ETCHED FBG AS CHEMICAL SENSOR FOR FUEL ADULTERATION

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Abstract

In this paper, we show how to detect the adulteration of kerosene in petrol by using etched Fiber Bragg Grating (FBG). The performance of the resulting grating is demonstrated by developing a fuel adulteration sensor based on refractive index changes. Changes in the percentage of kerosene in petrol result in different extents of blue shifts of the Bragg resonance wavelengths of the gratings. It is possible to detect presence of 10% adulteration level in petrol, whereas the traditional technologies i.e. American Standards for Testing Materials (ASTM) distillation, checking properties like density, flash point and viscosity, microprocessor based electronic method using principle of cooling on evaporation etc. were able to detect presence of about more than 20% of the same.

Keywords: Fiber Bragg grating, Effective refractive index, Etched fiber, Petrol, Kerosene.

1. Introduction

The standards for fuels are usually regulated by governmental agencies. Unfortunately, in many countries, people intentionally add cheaper organic substances in an attempt to raise profit margins. This illicit practice is called adulteration. It affects public coffers through tax embezzlement, since solvents such as mineral spirits, kerosene, rubber solvents, naphta, and thinner are levied at different rates [1]. It may also severely damage the engines and produce emissions that increase environmental pollution. In Greece, for example, three types of diesel fuel are commercialized: automotive, domestic heating and marine diesel fuel. Marine and domestic are cheaper than automotive diesel fuel, and are therefore used to adulterate the latter [2].

In the United States of America biodiesel blends are adulterated with soy oil (Mahamuni & Adewuyi, 2009). In Southeast Asia petrol is adulterated with kerosene, cyclohexane, crude hexane and turpentine oil [3]. Since 1979 the Brazilian gasoline labeled 'gasolina C' or gasohol has been combined with ethanol in different proportions from 19-27% (v/v) that are specified by the Brazilian governmental body 'Agencia Nacional do Petroleo' (ANP) [4]. The proportion depends on the national production of ethanol from sugar cane, and is currently 25% [1]. The end of the fuel distribution monopoly opened the road to the criminal practice of adulteration of gasohol [5], which mainly consists increasing the fraction of ethanol outside the range specified by ANP and/or the addition of organic solvents [6]. Since 1975 anhydrous ethanol has been used in Brazil and has been adulterated with methanol and even water [7]. Methanol is cheaper and quite similar to ethanol in many physico-chemical properties, but presents high toxicity and may cause temporary or permanent corneal, pancreatic and liver damage or even death by inhalation or skin absorption [7]. Some years ago, ANP begun to introduce tracers in all solvents commercialized in Brazil, which can be detected by specific analytical techniques. Although efficient, this measure is quite expensive [5]. For the purpose of overcoming fuel adulteration practices, it is necessary to develop novel, low-cost and reliable methods to monitor the fuel composition.

In recent years there is dramatic progress in the design and development of fiber optic sensors as detection of chemical species in many industrial and chemical processes in addition to environmental control. Fiber optic sensors offer several advantages over conventional chemical sensing systems, specifically immunity to electromagnetic interference, possibility of distributed sensing over long lengths of fiber and their capability for safe operation in hazardous environments. Fiber optic chemical sensors include refractometric sensors and evanescent wave absorption sensors, more recently indicator mediated, in which the evanescent field of guided light is absorbed by the chemical of interest.

Adulteration of petroleum products especially petrol is very common. Kerosene is the most important domestic fuel for economically weaker sections of society and hence is heavily subsidized. The large differences in the prices of petrol, diesel and kerosene, the easy availability of kerosene and the fact that it is miscible in petrol and diesel, make the unhealthy and unethical practice of adulteration of petrol and diesel.

There have been a number of methods proposed for checking adulteration of petrol and diesel by kerosene such as the filter test, American Standards for Testing Materials (ASTM) distillation, checking properties properties like density, flash point and viscosity, microprocessor based electronic method using principle of cooling on evaporation, odor based method, ultrasonic techniques, titration techniques, optical techniques, dyeing kerosene and adding chemical markers for kerosene etc [7].

