RealtimeImplementation and Design of a Sensor to determine Sulphur Content Variations in Kerosene Mixture

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Abstract
The variation in kerosene is challenging as it becomesheavier and higher withsulphurcontent. Sulphur is a pollutant in the air and affects life. The objective of the work is to design an efficient capacitive sensor using Finite Element Method (FEM), for analysis of sulphur content variations in kerosene andvalidate proposed work inrealtimehardware setup. Further, the measured capacitance is converted into voltage using a Desauty's bridge circuit. Results demonstrate that the measured voltage values show significant variations for different sulphur kerosene concentrations.

Keywords: Capacitive sensor, kerosene, Finite element method, Permittivity, Sulphur.

1. Introduction

There are different types of crude oils produced around the world with variation in hydrocarbons [1]. The main important quality characteristics of crude oil are density and sulfur content. The market value of an individual crude stream reflects its quality characteristics and properties. Kerosene is one of the byproduct of crude oil and is a combustible hydrocarbon liquid. It is usually called paraffin in the UK, Southern Asia, and South Africa.

Kerosene is widely used as a jet fuel,lighting fuel, cooking and for fire toys such as poi[7]. Kerosene lamps are widely used for lighting in rural areas of Asia and Africa where electrical distribution is not available or too costly for widespread use [3]. It is estimated that, about 1.5 million barrels per day of kerosene is being consumed for all purposes [12].

The main challenge is that kerosene quality is decreasing due to more amount in sulphur and metal content. Determination of sulphur content in kerosene is of high importance because, besides being corrosive to the fuel systems, it is a pollutant to the atmosphere and disturbs eco-system [2], [6]. The relative increase of low sulphur oil is important because the demand for fuel of low sulphur content is increasing owing to air quality standards [11]. Kerosene, one of the byproducts of crude oil, is easily available and is used for realtimeexperimental setup.

The objective of the work presented is to design an efficient capacitive sensor using Finite Element Methods (FEM), for analysis of percentage sulphur content in kerosene and validate using a realtime hardware setup. Further, the measured capacitance values were converted into voltage values using a Desauty's bridge circuit. Results shows the measured voltage values show significant variations for different sulphur kerosene concentrations.

2.Modeling and FEM design

2.1. Modeling equations

In the proposed work, 3D geometric FEM models of 'E' shaped metallic plates are modeled. Corrosion resistive metal silver is used for the analysis, and measured capacitance values are converted into voltage values using a Desauty's bridge circuit.

The capacitance of the implemented sensor is given as in Eq. (1),

$$C = \frac{2W_e}{\Delta V^2} \tag{1}$$

where, W_e is the electrostatic field which is equal to energy required to charge a capacitor.

ΔV is voltage difference across the capacitor plates.

Kerosene comes in two grades depending on sulphur content mainly 1-K grade kerosene and 2-K grade kerosene [10]. One-K grade is the purest form of kerosene. It's clear or slightly yellow, with a maximum sulfur content of 0.04 percent by weight. Due to its low sulfur content, it's possible to burn 1-K kerosene without a flue to remove combustion byproducts from the room. Two-K grade kerosene contains 0.30 percent sulfur, which is a much higher level than 1-K grade kerosene. Two-K kerosene must only be burned in appliances with a flue, as the fumes released can be very harmful if inhaled.

2.2. Generation of 3D geometric model of capacitive sensor embedded in kerosene sulphur mixture

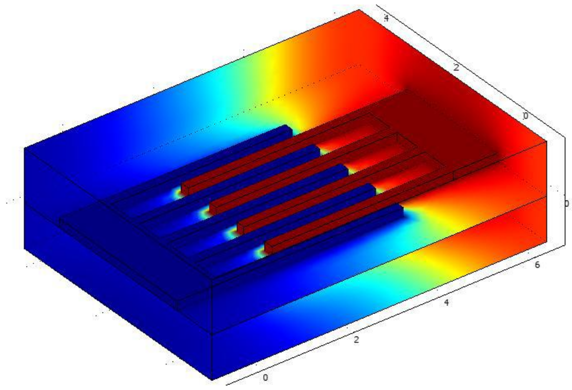

Fig. 1: 3D geometric model of Metallic plates embedded in different kerosene sulphur mixture

The 3D geometric FEM model of different kerosene sulphur mixtures were developed using COMSOL 3.5a Multiphysics finite element software. Further a set of 'E' shaped metallic plates, are modeled as shown in Fig. 1. Material properties of silver are incorporated into the metallic plates. The developed pair of metallic plates is embedded in different kerosene sulphur mixture models are shown as in Fig.1.

