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Review on the Detection of Fuel Adulteration through Sensor based Techniques

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Abstract- The scope of the article is to review various types of fuel adulteration detection sensors using various sensors based techniques. Petrol and diesel are major fuels used for transport and electricity generation globally. Now a day's huge number of consumers are facing the fuel adulteration threat. Adulterants are added to these base fuels with other inexpensive boiling point range hydrocarbons containing more or less similar composition leading to modify and degrade the base fuel quality. These adulterants are added by the business vendors for their monetary profits. Sensing such adulterant in fuels is a principal task in the interest of the end consumer. We believe that this is first literature reviewing the sensor based techniques to estimate the adulteration in fuel samples.This review summarizes the various fuel adulterated sensors design and their function in detecting adulteration in fuel samples.

Index Terms- Fuel adulteration, Petroleum Products,Hydrocarbons, Sensors.

I. Introduction

Petroleum is a fossilized mass existing beneath the earth's surface as geological formations. Its raw form is known as 'crude oil' that mostly contains organic compounds and hydrocarbons. Its elemental composition by weight is usually distributed among carbon (83-85%), hydrogen (10-14%), nitrogen (0.1-2%), oxygen (0.05-1.5%), sulfur (0.05-6%) and organometallic compounds (vanadium, nickel, lead, arsenic, and other trace metals[1]. The important hydrocarbons groups existing in the crude oil are naphthene's (cycloalkanes), paraffin (alkanes), and aromatics, whereas olefins (alkenes) are formation, occurs during the processing of crude. Petroleum processing industry categorized into three different sectors; 1) upstream 2) midstream and 3) downstream. Exploration of the crude oil carried out by upstream and midstream sector involves in transportation of crude oil from the exploration site to the refinery site. Crude oil refining into various products such as petrochemicals is significant activity in the downstream sector. Various types of hydrocarbon fuels and valued components are produced through the petrol refinery process. A variety of finished products such as aviation fuel, liquefied petroleum gas, petrol (gasoline), diesel, kerosene, lubricants, asphalt, and waxes etc are obtained. Hydrocarbon fuels obtained from refining streams before being supplied to the market for their use are mandatory to comply with regulatory requirements which are in agreement with the global norms. Petrol and diesel are automobile fuels extensively used worldwide for transport. Being a low boiling hydrocarbons mixture, petrol is suitable for spark ignition engines where an electrical spark ignites the mixture of fuel vapors and air[2]. Petrol is a petroleum-derived product containing a mixture of liquid aromatic and aliphatic hydrocarbons, ranging between C4 to C12 carbon atoms with the 30-225 °C boiling range. It is primarily a mixture of naphthene's, paraffin, olefins, and aromatics. Some additives such as methyl ethers and aliphatic alcohols are also required for improving its octane number[3]–[7].

Diesel fuel is extensively used across several sectors such as in the automobiles, household appliances, agricultural equipment, etc. Diesel is combusted in a compression-ignition engine in which ignition of the fuel that is injected into the combustion chamber is caused by the high temperature which gas achieves when greatly compressed[2].The hydrocarbons types in the diesel fuel are typically similar to the petrol however the carbon number and molecular weight are higher. The usual boiling range of diesel is within 180-370 °C whilst carbon number range lies within C10-C19. Similar to the petrol, thedifference in the nature and composition of diesel fuel is usually accounted due to the difference in the refining processes[8]. The requirement for the energy is rising at a rapid pace in the developing world setting a thrust on the usage of fossil fuels. International Energy Agency (IEA) has accounted for, in general, the worldwide energy supplies, gross consumption of fuel across various sectors and predicted requirements in the future[9]. Worldwide, the transportation is considered a substantial energy demanding sector, requirements of which are mostly met through fossil fuels[10].

The petroleum products have been exploiting in transportation, power generation as fuel, universally in everyday life. The consumption is escalating every single year to the tune of nearly 4%. The business person who vends the transportation fuels are adopting fraudulent practices for their profit by adding low-priced hydrocarbon additives to the base fuel. This kind of practices are triggering environmental pollution. The pollutants exiting as exhaust tail pipe is posing an immense threat both to the human health as well as environment. To check, control the adulterants both in gasoline and diesel there shall be flawless mechanism both atstatutory level as well as laboratory level. On board fuel adulterant detection sensors offer easy and quick detection of adulterants present in the fuel sample than the expensive and tedious laboratory methods. Various fuel adulteration detection sensors have been designed and fabricated to evaluate the fuel adulteration[11]–[13]. In addition, computational techniques also have been employed to detect the fuel adulteration. One such method to evaluate the fuel adulteration is Artificial Neural Network(ANN)[14].

