GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 7, NO.3, JUNE 2001:579-584
COPYRIGHT (C) BACHUDO SCIENCE CO. LTD. PRINTED IN NIGERIA. ISSN 1118-0579

# VERIFICATION OF RELATIONSHIP BETWEEN RELATIVE PERMITIVITY AND VISCOSITY FOR DETERMINATION OF ADULTERATION AND GRADES OF ENGINE OIL SAMPLES

SUNDAY E. ETUK, LOUIS E. AKPABIO and SAMUEL D. EKPE

(Received 28 March 2000; Revision accepted 13 December 2000)

## ABSTRACT

The relative permittivity of adulterated engine oil with diesel oil was determined using parallel plate technique. Results show that the greater the proportion of diesel in the mixture of engine oil with diesel oil sample, the greater the relative permittivity and the less the viscosity. It was observed that the relative permittivity decreases exponentially with increase in the viscosity of the adulterated engine oil.

A mathematical model based on the relationship has been developed for the prediction or determination of adulteration of engine oil with diesel. Calibration curve showing linear relationship between capacitance and height was plotted and used to establish capacitance height calibration curve model.

**Keywords**: Adulteration, Relative Permittivity, Level, Viscosity, Dielectric

## Introduction

Viscosity is a measure of the combined effects of adhesion and cohesion of a fluid's molecules, which manifests itself as an internal force resisting the flow of the fluid. Fluids with a high internal resistance to flow are said to be viscous and will not pour or spread as easily as fluids of lesser viscosity. In many cases, the rate or degree of a reaction or the indication of the end point of a chemical process can be obtained by viscosity measurement. Where viscosity can be related to another variable such as concentration, density or colour, it can be used as an indirect measurement of these variables, which are difficult to obtain in the more conventional manner (Lavigne, 1977, Brown, 1980; Marsh et al., 1979).

Viscosity would produce retarding forces proportional to the velocity gradient normal to the direction of flow, and to the area of contact for all homogenous liquids. Viscosity depends on molecular size, length in particular and also on the magnitude of the intermolecular forces as well as temperature (Alexander, 1967; Althouse et. al., 1996 and Elbashbeshy et. al., 1993).

Viscous liquids such as engine oils are generally used for lubrication. Engine oils of different grades are used for this purpose. The particular grade of oil depends on the rated range of viscosity required for a given engine

When oil outside the rated range is used the performance of such engine is affected. Adulterated engine oils are found to damage most engines (Ekpe et al., 1999).

Automotive Air condition systems need refrigerant oils of particular viscosity to lubricate the moving parts of the compressor. These oils are highly refined and dehydrated to be compatible with Refrigerant R-12 (Marsh, et al., 1979).

Lubricating oils for motor engines are refined to have and maintain their viscosity irrespective of changes in season. Lubricating oils, which have the same coefficient of viscosity in summer and winter are known as viscostatic oils (Nelkon et al., 1982).

Engine oil, a non-polar molecules viscous liquid is dielectric in nature (Nelkon et al., 1982 and Marsh et al., 1979). Diesel, a good insulator at a very pure form is often mixed with engine oil by roadside oil dealers in order to increase the quantity and

---

SUNDAY E. ETUK, Department of Physics, University of Uyo, Uyo, Nigeria
LOUISE E. AKPABIO, Department of Physics, University of Uyo, Uyo, Nigeria
SAMUEL D. EKPE, Department of Physics, University of Uyo, Uyo, Nigeria

maximize profit. This action by the dealers result in the engine oil being adulterated, hence, changing the original properties which include density, optical density, refractive index, concentration or colour, therefore, viscosity leading to possible change in relative permittivity (Lavigne, 1977).

## Theory

Consider a parallel plate capacitor consisting of two conductor plates P and Q of area (A)m$^2$ separated by a thickness (d)m of dielectric medium of relative permittivity $\varepsilon_r$, the capacitance C of the capacitor is given by (Haslam et al., 1997).

