Investigations of Complimentary Split Ring Resonator (CSSR) as Viscometer for Engine Oils

(Kajian penggunaan Complimentary Resonator Split Ring (CSSR) sebagai Viscometer untuk Minyak Pelincir)

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Abstract

Engine oils or lubricating oils are used to reduce friction and wear by interposing a film of material between rubbing surfaces. Meanwhile, a viscometer is an instrument used to identify the resistance of a fluid to shear or tensile stress. Therefore, the material property of viscosity is important in analyzing many engineering situations, specifically in the automation industries that utilizing engine oils that are associated with the functionality or performance of vehicles and machinery. Hence, this work aims to design and fabricate a Complementary Split Ring Resonator (CSRR) sensor to measure the viscosity of different types of engine oils by evaluating their dielectric properties. The CSRR is used to measure the dielectric property of engine oils and establish the relationship between viscosity and dielectric properties. The findings show the lowest viscosity oil produces the lowest dielectric constant values and the highest viscosity oil has the highest dielectric constant values. These results gained enable the possibility of distinguishing the oil engine oils based on their dielectric properties. Therefore, future works on a more comprehensive study can be conducted by purchasing various engine oils that are available in the Malaysian market.

Keywords: Engine oils, Viscometer, Dielectric

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INTRODUCTION

Engine oils are made from crude oil and its derivatives by mixing of certain other chemicals (additives) for improving their certain properties. Lubricating oil is used to lubricate moving parts of the engine, reducing friction, protecting against wear, and removing contaminants from the engine, act as a cleaning agent, and act as an anticorrosion and cooling agent. Lubricating oils are used to reduce friction and wear by interposing a film of material between rubbing surfaces. Used engine oils or lubricating oils are by-products of oil used in vehicles and machinery. They must be replaced on a regular basis in all operating equipment due to the contamination from dirt, water, salt, metals, incomplete products of combustion, or other materials

Meanwhile, viscosity is a parameter used to describe the resistance of a fluid to gradual deformation by shear stress or tensile stress. Viscosity is also an important control variable as it comes to the functionality or performance of vehicles and machinery in the automation industries that utilizing engine oils. It is found that dielectric properties such as dielectric constant, loss factor, loss tangent and conductivity can be related closely to the viscosity (G. E. Leblanc, 1999).

Dielectric materials are electrically non-conducting materials such as glass, Ebonite, mica, rubber, wood and paper and is called dielectric property when the main function of non-conducting material is to store electrical charges (Spohner, 2012). A dielectric characteristic of a material is determined by its dielectric constant or relative permittivity.

LITERATURE REVIEW

The interrelationship between material properties such as viscosity and dielectric properties, particularly in oils has been proven by various researchers. (Kumar, Singh, & Tarsikka, 2013) were able to develop a regression equation related to viscosity with dielectric properties that had a high correlation coefficient for all the oils under investigation within the temperature targeted. Hence, they suggested these properties can be sensed with appropriately designed instruments when a good correlation exists to provide the desired information such as the quality of the product.

Therefore, electrical properties provide opportunities for non-destructive sensing of quality characteristics in products where those quality characteristics can be well correlated with the electrical properties. The findings were coherent with (Guan, 2008), research where the classification of engine lubricating oils by SAE grade and source can be done simultaneously on the same dielectric spectroscopy (DS) data coupled with different support vector machine classification models. The DS data are the comprehensive responses of all the components in the engine lubricating oil and dielectric response signals can be obtained because the relaxation behaviors of the same component at different stimulating frequencies and different components at the same frequency are different and characteristic. Additionally, researchers also found this method has high accuracy and reliability but also low-cost and portability features (Piuzzi, Cataldo, & Catarinucci, 2009); These findings convince us that the approach suggested in this research is practicable.

It is found that the current standard laboratory viscometers for liquids such as U-Tube, falling sphere, falling piston, and so on, require cumbersome operating procedures and time consuming (Leblanc, 1999). Hence, this research embarks on the objective to use a fabricated CSRR resonator to investigate the relationship between the viscosity and dielectric properties of engine oils. This measuring technique is simple, user friendly without involving tedious operating procedures, thus reducing the measurement duration and efficiency.