All these technique require taking out the sample for measurement, thus, they are time consuming and unable to detect adulteration level below 20%. Thus the above methods suffer from limitations in terms of accuracy and sensitivity in determining adulteration levels. In this paper etched FBG is modeled as a chemical sensor. Etched FBG is based on the principle of change in refractive index for detecting adulteration in petrol by kerosene, and trying to demonstrate its suitability.

2. Principle

FBG is a periodic modulation of the refractive index in the core of a single mode fiber. The reflected Bragg wavelength (λ_B) is characterized by the grating periodicity (Λ) and the refractive index of the waveguide mode n_{eff}. The first-order Bragg condition is [8].

$$\lambda_B = 2\, n_{eff}\, \Lambda \qquad (1)$$

When the cladding part of a FBG is removed or sufficiently reduced, n_{eff} of the grating is strongly affected and a change in induced refractive index is seen that causes a wavelength shift [8].

$$\Delta\lambda_B = 2\, \Lambda \eta_p\, \Delta n \qquad (2)$$

where $\Delta\lambda_B$ is the change in wavelength of the Bragg reflection, Δn is the difference between the cladding refractive index and the surrounding refractive index, Λ is the period of the grating and η_p is the variation of the fraction of the total power of the unperturbed mode that flows in the etched region. Changes in the surrounding refractive index also change the effective index of the core mode (n_{eff}) via the relation [8].

$$\eta_p\, \Delta n = n_{eff} \qquad (3)$$

2.1 Reflectivity

By using coupled mode theory one can obtain a description of the reflectivity properties of a grating [10].

$$R(L,\lambda) = \frac{\xi^2 sinh^2\left\{\sqrt{(\xi^2}-\Delta K^2)L\right\}}{\left[(K-\frac{\pi}{\lambda})^{22}\left\{\sqrt{(\xi^2}-\Delta K^2)L\right\}+(cosh^2)\left\{\sqrt{(\xi^2}-\Delta K^2)L\right\}\right]} \qquad (4)$$

Here R (L, λ) is the reflectivity of a grating and is a function of the wavelength λ and the grating length L, where k is the propagation constant, given as

$$k = 2\pi \frac{n_0}{\lambda}$$

and Δk is the differential propagation constant, given as

$$\Delta k = k - \frac{\pi}{\lambda}$$

and ξ is the coupling coefficient, given as

$$\xi = \frac{\pi \Delta n(V)}{\lambda}$$

and

$$(V) = 1 - \frac{1}{V^2}$$

is the fraction of the integrated fundamental mode intensity contained in the core of the fibre. η is a function of the normalized frequency V of the fibre. [11].The reflectivity of a grating is normally a function of the grating length and the wavelength. At the centre wavelength of a Bragg grating Δk = 0 and the reflectivity can be written in the following form

$$R(L,\lambda) = tanh^2(\xi L)$$

3. Simulation

Fig1 show, FBG Spectra with the central wavelength 1550.35µm. As the percentage of kerosene in petrol increases, there is blue shift in bragg wavelength (λ_B) i.e at 20% the shifted wavelength will be 1550.30µm. So there will be shift of .05µm and so on, shown in fig 2.

Table 1: Wavelength response with percentage of kerosene in petrol.

Percentage of kerosene in petrol(%)	Wavelength Shift(nm)
0(Pure Petrol)	1550.35
20	1550.30
50	1550.22
100(Pure Kerosene)	1550.10

Table 2: Reflective index response with percentage of kerosene in petrol [8].

Percentage of kerosene in petrol(%)	Change in reflective index
0(Pure Petrol)	1.418
20	1.422
50	1.429
70	1.433
90	1.4375
100(Pure Kerosene)	1.440