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \quad [\text{farads}] \qquad (1)$$

But where $C_1$ is the capacitance of the parallel plate capacitor with air as dielectric medium and $C_2$ the capacitance of similar capacitor with oil as dielectric, the mathematical equations for the capacitance can be written thus (Theraja , 1979)

$$C_1 = \frac{\varepsilon_0 A}{d} \qquad (2)$$

$$C_2 = \frac{\varepsilon_0 \varepsilon_r A}{d} \qquad (3)$$

Supposing $C_1$ and $C_2$ are connected in parallel, their resultant capacitance $C_T$ is given as (Ibrahim, 1982):

$$C_T = C_1 + C_2 \qquad (4)$$

Substituting equations (2) and (3) in (4) we have

$$C_T = \frac{\varepsilon_0 A}{d} + \frac{\varepsilon_0 \varepsilon_r A}{d} \qquad (5)$$

$$C_T = \frac{\varepsilon_0 \varepsilon_r A}{d} + \frac{\varepsilon_0 A}{d} \qquad (6)$$

$$C_T = \frac{\varepsilon_0 \varepsilon_r wh}{d} + \frac{\varepsilon_0 A}{d} \qquad (7)$$

Where A = area of the plate in meter square (m$^2$)
d = distance or separation between plates in meters (m)
$\varepsilon_r$ = relative permittivity of dielectric
$\varepsilon_o$ = permittivity of free space which is $8.854 \times 10^{-12}$ Fm$^{-1}$
w = width of the plates in meters (m)
h = height of the plates in meters (m)

Assuming the parallel plates are inserted in an insulated tank containing dielectric liquid, forming a capacitor system whose dielectrics are the liquid itself and the air in the space above the liquid, variations of the liquid dielectric by its rise and fall in the tank can alter the effective capacitance of the system since the dielectric constants of liquids are normally much greater than those of gases (Miller, 1978).

Considering equation (7) above, a plot of combined capacitance, $C_T$ in farads, against height of the level of the oils, h in meters, gives a straight-line graph. The slope of the graph giving the numerical values of $\varepsilon_o\varepsilon_r w/d$ where the relative permittivity, $\varepsilon_r$, of the oil sample can be calculated having known the values of d and w.

## Materials and Methods:

**Materials:** Engine oil (SAE 40, SAE 90) and diesel oil were obtained from petroleum oil station, Aka Road, Uyo in Akwa Ibom State, Nigeria. The engine and diesel oil samples were subsequently mixed in the ratios of engine oil to diesel oil by volume being 5:1, 4:1, 3:2 and 1:1. Two identical plates, measuring 0.032m by 0.26m, were cut from a sheet of aluminium, each having a copper wire connected to its midpoint by tight and firm screwing and soldering to serve as a connecting terminal for each of the plates. The two plates were insulated on one surface each. Other materials used include two graduated measuring cylinders with 100ml and 1000ml capacities, beakers, density bottle, Oswald viscometer, stopwatch, sensitive mettler balance (Mettler P165, Gallenhamp) and a high sensitive LCR Digital Avometer B183.

**Experimental Method:** The two identical aluminium plates were placed parallel to each other at a distance 0.005m such that the conducting surfaces faced each other in a clean dry graduated cylindrical open glass vessel of 1000ml capacity, with the two conducting terminals protruding out. The two terminals of the parallel plate capacitor system were firmly connected to the two terminals of the sensitive LCR Digital Avometer switched to capacitance range for capacitance measurement.

The capacitance of air medium without oil sample was first measured and recorded. Diesel oil was then introduced into the vessel and capacitance measured and recorded at different heights; 0.026, 0.052, 0.078, 0.104, 0.130, 0.156, 0.182, 0.208, 0.234, 0.260 meters.

The experiment was repeated for pure engine oils, and the mixtures of engine oil with diesel at different proportions (Miller, 1978). At each instance, the graduated cylinder and the plates were washed and dried before introducing a new sample to avoid error. The same glass vessel, conducting plates with fixed distance, 0.005m, between the plates were used throughout the experiment to ensure uniformity.

SAE 40 grade of Engine oil was then poured into the vessel to 100ml volume mark corresponding to a height of 0.026m and the corresponding capacitance C was read and recorded. The procedure was repeated for 200ml, 300ml, 400ml, 500ml, 600ml, 700ml, 800ml, 900ml and 1000ml marks with the corresponding heights and capacitance measured and recorded. The same procedure was carried out for SAE 90 and a mixture of 50% SAE 40 with 50% SAE 90.