II. FUEL ADULTERATION

The crude oil may vary with the place to place and shall have alkanes (straight and branched chain from about C1 to C4) (low boiling fraction), cyclo alkanes or naphthenes, and aromatic hydrocarbons. The main fractions of the petroleum are Gas (52CC−) light Naptha (795−C°C), medium Naptha (79°-121°C), heavy Naptha (121°-191°C), kerosene (191°-277°C), distillate fuel oil (277°-343°C), gas oil or lube stock (343°-566°C), residuum (566°C +)[15].

Fuel adulteration means introduction of a foreign constituent into petrol and diesel, illegally or unauthorized with the result that the product does not correspond to the requirements and specifications of the Bureau of Indian Standards specifications number IS 2796 and IS 1460 for petrol and diesel respectively or any other requirement notified by the Central Government from time to time. Adulteration involving the addition of organic solvents, such as alkanes that are straight and branched from about C1 to C4,light aliphatic (C4-C8),heavy aliphatic (C13-C15), and aromatic hydrocarbons ,especially, benzene, toluene,xylenes, hexane, complex hydrocarbon mixtures, mineral spirits,kerosene, rubber solvent, petrochemical naphtha, diesel, and thinner have been used to carry out the adulteration[16].

2.1. Extent of Adulteration

The studies obtained from the Indian Oil Corporation revealed that 8.3% samples which are tested are adulterated. This encourages the dealers and the businessmen to go for the intelligent mix in the fuel. Thus, reaping profit at around rupees 25000 a day.

2.2. Approach for fuel adulteration detection

a. For petrol:

The parameters like density, distillation, stability (Existing gum, Potential gum), hydrocarbon composition (aromatic, Vol%, olefins, Vol%, Benzene, Vol%, sulphur, ppm), octane number (Research, Motor), multifunctional additives-dosage are conducted for petrol[2], [5], [8], [11], [12], [14], [16]–[19].

b. For diesel:

The parameters density, flash point, distillation, sulphur, total sediment, polycyclic aromatics (+2 rings), cetane index, cetane number, multifunctional additives dosage, cetane improver presence are selected for test[2], [4], [5], [8], [11], [12], [14]–[19].

2.3. Consequences of adulteration:

Fuel adulteration induces economic losses to the end consumer, higher emissions, decrease in the rated efficiency of the engines apart from the damage to the engine parts. Emissions of the tail pipe in the form of carbon monoxide(CO), hydrocarbons (HC), oxides of nitrogen (Nox), particulate matter(PM), may lead to toxic substances in theair. These toxins bring about carcinogenic pollutants,which are air toxins like benzene and polyaromatic hydrocarbons(PAH's) pollutants. Moreover, the use of biomass as domestic fuel lead to indoor air pollution[20].

Petrol Adulteration: The solvents that are within the same boiling point ranges such as toluene, xylene, and other aromatics when added to the petrol will not show much perceive variation. These solvents when added in higher quantity lead to enhanced HC, CO, Nox emissions, air toxins[21].

Diesel adulteration: - Kerosene is often blended with diesel due to the low-temperatureoperability (particularly for cetane number and viscosity) of the fuel and upon increased blending would lead to more sulfur emission. There will be a noticeable change in color in case of heavy oil blending in diesel[21].

III. FUEL ADULTERATION DETECTION SENSORS

Difficulty in the composition of petroleum-derived fuels and their potential adulterants leads to a challenging situation where compliance and implementation of standard norms are not easy. Widely approved and adopted standard methods such as EN, ATSM, and ISO that encompass a variety of properties for testing fuels. There is no particular technique is precisely designed to assess the adulteration of fuel while most of these techniques are equally applicable to assess the adulteration of petrol and diesel fuels.

Due to price hike in petroleum products, adulteration is being observed everywhere. Suppliers could have profit about 10-15% by mixing petrol and various constituents. There are several sensors were designed to define theconcentration of adulteration in fuel samples.