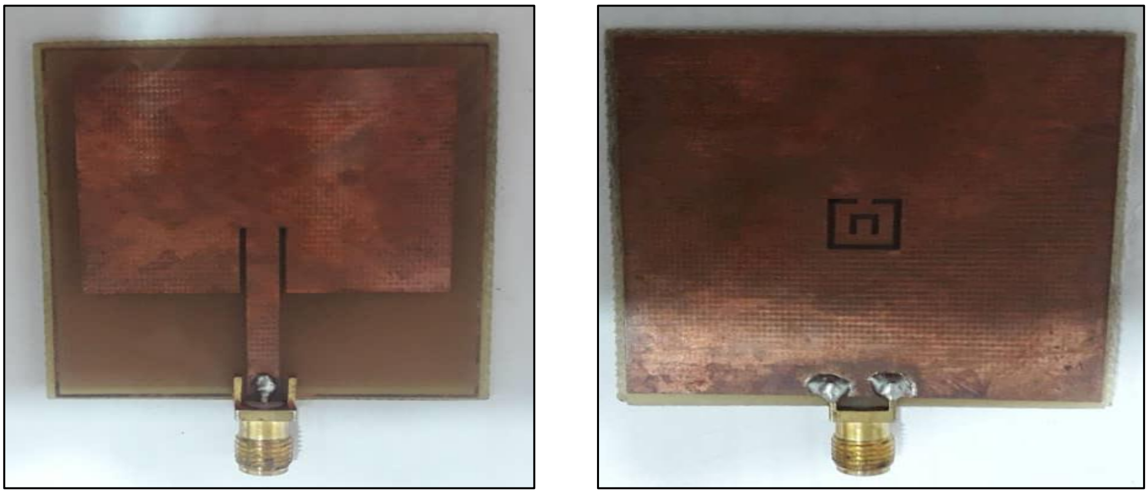
PROBLLEM STATEMENT

Since automated viscosity measurement based on dielectric assessment is not yet available on the market, this solution is required. Because this technique allows for in-situ measurement, it saves time, energy, and money on testing. The viscosity results can be obtained directly and saved for future reference. Currently, viscosity measurements are carried out using techniques such as the U tube, the falling sphere, the falling piston, the rotational viscometer, the bubble viscometer, and so on. In general, these techniques necessitate laboratory testing of the liquid. In the falling sphere technique, for example, a specific amount of liquid is inserted into a cylinder. A ball is then dropped into the cylinder and allowed to fall naturally until it reaches the bottom. A stopwatch is used to time how long it takes the ball to travel between two marks on the cylinder. The recorded time will be combined with other parameters such as the density of the liquid, the density of the ball, the radius of the ball, and the gravitational constant to calculate viscosity.

The duration of the ball falling is strongly dependent on the human factor, so this measurement process is not automated. Furthermore, the level of difficulty rises, particularly when the liquid is dark in color. Extra information, such as the density of the liquid, must be included during the calculation, which means that additional measurements to determine the density of the liquid, the density of the ball, and the radius of the ball must be performed before the viscosity measurement, lengthening the measurement time. Different sizes of balls are used for different viscosity ranges. This complicates the measurement process even more. After the viscosity is calculated, it is manually saved for further analysis; however, it is not suitable for monitoring purposes.

METHODOLOGY

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 SMA connectors by the soldering process in which PCB and SubMiniature version A (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.



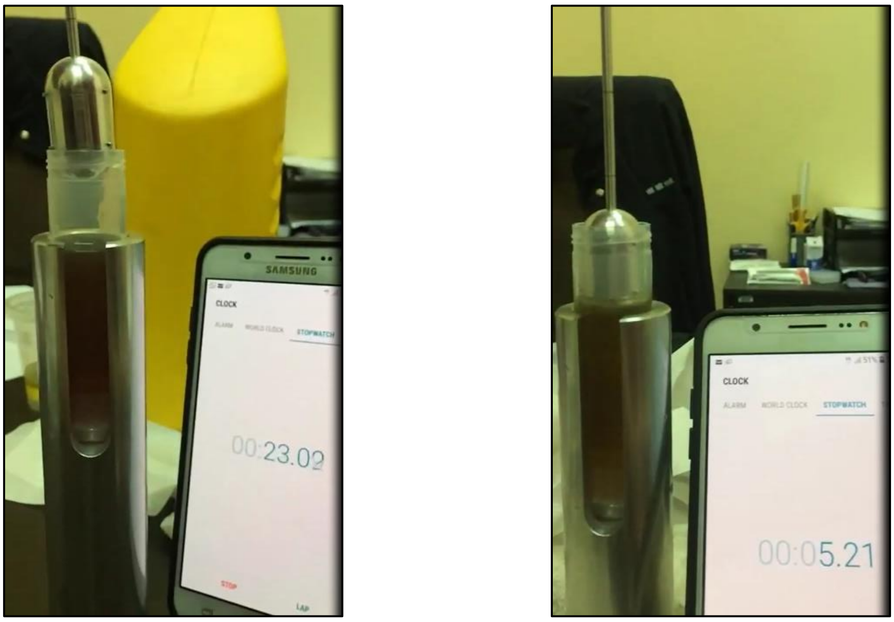
(a) (b)