2.3 Mesh generation of developed models

The meshing of the developed FEM models is performed using Delaunay Triangulation (DT) method. Triangulation is a subdivision of a geometric object into simplices or triangles [5]. Delaunay Triangulation for a set P of points in the plane is a triangulation DT (P) such that no point in P is inside the circumcircle of any triangle in DT (P).

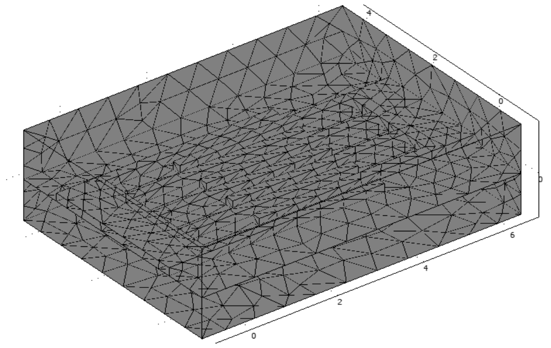

Fig. 2: Mesh model meshed model of parallel plate capacitive sensor

The circumcircle always passes through all three vertices of a triangle. Its centre is at the point where all the perpendicular bisectors of triangles sides meet [8],[9]. Delaunay triangulations maximize the minimum angle of all the angles of the triangles in the triangulation for avoiding skinny triangles. The meshed 3D geometric model of parallel plate capacitive sensor is shown in Fig. 2.

3. Design of capacitance to voltage conversion circuit

The capacitance to voltage signal conversion circuit is developed using Proteus 8 professional software as shown in Fig. 3.

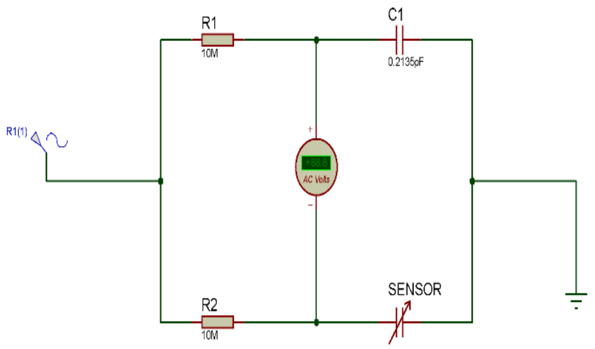

Fig. 3: Signal conditioning circuit for converting capacitance into voltage

Circuit contains two fixed resistors, one fixed capacitor and a variable capacitor. The input voltage is applied from a function generator with an amplitude of 2.2V (peak) and frequency of 7.14KHz. Parallel plates embedded in crude oil sulphur mixture will act as a variable capacitor. The values of fixed resistors are taken as 1 MΩ, and the value of fixed capacitor is taken as 12 pF using trial and error method to obtain the bridge balance condition.

4. Realtime fabrication of capacitive sensor and hardware setup

The multiplate capacitive sensor is fabricated using aluminium metal in realtime. The dimensions of the designed sensor are length 2.5cm and breadth 0.2 cm. There are 9 parallel plates which forms the designed multiplate capacitive sensor. The general schematic diagram of the experimental setup is as shown in Fig 4.

