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ETHANOL FUEL ANALYSIS BY TIME-DOMAIN REFLECTOMETRY

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Abstract—The technique of Time Domain Reflectometry (TDR) is applied for qualifying ethanol adulterated with water and/or methanol. We used the commercial TDR model VG400, which was originally developed for determining soil moisture, making this study an original approach for qualifying fuels. Several samples of alcohol with the addition of its main contaminants (water and methanol) were prepared and measured with the TDR sensor. The results indicate good response linearity, showing the TDR technique is a promising technique for fuel qualification.

Keywords—Time-Domain Reflectometry, TDR, Fuel Qualification

I. INTRODUCTION

There are numerous problems caused by illegal adulteration of automotive fuel commercialized in Brazil. First, adulterated fuel results in reduced engine lifetime. In extreme cases, the so-called “engine knocking” or “detonation” can occur, when the combustion process loses its synchrony [1]. This effect can make some of the engine parts (such as the piston) burn completely, rendering them useless.

Another problem involves the pollution resulting from “bad” fuel burning. The production of toxic gases is unavoidable in fuel combustion, but the use of adulterated products results in far more dangerous pollution. Methanol, used to adulterate ethanol, can cause permanent blindness or even death in sufficiently large doses.

The country national economy also suffers due to adulterated fuels. One of the main reasons why occurs is the different amount of tax revenue (illegal compounds are cheaper). Tax evasion results in the creation of unfair competition and irregular tax payment.

Usual fuel analyses often involve the use of large and expensive equipment and require destructive chemical methods. This work introduces studies of the TDR (Time-Domain Reflectometry) technique as an auxiliary to the analysis, proposing a fast, simple, compact and non-destructive method for alcohol qualification. Being a widely known method in telecommunications, with “cable-tester”, and in geotechnical studies, the relation between the TDR technique and the electrical permittivity of the medium under analysis might indicate it for fuel qualification.

II. TDR TECHNIQUE

This technique consists in the application of electromagnetic wave pulses between two parallel conductive tracks and observing its time-dependent response [2]. Its operation is based on transmission-lines principles in which, by impedance mismatching between load and the line characteristic impedance, there is partial or total reflection of the incident wave. The key factor that allows the analysis of fuel, as well as soil, by TDR is the electromagnetic signal propagation speed $v_p$ [3]:

$$v_p = c/\sqrt{\varepsilon_r \mu_r}$$

(1)

In equation (1), the effect of the conductivity of the medium was ignored, $c$ is the vacuum propagation speed of light, $\varepsilon_r$ is the relative permittivity of the medium (or dielectric constant) and $\mu_r$ is the relative magnetic permeability of the medium.

It is worth mentioning that the permeability is considered the same for the mediums involved in this study and, as a result, the wave propagation speed can be said to depend mainly on the permittivity.

In a TDR probe with constant length $L$, the variation time $\Delta t$ that a wave takes to travel and reflect back to the origin of the line should be:

$$\Delta t = [2L(\varepsilon_r \mu_r)^{1/2}]/c$$

(2)

This expression (2) shows the direct relationship between the time variation and the electric permittivity of the medium.

There is a relationship between the permittivity of a sample of soil and its moisture because there is a large contrast between the involved permittivites (the permittivity of water is typically 20 times as high as that of any other component of a clean soil) [4]. The same can be considered for alcohol fuel, in which the water relative permittivity is 80 whereas it is 24.3 for ethanol and 33.1 for methanol [5].
III. METHODOLOGY

The experimental setup used in the study (shown in Figure 1) consisted of a moisture TDR sensor model VG400 from Vegetronix (see Table 1), a symmetric power supply E3631A (Agilent), and a digital multimeter 34401A (Agilent) for monitoring VG400 output. As indicated by the manufacturer, this sensor doesn’t need any internal calibration to work [6], thus, the output depends only on the medium surrounding the probe (the samples) and the supply voltage (stipulated at 5V for convenience). Also, the sensor have an output of 3V for completely wet mediums and 0V for completely dry mediums.