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

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 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 center 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 measurement, the ball drop method was selected. The ball drop method involves the density measurement of the liquid sample under investigation (SUI). This is obtained by measuring the weight of the SUI with a fixed 100ml volume to calculate its density. Next, the SUI was filled into the cylinder of the ball drop apparatus and placed in its holder. Then the time taken for the ball to reach the level desired was measured by stopwatch with video recording for high precision reading (Figure 3).



(a) (b)

Figure 3. Ball drop viscosity measurement; (a) start level (b) ball drop

The dynamic (absolute) viscosity, μ(cP) is calculated using equation 1.

$$\mu\ (cP) = 9.1463 \times (\rho_s - \rho_f) \times t \quad (1)$$

whereas ρ denotes the density and t is the time drop taken and subscript s and f denote solid and fluid, respectively.

RESULT AND DISCUSSION

A total of nineteen samples was examined for their dielectric constant and viscosity. Table 1 shows the viscosity measurement via the ball drop method. As shown in table 1, Shell helix 20w-50 and Honda mixed-used oils have the highest and lowest viscosity at 288.89 and 50.61303 cP respectively.

Table 1. Viscosity results

S	Type	weight at 100ml, g	Density, g/ml	starting time, s	ending time, s	Time, s	μ, cP	Pa S
1	SAE 30 Petronas	85.8	0.858	18.56	26.93	8.37	158.3412	0.158341
2	SAE 10 Castrol	84.8	0.848	9.25	12.55	3.30	62.73024	0.06273
3	50:50 SAE 30 &10	85.2	0.852	16.56	20.66	4.10	77.78757	0.077788
4	Petronas 10w-30 Mach 5	83.2	0.832	13.88	19.52	5.64	108.037	0.108037
5	Honda 5w-30	83.5	0.835	12.59	16.83	4.24	81.103	0.081103
6	Honda 0w-30	82.7	0.827	12.80	16.67	3.87	74.30878	0.074309
7	Honda 10w-30	84.8	0.848	8.14	13.63	5.49	104.3603	0.10436
8	Shell helix 5w-30	82.3	0.823	12.11	17.74	5.63	108.3089	0.108309
9	Shell helix 20w-50	87.0	0.87	16.03	31.39	15.36	288.89	0.28889
10	Shell helix 15w-40	84.8	0.848	10.78	18.93	8.15	154.9247	0.154925
11	Shell helix 10w-30	84.4	0.844	22.05	28.47	6.42	122.2737	0.122274
12	Petronas 15w 40 syntium 500	85.1	0.851	14.08	23.36	9.28	176.1504	0.17615
13	Petronas 0w-40 syntium 7000	82.5	0.825	16.52	22.05	5.53	106.284	0.106284

Table 1 (continued).

14	Petronas 10w-40 syntium 800	85.0	0.85	9.58	17.08	7.50	142.4315	0.142432
15	Honda 0w-20	82.9	0.829	6.82	9.85	3.03	58.12432	0.058124
16	Voils SAE 40	85.5	0.855	9.02	14.96	5.94	112.5341	0.112534
17	Voils 20w-50	85.1	0.851	12.70	21.2	8.50	161.3447	0.161345
18	Honda mixed used	84.6	0.846	11.81	14.47	2.66	50.61303	0.050613
19	Shell helix 5w-40 used	82.6	0.826	12.43	18.43	6.00	115.2623	0.115262

Meanwhile, Figure 4 illustrates the dielectric constant for these oils. The results indicated some considerable relationships between the viscosity and dielectric constant at some range of frequency.