2.4. Fuel Adulteration detection sensor using IR sensor/imaging processing

Jersha V and his co-workers have been described automatic fuel adulteration detection and reporting system. In this fuel adulteration detection technique, a sample of the fuel is heated to a temperature which is equal to the boiling point of the kerosene and petrol. In thecase of petrol, it is being heated to a temperature equal to the boiling point of petrol and in thecase of diesel, it is being heated to a temperature equal to the boiling point of kerosene. So that any one of the constituent fuel gets evaporated and another constituent fuel is left in the in thesample. For instance, in thecase of diesel adulterated with kerosene, the constituent fuel left would be diesel. Similarly, in thecase of petrol adulterated with kerosene, the constituent fuel left would be kerosene. From this study amount of the fueladulteration can be detected. The quantity of the left-out sample after heating the adulterated fuel is detected by using two different techniques. The first technique employs Infrared (IR) sensors and the second technique employs camera based Imaging system for detection of sample level. At theend two techniques were compared and image processing technique has been given better results than IR detection technique[11].

2.5. Fuel Adulteration detection sensor using Micro-controller(ARM)

S.D. Kale et.al had described a micro-controller based technique for determination of adulteration concentration in thesample. In this technique, fuel adulteration has done by investigating various parameters such as viscosity and density are which are determined by experimental setup and whereas parameters such as temperature and humidity determined by using sensors. The determined test results were compared with standard references using ARM micro-controller which provides anoutput on LCD screen[22].

2.6. *Fuel adulteration detection sensor based on nonporous silicon micro cavity*

An optical sensor has been developed to estimate the amount of adulteration in fuel sample using a porous silicon microcavity which is fabricated using electrochemical anodization method. Reflectance quantities are used to estimate the concentration of kerosene which is the most frequently used fuel adulterant for diesel and petrol. The principle behind the sensing is based on the change in the effective refractive index of the silicon microcavity due to the fuel introduction into the pores leads to modification in the reflectance spectrum of the structure. This sensor also can be used for the detection of adulteration in both in diesel as well as petrol. The process of this sensor is reversible; thus, thesensor can be reusable[13].

2.7. *Simulation based fuel adulteration detection sensor*

Rajan Dey et.al developed a device design using TSM BAW micro acoustic sensor with dual density-viscosity sensing and integrated temperature sensor in COMSOL Multiphysics v4.2 and analysed both AT and SC cut quartz resonators for comparison, and found that there is a shift in frequency response of the resonator whenever the density and viscosity are changing, this change in the resonant frequency is analysed to detect the amount of adulteration [23].

2.8. *Fuel Adulteration detection sensor using highly sensitive electrical meta-material sensor*

Vaishali R and her co-workershave developed a device which works based on the electric meta material concept, i.e. complementary split-ring resonator (CSSR), operating at 2.47GHz (The industrial, scientific, and medical radio band – ISM band). This device is used to detect the kerosene adulteration in petrol. The sensor is a CSRR circuit, which exhibits sub-wavelength resonance having high sensitivity and Q-factor. Further, a Polydimethylsiloxane(PDMS) based sample cavity is designed for micro-quantity sensing to make the device more precise, sensitive and selective. A device operating at 2.47 GHz is hence proposed for adulteration of kerosene in petrol, varying up to 30 per cent. Unadulterated samples (Standard samples) were derived from the Company operated Company owned petrol pump, and the adulterated samples were made in the laboratory for precise calibration. Systematic variations in the resonance frequency and magnitude were examined with adulterated fuels. The sensing measurements were done on Vector Network Analyser (VNA). The sensing was rapid and the recovery was almost instantaneous; ensuring a sensitive and accurate device for detection of adulteration in petrol[24].

2.9. *Fuel adulteration detection sensor using long period fiber grating technology*

Vandana M et.al depicted the capability of long-period fiber grinding (LPFG) sensor innovation to distinguish the nearness of 10% contaminant in automotive fuels utilizing LPFG method while the conventional advances can identify nearness of about over 20% of the same. LPFG technique involves the shift in the transmission spectra of the different proportions of the fuel and this shift is an index of the fuel quality[17].

2.10. *Biofuel blending sensor using a microfluidic viscometer*

Sanket G et.al employed computational and the comparative experimental analysis of a micro fluidic device that examines the amount of blending by observing the interaction between the two fluid surfaces. Acrylic material with the help of well-established micro-fabrication technique. The viscosity of the different bio-diesel mixes can be utilized to demonstrate the part of bio-diesel in the fuel. The interface move is a direct result of the more prominent inhabitancy rate of a liquid having ahigher viscosity in the channel[25].

