

# Piezosensors for Monitoring Degradation of Automotive Engine Oil

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**Abstract** Effect of the time of heating on piezoelectric sensing of engine oil has been investigated with different heating times (0, 15, 30, 45 and 60) min. Sensing signals (piezoelectric) characterized and achieved by using transducer which transmits a mechanical waves towards the glucose solution cell, and then the receptor received the attenuated signals. The range of operating frequencies was (950 kHz to 50MHz), the results of measurement which included recording the resonance frequencies (in the first order) for all prepared samples. The results showed that the resonance frequency shifted to the higher values (from 12MHz to 26MHz) for heating times (from 0 to 60 min) of engine oil.

**Keyword** Engine Oil Degradation, Piezoelectric Sensor, Resonance Frequency, Damping Coefficient

## 1. Introduction

Internal combustion engines in automobiles and other vehicles can only perform efficiently if there is proper lubrication between moving parts. Automotive engine oil is a mixture of base stock, and a number of additives which improve the operational properties of the lubricating oil[1]. Engine oils are susceptible to degradation by oxidation when operating at increased temperature, and by shear stress. The degradation of oil is very complex process and affects both additives and the base stock. Oxidation of the base stock leads to formation of different acidic products, especially carbonic acids, and polymerization processes. The reduced lubrication capabilities caused by inadequate oil viscosity and the presence of potentially corrosive oil degradation products can damage the engine[2]. Thus, there is a need to design a sensor device which can monitor oil degradation while placed directly in the oil. A variety of oil sensors monitoring different parameters such as viscosity[3], conductivity[4], and acidity[5] have been proposed. Further improvements were carried out by introducing molecular recognition properties in sensitive layers to determine the chemical composition of engine oil in gas or liquid phase by employing mass sensitive transducers[6-8]. Recently, dielectric spectroscopy has also been employed to detect the age of used engine oil[9]. In this paper, we have analyzed the piezoelectric properties of Engine oil.

## 2. Experimental Work

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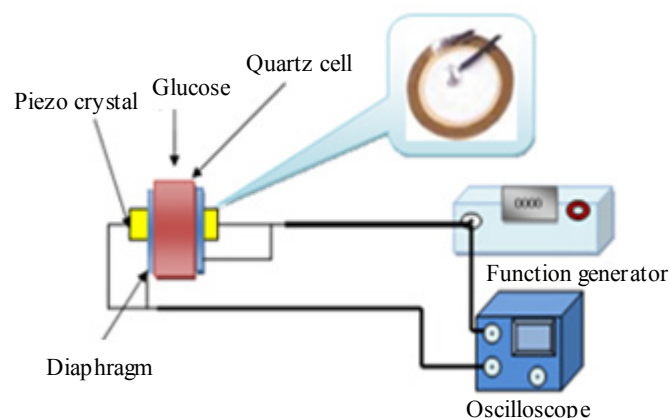
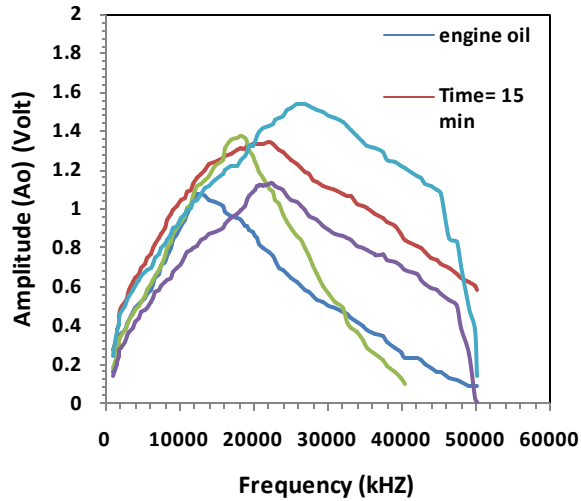