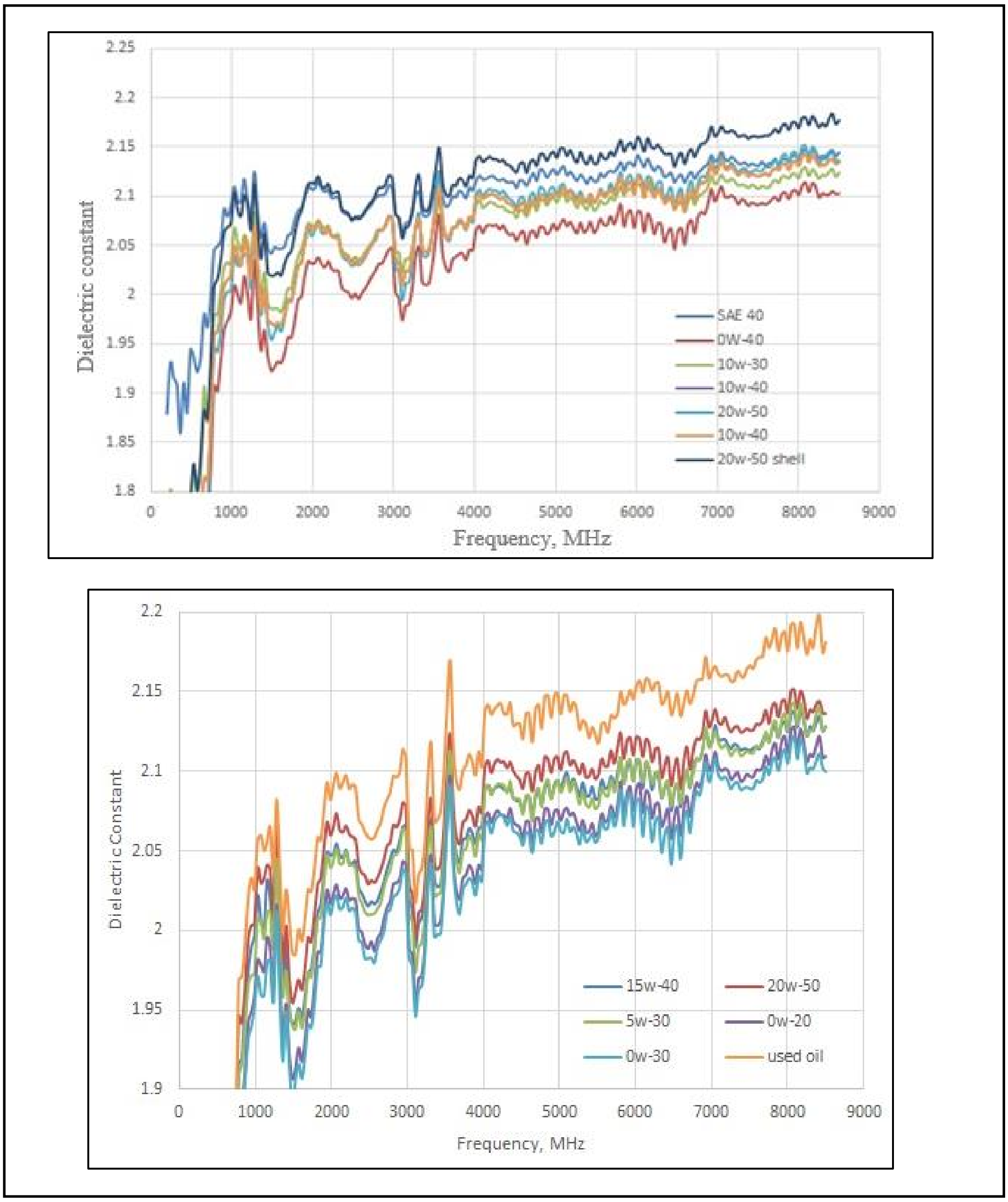


Figure 4. Initial results for various oils

For more comprehensive investigation, five engine oils were selected from the above list with consideration of increment in their viscosity as listed in Table 2.

Table 2. Five selected engine oils

Sample	Viscosity, cP
S18	50
S13	106
S17	161
S12	176
S9	288

Results on measurement done at the range frequency between 0-8.5 GHz is the focus of the study. Initial results as in Figure 5 shows a logical relationship between dielectric constant and viscosity at a certain range of the frequency.