2.11. *Fuel adulteration detection sensor using turnaround point long period fiber gratings in B/Ge doped fiber*

Sanjay K et.al recommended the utilization of turnaround-point long-period fiber gratings for wavelength encoded thelocation of adulteration in fuels, they have exhibited CO2 laser composed correct TAP-LPGs in B/Ge doped filaments for fuel adulteration recognition with high affectability of 0.96nm/% change of lamp fuel in gas. A normal grinding affectability of 1635 nm/RIU for SRI in the range 1.397 to 1.4372 has been illustrated**.**

2.12. *Fuel adulteration detection sensor using silicon oxynitride based evanescent optical waveguide sensor*

Aradhana D et.al designed and fabricated a silicon oxynitride based Evanescent Optical wave guide sensor (EOWS) as the core layer on silica-silicon wafer and its operation for quick and easy detection of adulterants in petrol encompassing geometry of composite planar waveguide. The embedded waveguide of core width ~ 50 μm and length ~ 10,000 μm was fabricated using Reactive Ion Etching (RIE) and Plasma Chemical Vapour Deposition (PECVD) techniques. The vital aim of this sensor is to incorporate an abrupt choice to the time-consuming existing adulteration detection techniques which usually needs some time to give the consequence. Experimental results and theoretical predictions at wavelength 632.8nm are investigated and displayed using Simple Effective Index Method(SEIM), which established that the sensitivity of the proposed (EWOS) is 20 times more than that of asymmetric wave guide structure and nearly 40 times more than that of existing planar wave guide sensors. thereby allowing rapid detection of adulterant constituents in petrol without using any chemicals[26].

2.13. *Optical sensor for determining adulteration in a fuel sample*

An optical sensor has been developed to estimate the relative composition of two liquids in themixture. It is based on detecting changes in the intensity of reflected light at the interface of the glass-mixture brought about by changes in the one liquid proportion over that of the other in the mixture. Sample mixtures for this study have been prepared by altering the concentration of substances such as diesel and kerosene fuel in a fixed volume of petrol. A technique for detecting as well as estimating the concentration of diesel fuel or of kerosene or of a mixture of the both in a sample of petrol has been described. Evaporation of these fuel sample mixtures is achieved by exposing them to a constant air flow at the same temperature as that of the fuel sample mixtures. Determination of the changes in the reflected intensity is attained by using an arrangement in which one of the two isosceles surfaces of a prism (right-angled isosceles) is interfaced with the fuel sample mixture. Determined values for some of these changes are compared with the theoretical assessments for them obtained from Fresnel's equation[27].

2.14. *Fuel quantification using quartz sensors*

Muhammad R et.al developed a sensor to detect the fuel quantification and adulteration by using an array of quartz crystal sensors modified by chemical materials. The sensor response spent only up to 60 seconds for a measurement cycle. Later statistical data analysis such as Neural Network (NN) methods and Principal Component Analysis (PCA), it was possible to deduce that the sensor array is able to differentiate the fuel vapors with high reproducibility and to find out the rate of fuel adulteration with linear correlation[28].

2.15. *Mass and capacitance transducers for the detection of adulterated gasoline*

Among the existing technologies, mass and capacitance transducers are typically interesting because they can take benefit also from non-conductive sensing layers, such as most of the fascinating molecular recognition systems. In this experimental procedure, an array of quartz micro-balance sensor is accompanied by an array of capacitors obtained from a commercial biometric device. The two sets of transducers which are functionalized by sensitive polymeric and molecular films are used to measure the content of ethanol in gasoline[19].

IV. Conclusion

This review article has recapitulated some of the imperative literature reports which involved analytical approaches for monitoring of adulteration of petroleum fuels. Petrol and diesel adulteration can be analyzed more precisely with the help of fuel adulteration detection sensors, which are a perfect mechanism at thestatutory level.On-boarddetection systemscould be used in real time by developing sensor based detection in fuel adulteration. This kind of techniques can avoid the complex obstacles which generally appear in the laboratory based methods. There is arequirement of research in the area of sensor based detection, which is used for easy and quick identification of adulteration concentrations in sample fuel.

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