The coefficient of viscosity of the engine oil, (SAE 40, SAE 90, and a mixture of 50% SAE 40 with 50% SAE 90), diesel oil samples and their mixtures were determined, using Oswald viscometer (Philip Harris, 1985).

Densities were measured using specific gravity bottle (Abbott, 1976). Relative permittivity for each sample was determined by plotting capacitance, $C_T$ in farads, against height, h in meters, in equation (7). The lines were approximated using the least square method. Relative permittivity, $\varepsilon_r$, for each sample was deduced from the slope of the graph corresponding to the sample.

## Results and Discussion

Fig I shows the plot of the capacitance, C, against height, h, for engine oil, diesel oil and their mixtures. The lines were approximated by using the least square method. Height correlates positively with capacitance with correlation coefficient of 0.98 for engine oil, 0.98 for diesel, 0.98 for 1:1, 0.98 for 2:3, 0.96 for 1:4 and 0.97 for 1:5 mixture of diesel to engine oil samples using Pearson moment correlation coefficient method. It shows that capacitance of each sample increases as the height increases [Miller, 1978]. It was observed from the deduction of relative permittivity using the slope of the graph that relative permittivity increases as the proportion of diesel with engine oil increases. Experimental results for the relative permittivity and viscosity of engine oil, diesel and engine oil adulterated with diesel at temperature of 301K is presented in Fig. 2. A plot of relative permittivity, $\varepsilon_r$, against viscosity, $\eta$, for the oil samples (Fig. 2) gives an exponential

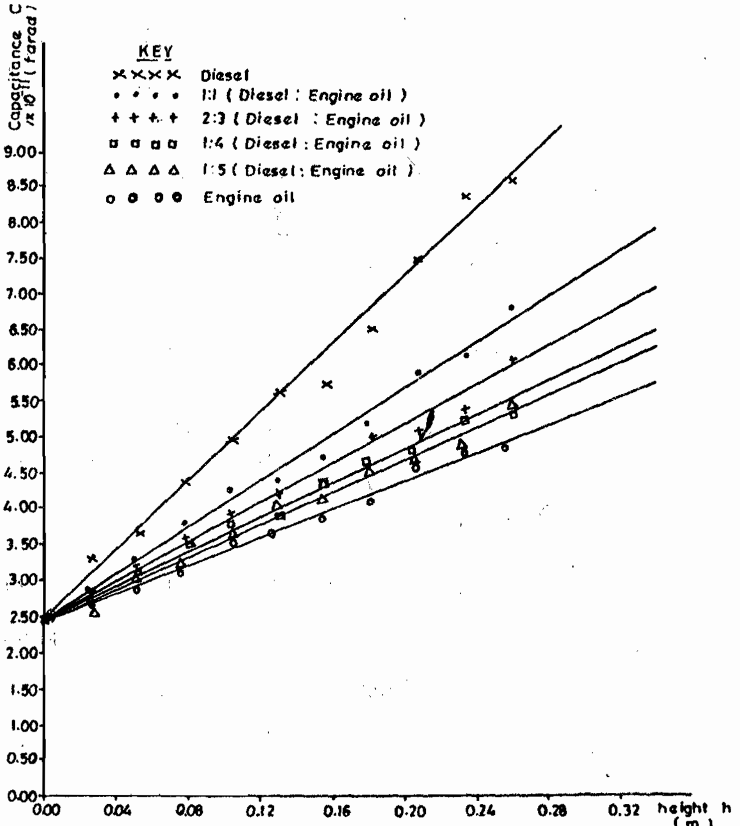

Fig. I. PLOT OF CAPACITANCE VERSUS HEIGHT FOR ENGINE OIL DIESEL OIL AND THEIR MIXTURES.