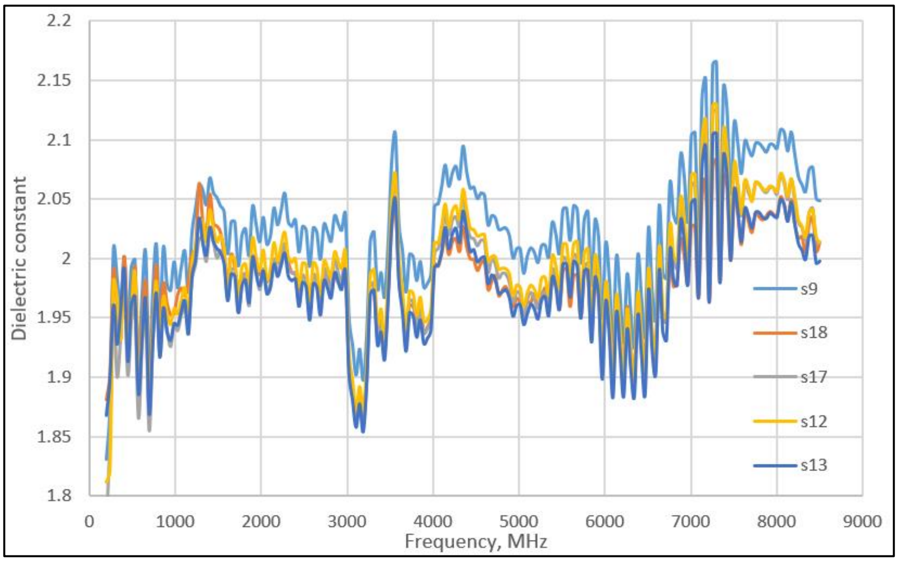


Figure 5. Early dielectric results

The best range is found to be at the frequency range of 2-3GHz (Figure 6) shows promising relationship as lowest viscosity oil, S18 produces the lowest dielectric constant values and highest viscosity oil, S9 has highest dielectric constant values.

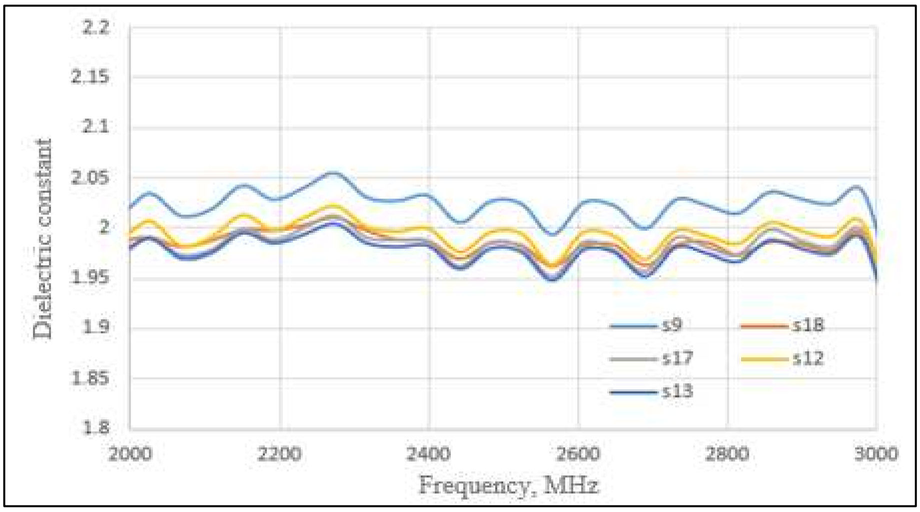


Figure 6. Dielectric constant at 2-3GHz

Later, the oils were classified into low, medium and high viscosity as S18, S17 and S9 respectively were further examined at range 4-6GHz as shown in Figure 7. Some positive relationships between dielectric constant and viscosity can be seen in the frequency range 4-5GHz.