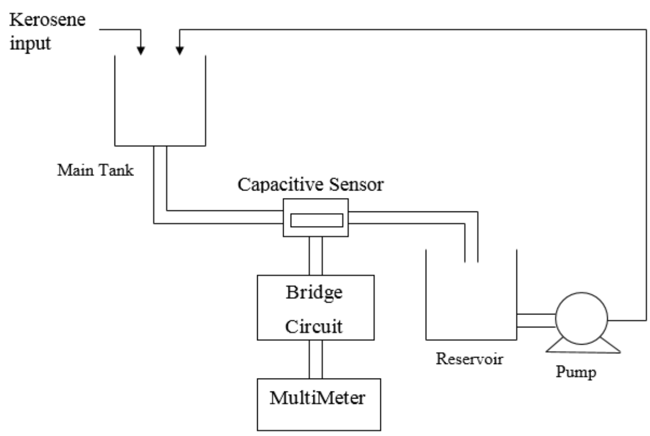

Fig. 4: Schematic diagram of sulphur kerosene hardware setup

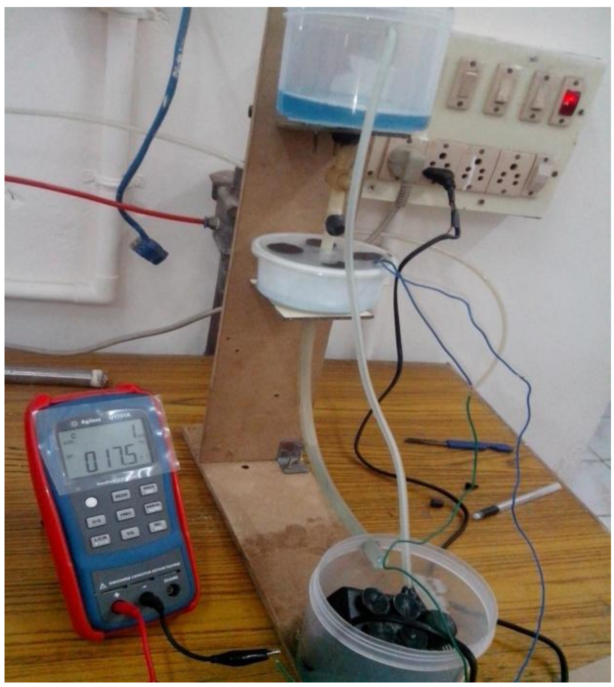

Fig. 5: Proposed realtime hardware setup for testing sulphur in kerosene

The experimental setupto determine sulphur variation in kerosene is performed as shown in Fig. 5. The hardware setup for determining sulphur variation in kerosene consists of modules like main tank, capacitive sensor, modules, reservoir, pump, bridge circuit and multimeter.

5. Results and Discussion

In this section, the hardware testing results of capacitive sensor for analyzing capacitance and voltage measurements for various dielectric mediumwere studied. The sensor is immersed in different dielectric medium and the capacitance values and its equivalent voltage measurements are determined using De-sauty's bridge circuit and are summarized in Table 1.

Table 1: Simulation results of capacitance and voltage measurements for various dielectric medium

Dielectric medium	**Dielectric constant**	**Capacitance** (F)	**Voltage** (V)
Aircore	1.000	11.00×10^{-12}	0.92
Water	80.40	4.140×10^{-6}	16.0
Glycerol	42.50	195.7×10^{-12}	7.60
Kerosene	1.800	17.90×10^{-12}	1.20
Kerosene with 1.5g sulphur	5.308	18.40×10^{-12}	1.28
Kerosene with 6.5g sulphur	5.420	18.70×10^{-12}	1.44
Kerosene with 10g sulphur	5.539	19.20×10^{-12}	1.48

The voltage measurements for different composition of sulphur in kerosene are tabulated when aninput of 2.2 V peak and 7.14 KHz frequency is applied to the bridge circuit.

Table 2: Realtime measurement of capacitance and voltage values for different sulphur concentration in kerosene

Sulphur Concentation(g)	**Capacitance(pF)**	**Voltage(V)**
1	17.5	1.50
2	18.0	1.60
3	18.2	2.25
4	18.4	2.45
5	18.5	2.50
6	18.8	2.60
7	19.0	2.66
8	19.2	2.80
9	19.3	2.92
10	19.4	3.00

The capacitance and voltage measurementsfor various sulphur concentration ranging from 1g to 10g are tabulated in Table 2. Initially, 1 g of sulphur is added to the kerosene mixture and its capacitive sensor output and bridge circuit voltage measurement are noted. Further, 1 g is added till 10 g of sulphur concentration in kerosene and various reading are listed.

