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Complimentary Split Ring Resonator (CSRR) As A Viscometer for Engine Oils

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ABSTRACT

The viscosity of engine oils often deteriorates by the dynamic process with the combined effects of working conditions, contaminations and wear conditions. Therefore, the precise characterization of viscosity is important due to its association with the functionality or performance of vehicles and machinery. The current standard laboratory viscometers for liquids require cumbersome operating procedures and are time-consuming. Thus, a portable viscometer that encourages the in-situ measurement reduces the measurement duration and hassle during the sample collection will be the interest of to this study. This work aims to investigate the Complementary Split Ring Resonator (CSRR) as a viscometer for engine oils. The antenna using radiation path such as CSRR is commonly used to measure the dielectric property of substances. Hence, this approach is applied to identify the dielectric properties of engine oils and establish the correlation between viscosity and dielectric properties. Eight engine oils from Shell were tested based on their margins in the terms of kinematic viscosity. Each oil was tested and repeated three times before the mean values were determined along with the frequency of 1-9GHz. The findings show no convincing and solid correlation between the two variables due to the small dielectric constant variation of engine oil with different viscosity. The possible explanation of the results gained is the little number of additives that could affect the oil viscosity but it is too little and less likely to affects the dielectric properties of engine oil. Therefore, future works using the current resonator will be applied using different substances associated with different material properties to build a predictive model. In addition, future work can consider sweeping in low frequency that might show positive results.

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1. INTRODUCTION

Dielectric properties of materials are the interaction between electromagnetic energy and materials and are associated with the capability for energy storage in the electric field in the material [1]. A dielectric characteristic of a material is determined by its dielectric constant or relative permittivity. Hence, the dielectric properties approach has enabled researchers to apply it in various fields as sensing tools to solve contemporary problems in modern physics. Nelson [1] had carried out dielectric's potential in quality sensing applications of the agricultural field and he has found that agricultural products such as moisture content and dielectric properties can be correlated well. These results provide new information concerning the frequency and temperature-dependent behaviour of the dielectric properties that may be useful in dielectric heating applications.

Meanwhile, engine oils are made from crude oil and its derivatives by mixing additives to improve certain properties. Engine oil is used to lubricate moving parts of the engine, reducing friction, protecting against wear, removing contaminants from the engine, act as a cleaning agent and also cooling agent, by interposing a film of material between rubbing surfaces [2]. The performance and functionality of the engine oils correlate with the viscosity, which characterizes as the parameter to describe the resistance of a fluid to gradual deformation by shear stress or tensile stress. The viscosity will reflect the health status of the engine, machinery and its components that utilizing engine oils. Some analysis also reveals that engine oil viscosity can determine favourable prospects in terms of enhanced fuel economy and reduced exhaust emissions due to engine oil [3].

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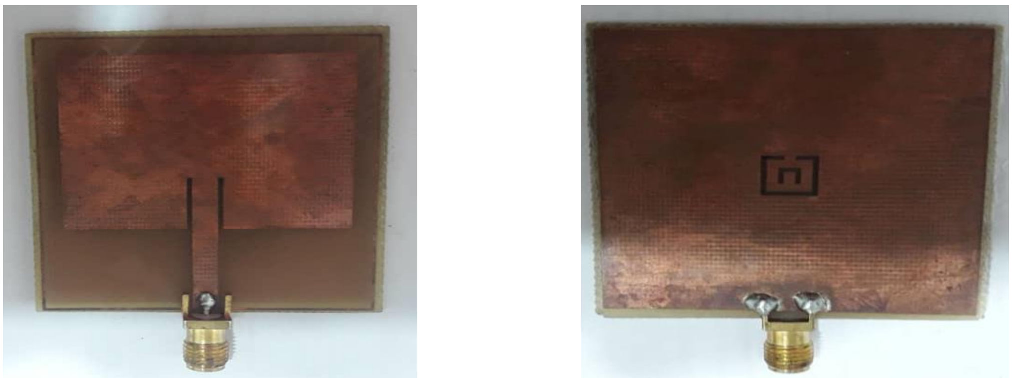
It is found that viscosity can be related closely to dielectric properties such as dielectric constant, loss factor, loss tangent and conductivity [4]. Guan [5] has obtained comprehensive responses of different dielectric response signals in the engine lubricating oil because of the relaxation behaviors of the same component at different stimulating frequencies due to the material structural and compositional characteristics. In addition, the deterioration degree of the engine oil can be measured with the change of the dielectric constant when measuring the mixture of engine oil and water using a flexible microstrip patch antenna as a sensor [6]. Similarly, three monitoring variables, namely viscosity, permittivity and wear debris were able to reflect the ageing process of lubricating oil in the investigation on the process of lubricating oil deterioration with an online multi-object monitoring system. The variation rate of viscosity can represent different working conditions of the tribe pairs, the permittivity indirectly represents the oxidation degree of lubricating oil, and the wear characteristics indicate three wear stages of tribo-pairs [7].