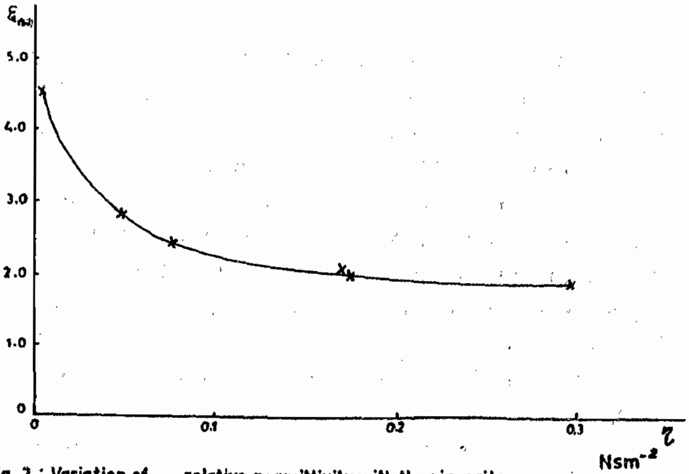

Fig. 2 : Variation of relative permittivity with the viscosity

Table 1: Experimental results for the relative permittivity and viscosity of Engine oil, Diesel oil and Engine oil adulterated with Diesel oil at Temperature of 301k.

| Sample | Density ρ Kgm-$^3$ | Relative permittivity $\varepsilon_{r(oil)}$ | Viscosity η | lnη |
|---|---|---|---|---|
| Diesel oil | 858.03 | 4.5140 | 0.0023 | -6.0748 |
| Diesel: Engine oil 1:1 | 867.00 | 2.8359 | 0.0477 | -3.0428 |
| Diesel: Engine oil 2:3 | 878.00 | 2.3890 | 0.0741 | -2.6023 |
| Diesel: Engine oil 1:4 | 880.02 | 2.1100 | 0.1700 | -1.7719 |
| Diesel: Engine oil 1:5 | 881.69 | 2.0110 | 0.1747 | -1.7447 |
| Engine oil | 883.60 | 1.9000 | 0.2966 | -1.2154 |

Table 2: Experimental Results for the relative pemittivity and viscosity of Engine oil at Temperature of 301K.

| Sample | Viscosity η (Nsm$^{-2}$) | Relative permittivity $\varepsilon_{r(oil)}$ | | Percentage error (%) |
|---|---|---|---|---|
| | | Measured | Calculated | |
| SAE 40 | 0.2966 | 2.00 | 1.704 | 14.8 |
| SAE 90 | 0.7338 | 1.44 | 1.179 | 18.0 |
| 50% SAE 40 with 50% SAE 90 | 0.4892 | 1.60 | 1.414 | 11.0 |

*relationship between the variables. Fig. 3* shows the plot of the relative permittivity against the natural logarithm of viscosity, lnη, resulting in a straight-line graph with negative slope passing through $\varepsilon_r$ axis at 1. The point of interception gives the value of the relative permittivity as a result of stray capacitance of a parallel plate capacitor (Tyler, 1971). *The value of the intercept is* the relative permittivity of air when there is no oil sample.

Table I shows the relationships between relative permittivity and viscosity. The variations in Figs. 2 and 3 could be expressed (respectively) as:

$$\eta = \eta_0 e^{-\varepsilon_{r(oil)}A} \qquad (8)$$

$$\varepsilon_{r(oil)} = \frac{\ln\eta_0}{A} - \frac{\ln\eta}{A} \qquad (9)$$

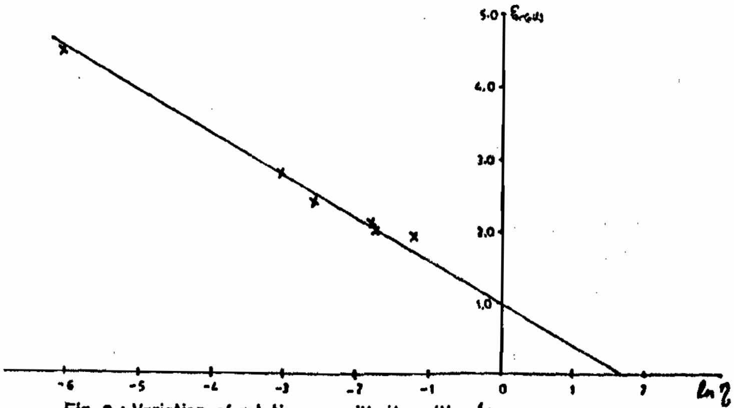

Fig. 3 : Variation of relative permittivity with ln η

Equation (9) yields:

$$\varepsilon_{r(oil)} = -0.579 \ln\eta + 1 \qquad (10)$$

Considering equation (9) illustrated by the straight line graph (Fig 3), the slope of the graph gives the value of 1/A, while the reciprocal of the slope gives the numerical value of A being −1.7271 which could be regarded as the adulteration constant. The value of $\ln\eta_o/A$ is indicated by the intercept. The quotient of the intercept and slope gives $\ln\eta_o$, from where the value of $\eta_o$ could be derived. $\eta_o$ which is approximately 0.20 is assumed to be the viscosity of pure SAE40 engine oil at temperature of 301K.