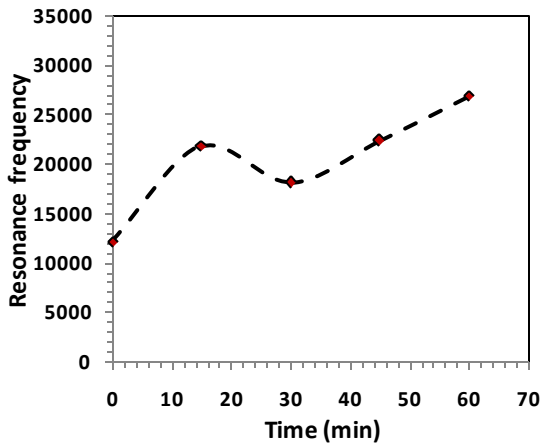
Figure 1. Experimental setup

The material used in this paper is (super diesel engine oil meets API service CF, produced and packaged by petromin corporation, Saudi Arabia) at 90°C heating temperature with different heating times. The effect of heating times (0, 15, 30, 45 and 60) min on piezoelectric sensing of engine oil was measured. The setting used in this paper include a standard two piezo-crystals (Model number: 3B12+9.0EAWC, Type: Piezoelectric Ceramics, Material: Piezoceramics, Metal type: Brass, Electrode form: (Thin) Diode, Connection terminal: Soldier wire or not, Parameter value: (D=12mm, T=0.15mm and f=9 kHz)) located tightly on the copper foil as a diaphragm shown in Fig. (1). The quartz cell ( contain the glucose solution ) embedded between the two piezo crystals, pressure (mechanical) signal was produced on the diaphragm using a function generator (B+K precision 3020) supplied an electrical signal of frequency in the range (1–100000) KHz. The pressure signal passing through the solution analyzed with the oscilloscope (KENWOOD 20 MHz CS – 1021).

### 3. Results and Discussion



**Figure 2.** The resonance frequency of engine oil at different heating times and 90°C heating temperature



**Figure 3.** Effect of heating times on resonance frequency of engine oil

The resonance frequency can be determined by measuring the output voltage as a function of frequency as shown in Fig. (2), we can observed that the resonance value varied from 950 kHz to 50 MHz at different heating times and heating temperature of 90 °C, this varied can be due to a number of reasons, such as humidity, atmospheric pressure and

mechanical loading. The effect of heating times on resonance frequency can be seen in Fig. (3).

The damping coefficient ( $\delta_D$ ) can be calculated using the relation[10]:

$$h(t) = A_0 \exp(-t/\tau) \sin(\omega t') \quad (1)$$

where:

( $A_0$ ) is the amplitude at resonance,

( $t' = 1/f$ ), ( $f$ ) is the frequency,

( $\omega = 2\pi f$ ),

( $\tau$ ) is the resonance time.

Fig. (4) (a, b, c, d and e) shown the behavior of the wave with time for different heating temperature. The damping coefficient ( $\delta_D$ ) of the water solution at different heating times were carried out from the graph and using the relation[10]:

$$\delta_D = A_1/A_2 \quad (2)$$

The shifting between the transmitted signal and that of engine oil at different heating temperature addition are shown in Fig. (5) (a, b, c, d and e), it is clearly that the large shifting vanish with increasing the source frequency.

The characteristic frequency can be calculated by using the relation (3)[11] depending on the band width and the quality factor, the result tabled in the table (1).

$$B = f_e/Q \quad (3)$$

Where:

$f_e$ : the characteristic frequency.

$Q$ : the quality factor.

The acoustic is traveling through the engine oil with velocity depending on the material addition of the water solution and on the characteristic frequency, and then the velocity could be evaluated using the relation (4)[11].

$$t = \lambda/2 = V_s/2f_e \quad (4)$$

where

$t$  = The plate thickness,

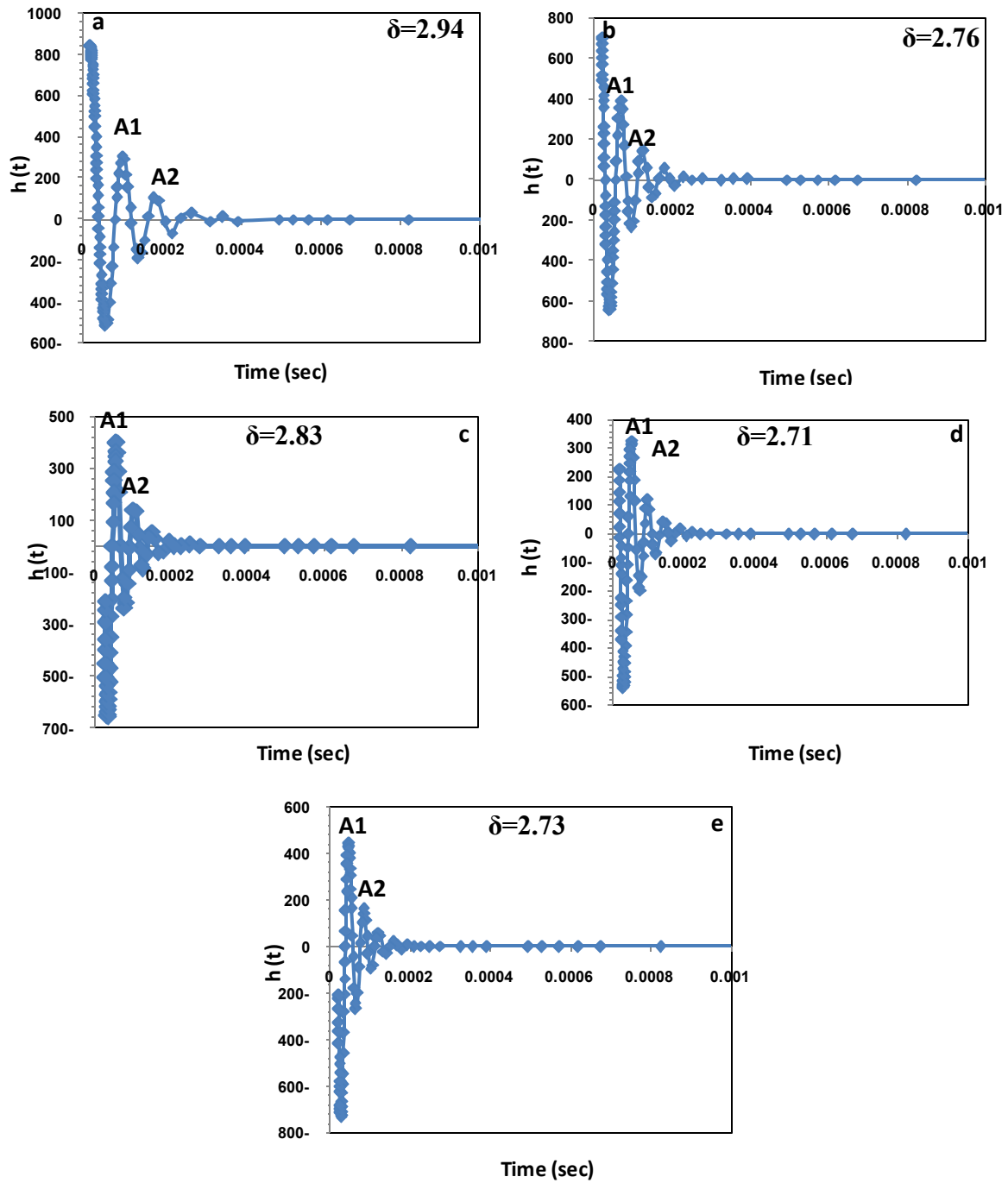
$V_s$  = The velocity of sound.

