.25	2.7492	1.5282	6.543×10^8
8	2.333	2.8506	1.6296	6.136×10^8
9	2.5	3.0546	1.8336	5.453×10^8
10	3	3.6656	2.4446	4.09×10^8

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```
A=(l*10^-3)*(b*10^-3); // Calculate the area of plate exposed to the dielectric.
ep0=8.85*(10^-12); // Value of epsilon0.
for l=1:n
    ep(l)=ep0*ep13(l); // Calculating the respective values of epsilon.
    C(l)=(ep(l)*A)/(d*10^-3); // Calculating the capcitances corresponding to the respective dielectric constant values.
end
disp('The calculated capacitances of the mixture are(F): ');
for e=1:n
    disp(C(e));
end
epair=ep0*1; // Epsilon for air as a dielectric.
C1=(epair*A)/(d*10^-3); // Calculating air capacitance.
disp('The air capcaitance is(F): ',C1); // Displaying the calculated air capaictance.
for t=1:n
    Ceff(t)=C(t)-C1; // Calculating the effective capacitance.
end
disp('The effective capacitance is(F): ');
for v=1:n
    disp(Ceff(v)); // Display the calculated effective capacitances.
end
R=10*10^3; // Setting R=10KOhm.
f=1*10^3; // Setting frequency at 1KHz.
Vin=590*10^-9;
Omega=(2*%pi*f); // Calculating Omega.
for w=1:n
    z(w)=(Omega*R*Ceff(w)); // Calculating (Omega*R*Ceff) for each value.
    z1(w)=(-1/z(w)); // Calculating it's reciprocal.
    Vout(w)=(z1(w)*Vin); // Calculating Output voltage obtained from the sensing circuit.
    disp("The output voltage obtained from the circuit is: ",Vout(w)); // Displaying the calculated voltage.
end
mprintf("\n[1/wRC]\t\tVout\n");
mprintf(" \t\t[V]\n");
for i=1:length(z1)
    mprintf("%.2f \t %.2f \n", z1(i), Vout(i));
end
```

(a)

```
clc;
vt=input("Enter volume of adulterant(ml): "); // Get the volume of adulterant from the user.
vd=input('Enter volume of diesel(ml): ');
v=(vt/vd);
disp('The displaced volume is: ',v);
n=input("Enter the number of dielectric constants you want to calculate: "); // Get the number of dielectric constants the user wants to calculate.
for i=1:n
    ep1(i)=input("Enter value of dielectric constant ep1 (diesel): "); // Dielecetric constant of fluid 1.
    ep2(i)=input("Enter value of dielectric constant ep2 (adulterant): "); // Dielectric constant of fluid 2.
    ep3(i)=input("Enter value of dielectric constant ep3 (air): "); // Dielectric constant of air.
end
for j=1:n
    ep13(j)=(v*(ep2(j)-ep1(j)))+ep3(j); // Relative dielectric constant calculation formula.
end
disp("The relative dielectric constants are: ");
for k=1:n
    disp(ep13(k)); // Print out the calculated dielectric constants.
end
l=input('Enter the length of the electrode plates: '); // Get the length of the electrode plates from the user.
b=input('Enter the width of the electrode plates: '); // Get the width of the electrode plates from the user.
d=input('Enter the distance/seperation between the plates: '); // Get the distance of seperation between the plates.
```

(b)

Figure 4(a). SciLab Code For Justifying Calculated Results (Part-1) (b). SciLab Code For Justifying Calculated Results (Part-2)

```
Scilab 6.1.1 Console
File Edit Control Applications ?
Scilab 6.1.1 Console

Enter volume of adulterant(ml): 3

Enter volume of diesel(ml): 6

  "The displaced volume is: "

   0.5
Enter the number of dielectric constants you want to calculate: 1

Enter value of dielectric constant ep1 (diesel): 2.35

Enter value of dielectric constant ep2 (adulterant): 2.2

Enter value of dielectric constant ep3 (air): 1

  "The relative dielectric constants are: "

   0.925
Enter the length of the electrode plates: 14

Enter the width of the electrode plates: 9

Enter the distance/seperation between the plates: 5

  "The calculated capacitances of the mixture are(F): "

   2.063D-13

  "The air capcaitance is(F): "

   2.230D-13

  "The effective capacitance is(F): "

  -1.673D-14

  "The output voltage obtained from the circuit is: "

   0.5613931

[1/wRC]              Vout
                     [V]
951513.72             0.56

--> |
```

Figure 5. SciLab Code Output For Justifying Calculated Results

The above code demonstrates an example of how Di-electric constants of samples were calculated and used along with Channel dimensions to calculate effective capacitance C. The effect of air capacitance is also considered. The result comes out to be similar to Table 2. in terms of how output voltage changes with change in di-electric constant.

3 Results and Discussion

The project advocates for capacitance to be a viable parameter for testing adulteration in fluids. A stationary sample of fluid with fixed volume and known relative permittivity, acts as a good di-electric medium. If all other parameters are equal, then capacitance increases with rise in permittivity and the same can be found in the project. The permittivity of diesel (Er=2.1) is less than that of Kerosene (Er=2.2). So, with increasing proportions of kerosene in the sample, the capacitance rises.

The system is capable of displaying the corresponding % adulteration in the test sample in LCD and relaying it to the dweet.io platform. The look-up table based algorithm fed in the IC is programmed using the physical experimentation done to study the relation between adulteration and capacitance of the fluid. The system is designed for Diesel considering Turpentine as a major adulterant. The % adulteration is depicted in ranges of 5% across the range of 0-50%. Upon increasing the adulteration beyond 50%, the properties possessed by the fuel are not dominant in the sample. Therefore, the samples having adulteration up to 50% adulteration have been considered.

Table 3. Percentage Adulteration (vol/vol) with observed Voltage (V)

SNo.	Adulteration % (V/V)	Observed Voltage (V)
1.	0%	4.86
2.	5%	4.84
3.	10%	4.82
4.	15%	4.8
5.	20%	4.78
6.	25%	4.76
7.	30%	4.74
8.	35%	4.72
9.	40%	4.7
10.	45%	4.68
11.	50%	4.66

The components that are used are easily accessible and make the device cost effective. If developed in batches, the process of channel fabrication (3D-printing) will also become economical. Operating the device is basic; however, sample insertion should be done carefully to avoid spillage. For reuse, the channel needs to be cleaned thoroughly. Be that as it may, to reuse the framework, the channel should be cleaned completely. The system is flexible and can be modified for identifying contamination/dilution of different liquids.

4 Conclusion

A low-cost portable system has been designed and tested for detecting the extent of adulterant (turpentine) in Diesel by determining its capacitance. It provides robust, real-time results. Keeping in mind the drawbacks of existing lab-based tests; the system offers rapid and robust results avoiding human errors. The PLA channel accounts for a very small sample size. The process of 3D-printing ensures high resolution of the channel. Moreover, the components employed are energy efficient enabling the system to be battery powered. An additional feature of embedded Wi-Fi gives the opportunity to read and save the data from anywhere. The components along with the program and tools are versatile and can be calibrated to adapt to different fuels (viz. Petrol, Ethanol fuel). With Wi-Fi connectivity, the device is capable of sending the data to the fuel companies along with the details of the distributor, which will help in identifying the malpractitioners. This would eventually help lower the revenue losses. The project was dedicated to minimize the contribution of oxidation of adulterated fuels in air pollution.

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