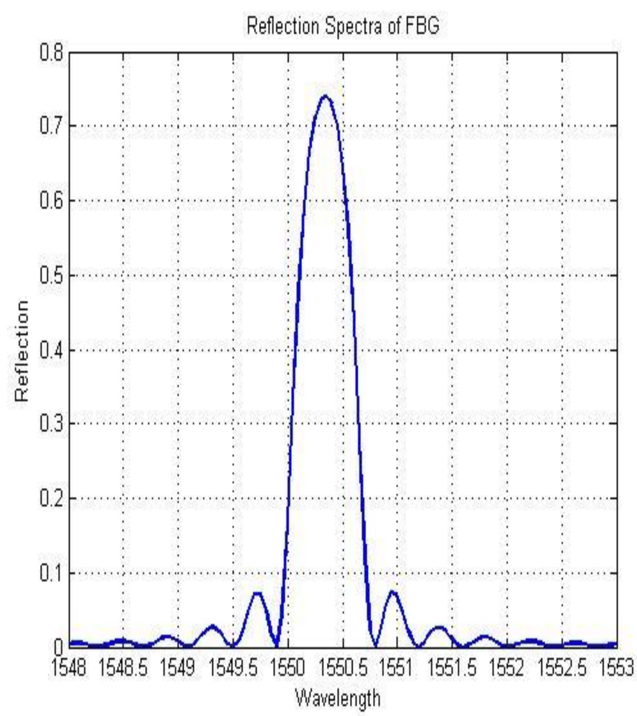

Fig 1: FBG Spectra

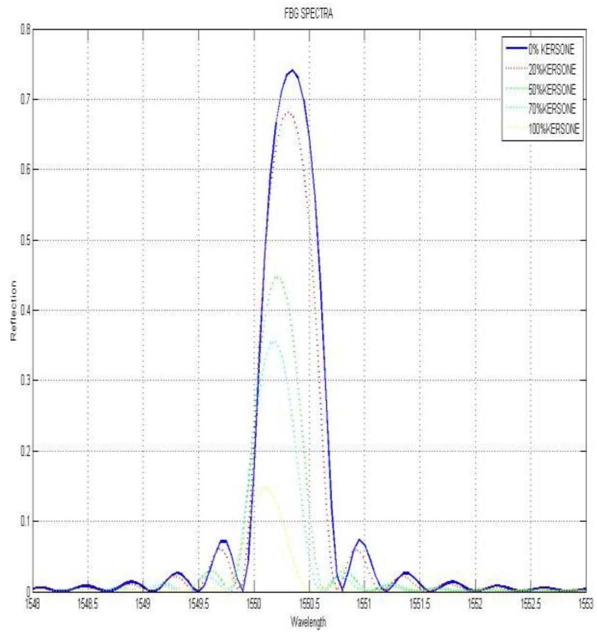

Fig 2: Change in reflectivity of FBG at different adulteration percentages of kerosene in petrol.

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Fig 3: Change in wavelength shift with percentage of kerosene added.

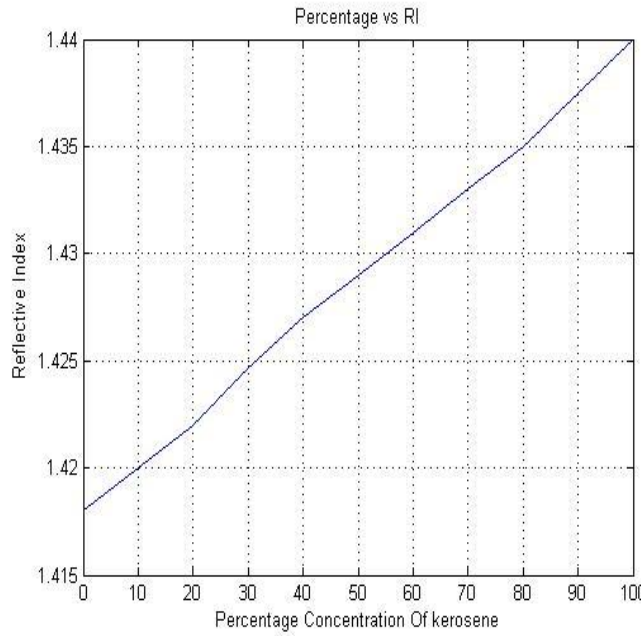

Fig 4: Change in RI with percentage concentration of kerosene.

4. Conclusion

We proposed fibre optic sensor based on the principle of change in refractive index for detecting adulteration in petrol by kerosene. The proposed sensor would be useful in automotive and petrochemical industries due to its safety with inflammable fuels, sensitivity and the fact that it can be made into a portable device for on-road measurements.

5. References

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