The variation in output voltage of De-sauty's bridge with respect to variation in sulphur concentration is plotted and shown in Fig.6.

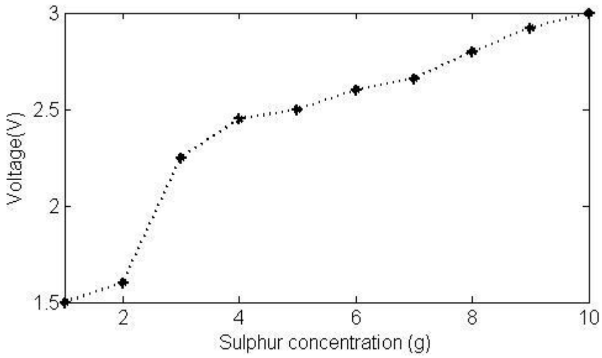

Fig. 6: Variation in voltage value for different concentration of sulphur in kerosene

The variations in capacitance value for different sulphur concentration are plotted as shown in Fig.7.

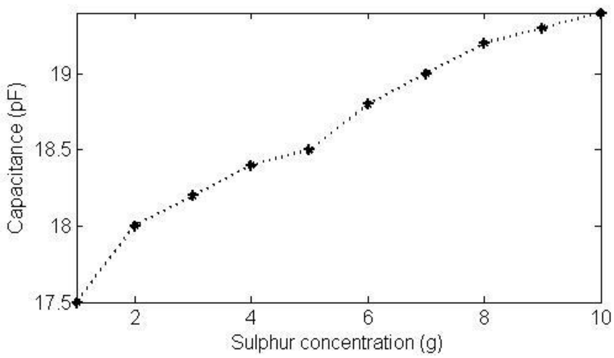

Fig.7:Variation in capacitance value for different concentration of sulphur in kerosene

It is observed from Fig. 6 and Fig7 that, both the responses show a significant variation in capacitance and voltage value. The variation of capacitance is very small, which is amplified to a significant voltage range by using signal conditioning circuit. For smaller variation in sulphur concentration the capacitance and voltage values exhibits non-linear characteristics. For medium and larger variation of sulphur concentration the voltage and capacitance value exhibits linear characteristics.

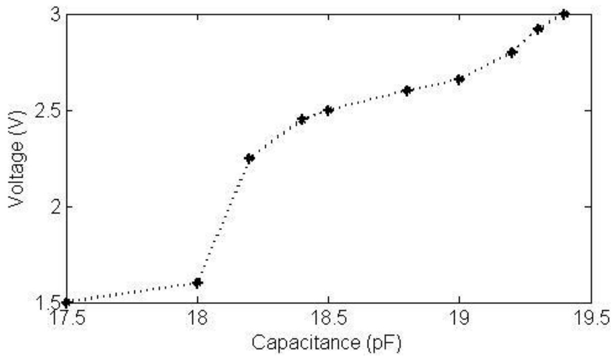

Fig. 8: Scatter plots for different concentration of sulphur in kerosene

The Scatter plot which showsvariations of capacitance and voltage value for different concentration of sulphur in kerosene is analyzed and shown in Fig. 8. It is observed that the sensor characteristic is linear as voltage increases linearly with increase in capacitance except for the starting changes.

7. Conclusion

In this paper, an attempt to 3D geometric models of different concentration of sulphur in kerosene has been proposed using COMSOL 3.5a, and an efficientmultiplate capacitive sensor is embedded in the developed sulphur kerosene models. Further, proposed work is tested in realtime setup to determine sulphur concentration variations in kerosene mixture.The sensor is fabricated using aluminium metal. Thefabrication of capacitive sensor can also be done using silver, gold, platinum etc.Since aluminium is cost effective and corrosive resistant, it is used for sensor design. The sensor is installed in the pipeline for testing. The capacitance values are obtained from the sensor for different concentration of sulphur in kerosene. The small variation in generated capacitance by the sensor is designed to convert low sensor output to a significant voltage range using Desauty's bridge. Results demonstrate that the developed capacitive sensor is efficient in determining the sulphur content in kerosene. This work can be applied to high industrial relevance areas for the designing suitable sensors in determination of percentage content variation in other mixtures.

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