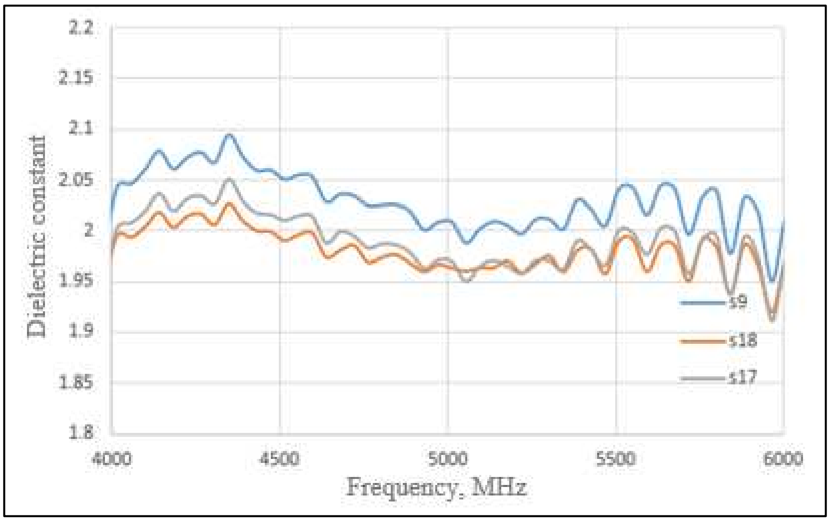


Figure 7. Results for low, medium and high viscosity at 4-6GHz

Eventually in this experimental work, the used engine oil and new engine oil were also tested and the result is shown in Figure 8. Also is shown in the figure 8, there might be some coherent relationship to distinguish the new and oil engine oils based on their dielectric properties. The viscosity of these oils is also different based on the previous research of degradation of oil showed a rapid increase of viscosity (Wang, 2001). This finding is coherent as the interrelationship between material properties such as viscosity and dielectric properties is proven by several researchers (Kumar et al., 2013). The researcher measured with correlation between viscosity and electrical properties of edible oils using experimental methods and found that the best correlating relations along with correlation constants, valid for the temperature in the selected range. They were able to develop the regression equation relating viscosity with loss tangent and electrical conductivity with high correlation coefficient. Beside that, the sensor developments and their industrial applications have been reviewed comprehensively and many sensors based on diverse physical and chemical principles have been grown and applied for detection and analysis of oil quality degradation, pollution, and wear debris concentration and constituents (Guan, 2008).

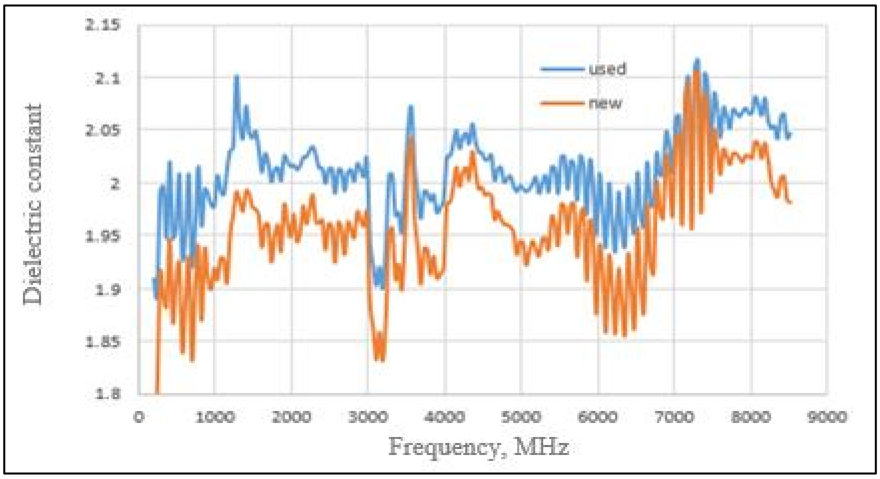


Figure 8. Used and new engine oils

CONCLUSION

In this work, a viscometer operated based on dielectric spectroscopy is proposed. A complimentary split ring resonator (CSRR) has been designed and fabricated as a censor.

By using CSRR comparison between various types of engine oil to get the relationship between viscosity and dielectric properties. Findings show there might be some coherent relationship to distinguish the viscosity of engine oils based on their dielectric properties. Typically, the lowest viscosity oil produces the lowest dielectric constant values and the highest viscosity oil has the highest dielectric constant values. Future works should be motivated by some promising results gained with a more comprehensive study that can be conducted by purchasing selected engine oils that are available in Malaysia market.

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