The quality factor was esteemed be using the relation (5)[12], as we observed the value of the quality decrease when the resonance frequency increase, the result was listed in table (1).

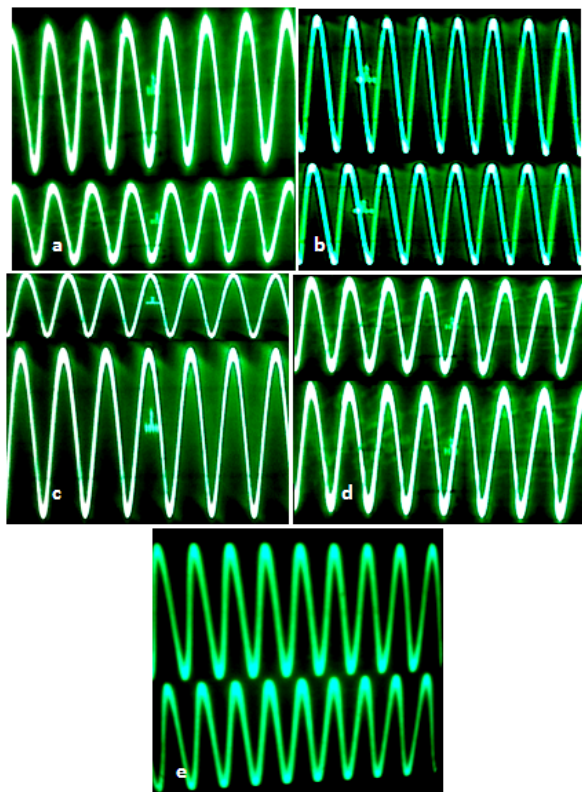
$$Q = \pi / \ln \delta \quad (5)$$

**Table (1).** The result of piezoelectric properties

Time of heating (min)	$f_o$ (kHz)	Band width (kHz) (B)	Damping coeff. ( $\delta$ )	Quality factor (Q)	Surface acoustic wave velocity ( $V_s$ )	Characteristic frequency ( $f_e$ ) (kHz)
Engine oil	12185.5	758.14	2.94	2.90	3398.23	2205.84
15	18187.3	951.01	2.76	3.08	4516.12	2931.48
30	21885.7	972.43	2.83	3.00	4507.58	2925.93
45	22415.7	800.43	2.71	3.13	3871.37	2512.96
60	26909.9	1084.89	2.73	3.11	5213.83	3384.37



**Figure 4.** Relation between the time of resonance and damping coefficient for engine oil at 90 °C with different heating times: a- engine oil, b-15 min, c-30 min, d-45 min and e- 60 min



**Figure 5.** The supplied frequencies (upper) and the sensing frequencies (lower) by the engine oil at different heating times: a- engine oil, b-15 min, c-30 min, d-45 min and e- 60 min

## 4. Conclusions

In this paper, effect of heating times on piezoelectric sensing of engine oil has been investigated with different heating times (0, 15, 30, 45 and 60) min. The results showed that the resonance frequency shifted to the higher values (from 12 MHz to 26MHz) for heating times (from 0 to 60 min) of engine oil.

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