As shown in the aforementioned studies, the results of dielectric sensors based on viscosity rates show convincing outcomes and the development of viscosity measurement based on dielectric assessment has great potential and opportunity. Currently, the viscosity measurement requires the sample under investigation (SUI) to be tested in the laboratory. In the falling sphere technique, a specific volume of SUI is poured into the cylinder and then, a ball is dropped into the cylinder to let it fall until it reaches the bottom of the cylinder. The time taken for the ball to fall from the start to the bottom of the cylinder is measured with a stopwatch. To obtain the viscosity value, the manual calculation involves recorded time with other variables such as density of the liquid, density of ball, the radius of ball and gravitational constant needs to be performed [4]. Hence, this process is tedious and the reading condition of the indicator in the cylinder will be difficult if the SUI has a dark colour. As this measurement process is complex, it is more suitable to be accomplished by a group of trained and skillful technicians or laboratory assistants. Therefore, the cost of obtaining the results is likely to increase when a large number of samples and testing is involved. Based on the review, the detection technique based on dielectric characteristics and material properties produced promising possibilities and tremendous potential. Therefore, in this work, detection using microstrip structure in form Complimentary Split Ring Resonator (CSRR) will be used as viscometer for engine oils. This in-situ measurement technique is simple, user friendly without involving tedious operating procedures, thus reducing the measurement duration and efficiency.

2. METHODS

The antenna design of CSRR is modelled as a shunt inductor-capacitor (LC) resonator tank. This principle works with the generation of the wave propagating along the plane of the ring surface and relies on the edges of the patch for radiation. The design of CSRR in this work is shown in Figure 1 as it has a pair of enclosed loops with splits in them at opposite ends to create capacitance that influences the resonance behavior of the structure [6] while the magnetic coupling occurs through the split of the outer ring. During the design process, the CSRR is designed by using CST MICROWAVE STUDIO® which utilized the approximative equations to calculate the dimensions of the rectangular patch antenna and CSRR. The modelling and simulation results were used as a guideline to determine the best design as the fabrication process can be a tedious and challenging process due to high precision and sensitivity are essential to ensure quality and precise results [8]. The following section will discuss the fabrication methodology of the CSRR.



(a) (b)

Figure 1: CSRR; (a) Front view, (b) back view

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2.1 Fabrication of CSRR

The fabrication of a resonator to substitute the commercial probe for dielectric measurement was executed. Initially, in the fabrication process, the milling process was performed to cut the printed circuit board (PCB) into the desired size and shape. A computer numerical control (CNC) router using a 3D printer concept was used and various PCB milling bits were tested to produce the fine and smooth cutting edges for the PCB. Next, the etching process was performed to form the design on the PCB. The Direct Toner Transfer method was selected where the design is printed with a laser printer on the PCB and the unwanted area of copper will be dissolved away by the etching acid. The etching process was done by using Iron Chloride 6-hydrate by HmbG Chemicals where the printed PCB was immersed into the solution in a simple plastic box. All the unwanted copper was got rid of after 20 minutes and dried the board with the cloth. Next, the resonator was attached to the Subminiature version A (SMA) connectors by the soldering process in which PCB and SMA connectors are joined by melting and then flowing a filler metal into the joint. Finally, the complementary split ring resonator (CSRR) (Figure 1) was ready for experiments and the network analyzer (NA) was connected to the SMA connector through a high precision cable to carry on this research.

2.2 Experimental Setup

The validation of the antenna design with CSRR, water quality monitoring was performed and results shown coherent and logical values with the standard [9]. Subsequently, the antenna was used in the next investigation involved as a viscometer. Before the start of the experiment, the sellotape was attached to the resonator and replaced after each testing to eliminate the washing process. The experimental setup for this attempt is shown in Figure 2. A 3D printed cubicle as the casing was placed at the sensing part of the resonator to avoid the oil leaking out from the sensing area. Then, the SUI oil (5 droplets) was dropped into a 3D printed cubical using a pipette to obtain relatively consistent volume in the samples each time and the cubical was placed at the centre location of the ring. The testing started only after a minute to allow any air bubbles formed during dropping to disperse and for the oil to settle or spread evenly.