Equation (10) gives the required model for predicting relative permittivity of adulterated engine oil with diesel. Hence, the mathematical model derived from Figs. 2 and 3 should be used for the determination of relative permittivity of adulterated engine oil $\varepsilon_{r(oil)}$.

Fig. 4 shows the plot of capacitance, C, in farads against height, h, in metres for the three oil samples SAE 40, SAE 90 and the mixture of the two respectively. The lines were also approximated by using the least square method. A high degree of correlation of height with capacitance with a correlation coefficients of 0.97 for SAE 40, 0.98 for SAE 90 and 0.98 for the mixture of 50% of each was obtained. A linear relationship between capacitance and height of the oils can be employed as a capacitance – level calibration curve to recalibrate capacitance metre to read level (Lavigne, 1977). Table 2 shows the experimental results for the engine oil samples and the calculated relative permittivity from equation (10). Percentage error of less than 19% was obtained between the measured values and the calculated values. This means that about 80% accuracy of the value of relative permittivity of engine oil could be calculated from our model.

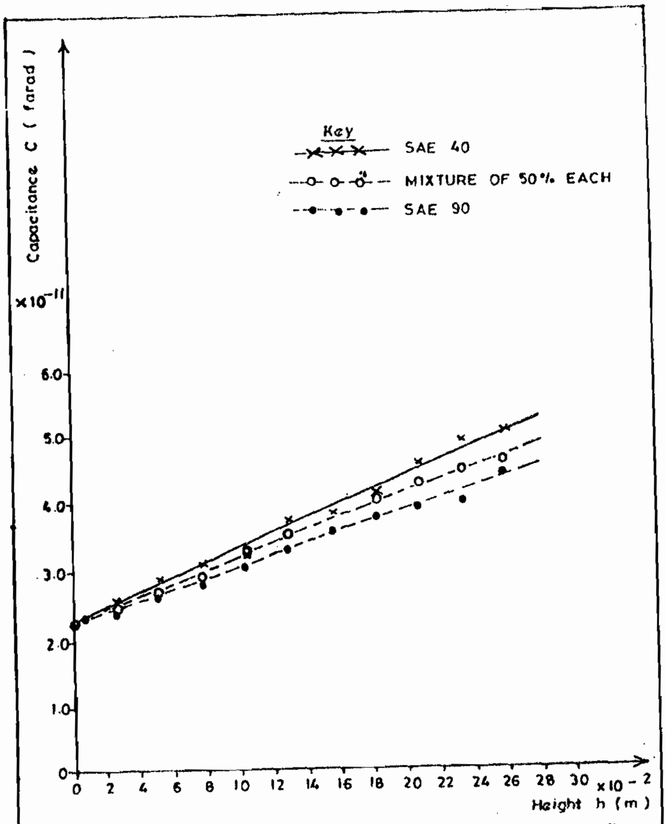

Fig. 4. Plots of Capacitance C versus Height h for the oil samples

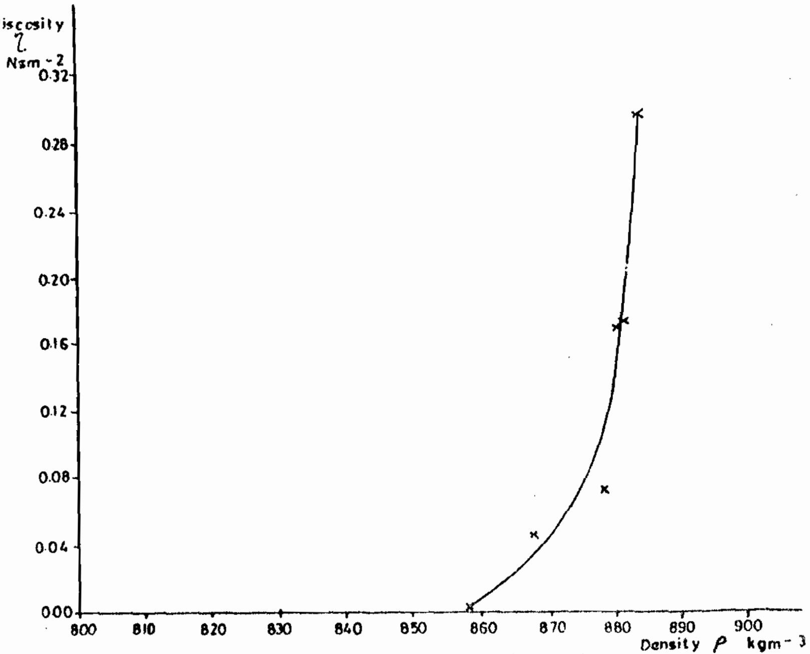

Fig. 5. Variation of Viscosity with Density of the oil Samples.

Experimental results for the density and viscosity determined for each sample are presented in Fig. 5. The values indicate that density decreases as the proportion of diesel increases (Ekpe et al, 1999). This shows that viscosity decreases as the proportion of diesel increases. It is suggested that the particles of the diesel which displaces some of the particles of the engine oil when the oil is mixed with diesel help in reducing the intermolecular forces between the particles and, hence, the reduction in viscosity. The corresponding increase in relative permittivity as a result of increase in capacitance is attributed to the increase in separation between the particles and the resulting decrease in density of the mixture. This confirms the assertion that the more the quantity of diesel added, the less the viscosity and the mass absorption coefficient of the resulting medium (Ekpe et al, 1999).