TABLE I. TDR REFLECTOMETER SPECIFICATIONS – VG400 SERIES [6]

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption</td>
<td>&lt;800 μA</td>
</tr>
<tr>
<td>Supply Voltage</td>
<td>3.3 ± 20 VDC</td>
</tr>
<tr>
<td>Power on to Output stable</td>
<td>400ms</td>
</tr>
<tr>
<td>Output Impedance</td>
<td>100kΩ</td>
</tr>
<tr>
<td>Operational Temperature</td>
<td>-40 to 80 °C</td>
</tr>
<tr>
<td>Output</td>
<td>0 to 3 VDC</td>
</tr>
<tr>
<td>Probe length</td>
<td>10 cm</td>
</tr>
</tbody>
</table>

A stainless steel tube of approximately 20 cm in height and 1.8 cm in diameter was constructed to serve as a container for the fuel samples and it was electrically grounded to the power supply to avoid external interferences. Fig. 1 shows the experimental setup.

![Experimental setup diagram](image)

For sample preparation, an alcoholmeter (type floating densimeter, from INCOTERM) graduated in °GL (Gay-Lussac) and a digital weighing scale mod. MARTE AL500 were used. For handling the compounds, mainly methanol, we used a chemical bench with exhaust fume hood, gloves, a burette beaker, and syringes.

Ethanol/water samples were prepared from a 97.5°GL ethanol (analytical grade, from Synth). The other samples (up to 70°GL) were prepared by gradually adding distilled deionized water and by monitoring the mixture through the alcoholmeter. To avoid possible errors caused by temperature variation, all ethanol/water samples measurement was made only after temperature stabilization.

Samples with methanol were prepared with the aid of the digital weighing scale. Initially measuring the mass of ethanol, water and methanol were added in their proper mass proportions to complete the total mass of the sample (stipulated at 50g), as indicated in the graph of Fig. 4. The stabilized temperature was 25°C for all measurements.

All the samples were inserted into the container through a burette of ±0.05 ml of uncertainty and with 50 ml capacity. The study of the sensor immersion was made from the empty tube, gradually adding 2 ml of liquid (via burette) to obtain new samples. In the tests, the sensor output was measured 10 times for each sample, and it was removed and immersed again in the sample between each reading.

IV. RESULTS AND DISCUSSION

Fig. 2 illustrates the study of TDR sensor immersion. From the volume of 30ml, the sensor starts to be influenced by the samples, whereas, for smaller volumes, its output is constant (influenced only by the air in the tube and its wall). A good linearity of the relationship between the immersion of the sensor and its output (correlation coefficients $R^2$ are shown in the graph) can be observed. Its sensitivity is demonstrated by the slope of the curves, which corresponds to approximately 8mm for each 2ml of immersion.

The voltage difference between the situations “100% water” and “100% ethanol,” becomes even more evident as the sensor is immersed in the sample, limited only by saturation (3V). Based on this graph, the volume of 48ml was chosen for the studies of alcohol mixtures with water and methanol. In this volume, there is a variation of the sensor output V between 2.05 (100% ethanol) to 2.50 V (100% water).

![Graph](image)

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The voltage difference between the situations °GL (alcohol volume/total volume) were converted to °INPM (alcohol mass/total mass) by using alcoholmetry concepts [7]. From Fig. 3, we verify the response
of the TDR sensor about -7.4 mV/°INPM, with a nearly linearity ($R^2 \approx 0.963$).

![Fig. 3. TDR Response for Ethanol/water mixtures](image)

$R^2 = 0.9631$

$R^2 = 0.9964$

![Fig. 4. TDR response for ethanol/water/methanol mixtures](image)

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For water-only adulteration, we verified a sensitivity of -7.4 mV / °INPM. For samples with added methanol, the sensitivity obtained is about 2.3mV/(methanol %) with an offset of about +0.15 V at the output, by the introduction of 20% water. In general, the variation of the output voltage (by the order of hundreds of millivolts) can be considered adequate for characterizing the fuel when the repeatability of the sensor is taken into account (represented by the order of errors shown in the graph). Other attractive characteristics of TDR technique are: simple mounting; ability to work in different tank geometries; intrinsically safe operation; reusable sensor; no sensor drift or poisoning; and non-destructive analysis.

It is also worth mentioning that the commercial sensor used for this study was designed to qualify soil moisture. The development of a sensor dedicated to the analysis of fuel is believed to optimize the results from this work, making it a new approach to fuel qualification.

V. CONCLUSION

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REFERENCES

Accessed in April 2013


[6] VEGETRONIX; VG400 manufacturer site.
Available in: http://www.vegetronix.com/Products/VG400/Soil-Moisture-Probe-FAQ.phtml (see question 9 for calibration matters).
Accessed in April 2013

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