Figure 2: Experimental setup

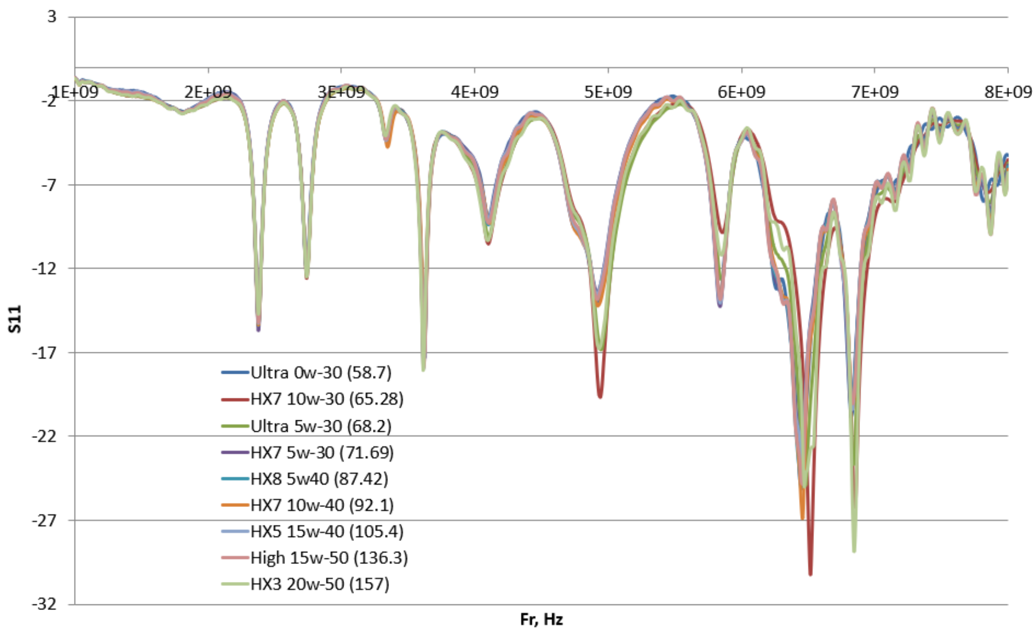
As for the viscosity, the data were extracted from a technical data sheet from Shell’s official website [10] and is shown in Table 1. Each oil was tested and repeated three times before the mean values were determined along with the frequency of 1-8GHz.

Table 1: Shell engine oils properties

Type	Ultra 0w-30	HX7 10w-30	HX7 5w-30	HX8 5w-40	HX7 10w-40	HX5 15w-40	High Mileage 15w-50	HX3 20w-50
Kinematic viscosity at $40^{O}C$, cSt	58.7	65.28	71.69	87.42	92.1	105.4	136.3	157
Level of viscosity	Low	Low	Low	Medium	Medium	Medium	High	High
Density, kg/m^3	838	854.7	841.3	843.3	880	885	858.5	888

3. RESULTS AND DISCUSSION

The results gained are shown in Figure 3. The dielectric property is denoted by the resonance frequency, S11 (dB) and the viscosity is given by kinematic viscosity, ranging from low to the high level to obtain possible correlation. The focus points were in the range of the frequency earlier that the exhibited possible relationship between viscosity and dielectric property, S11 at the range of 1.15-1.17GHz and 5.57-5.63GHz. The results show a different level of viscosity contributes to the shifting of S11 values at frequency ranges respectively as SUI is introduced to the antenna. As the viscosity of the engine oils increases, this also led to an increment of the S11 magnitude. Another obvious finding from this configuration is no consistent increment of the S11 magnitude that is proportional to the viscosity level even though in the frequency range of 1.15-1.17GHz and 5.57-5.63GHz, there are some promising correlations been observed. Therefore, the overall results gained are disappointing as weak or no consolidate relationships can be seen between the two variables measured. Even though there is a marginal difference in their dielectric property, it is still impossible to segregate them based on their correlation with viscosity property. These findings contradict with some research with pre-processed DS data of 20 samples showed comprehensive different dielectric response signals of all the components in the engine lubricating oil, although the characteristic information is hidden in the comprehensive dielectric response signals [5]. These findings might be caused by the complex nature of engine oil material properties [11]. Even some viscosity via dielectric sensors has achieved certain success, it is worth mentioning here that to date most electrochemical sensors for oil properties have not solved the cross-sensitivity problem (called overlapping) [11].