## CONCLUSION

From the experimental results, we

conclude that it is possible to determine the viscosity of engine oil from the relative permittivity of oil, hence, the level of its adulteration with diesel oil.

We also conclude that the two physical quantities (capacitance and height of liquid level) can effectively be employed in process control for the measurement, calibration and control of level in a tank, as well as the grading of engine oil.

## REFERENCES

Abbot, A. F. 1976. Ordinary Level Physics, Hienemann Educational Books, London, 616pp.

Alexander, F. 1967. Practical Physical Chemistry, 8th ed., Longman, London.

Althouse, A. D., Turnquist, C. H. and Bracciano, A. F., 1996. Modern Refrigeration and Air Conditioning, The Goodheart - Willcox Company, Inc. Illinois, 1199pp.

Brown, G. I. 1980. Introduction to Physical Chemistry, SI ed., Longman, UK., 582 pp

Collieu, A. M. and Powney, D. J., 1977. The Mechanical and Thermal properties of Materials, Edward Arnold, London, 283pp.

Ekpe, S. D. and Essien, I. O., 1999. Gamma Radiation determination of the Adulteration of Engine oil with diesel fuel. J. Sci. Eng. Tech., 6(3) 2049 - 2055.

Elbashbeshy, E. M. A. and Ibrahim, F. N., 1993. Steady Free Convection Flow with Variable Viscosity and Thermal diffusivity along a vertical plate. J. Phys. D. Appl. Phys. (26): 2137 - 2143.

Haslam, J. A., Summers, G. R. and Williams, D., 1997. Engineering Instrumentation and control, 12th ed., Edward Arnold, London, 310pp.

Ibrahim, K. F., 1982. Basic Electronic System, 2nd ed., Pitman Books Limited, London, 132pp.

Lavigne, J. R., 1977. An Introduction to Paper Industry Instrumentation. The Foxboro Company, Massachusetts, 488pp.

Marsh, R. W. and Olivo, C. T., 1979. Basics of Refrigeration, 2nd ed., Van Nostranc Reinhold Company, New York, 456pp.

Miller, J. T., 1978. Revised Course in Industrial Instrument Technology, United Trade Press Limited, London, 148pp.

Nelkon, M. and Parker, P., 1982. Advanced Level Physics, 5th ed., Heinemann Educational Books, London, 948pp.

Philip H., 1985. Science Education Equipment, Chemicals and Materials, Lynn Lane, Shenstone, Staffs WS14 OEE England, 1126pp.

Theraja, B. L., 1979. Electrical Technology, S. Chand and Company Limited, New Delhi, 1373pp.

Tyler, F., 1971. A Laboratory Manual of Physics, 4th ed., Edward Arnold (Publishers) Ltd., London , 275pp