(a)

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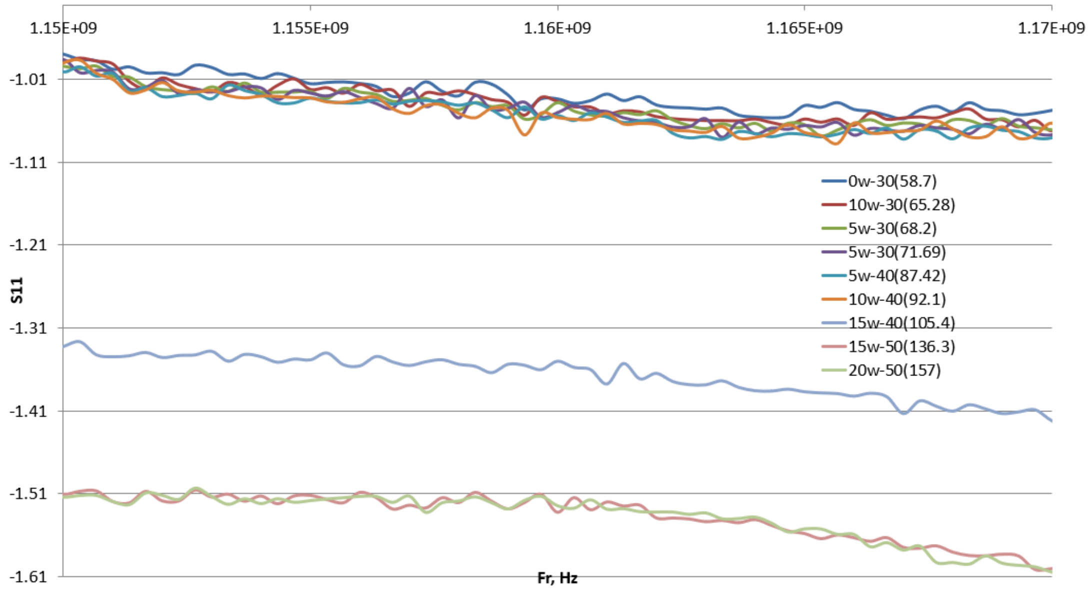

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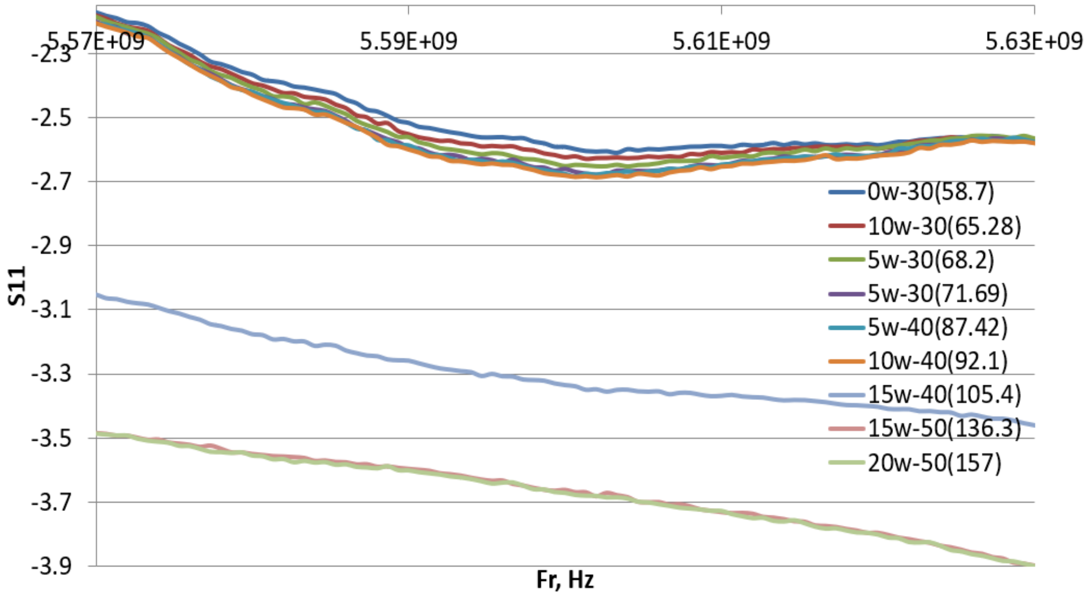

(c)

Figure 3: Shell engine oils results; (a) 1-8GHz, (b) 1.15-1.17GHz, (c) 5.57-5.63GHz

4. CONCLUSION

In this work, a viscometer operated based on dielectric spectroscopy is proposed. Antenna with CSRR as the dielectric sensors was designed, fabricated and tested with different engine oils with different viscosity. However, the results show no convincing and solid correlation between the two variables due to the small dielectric constant variation of engine oil with different viscosity. As for the recommendation, future work will be applied current resonators to other applications associated with different material properties to build a predictive model. With this innovation, data documentation will be systematic, the measurement can be completed in a shorter duration without involving complicated operating procedures. The robustness of this system will enable in-situ measurement.

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