Measurement of electrical conductivity of high insulating oil using charge decay

Qi Peng, Wang Diansheng, Liu Jing, Chen Yifei, Zhang Haotian
College of Science
China University of Petroleum (Huadong)
phone: (86) 15305323560
e-mail:qipeng@upc.edu.cn

***Abstract*—We propose a kind of measurement of electrical conductivity of high insulating oils (about 10^{-9}-10^{-15}S/m) using charge decay. Insulating and charging the oil fully, and then grounding, charge decay proceeds by exponential according to "Ohm" theory. The data of time dependence of charge density is automatically recorded using an ADAS and a computer. Relaxation time constant is fitted from the data using Gnuplot software. The electrical conductivity is calculated using relaxation time constant and dielectric permittivity. Charge density is replaced by electric potential, considering charge density is difficult to measure.**

I. Introduction

Dielectric permittivity and electrical conductivity are two important parameters to evaluate the electrical properties of the oil. Dielectric permittivity is easy to measure for the same order of magnitude for all oil. But electrical conductivity changes from 10^{-7} S/m to 10^{-15} S/m and is difficult to measure precisely, especially for the high insulating oil with electrical conductivity below 10^{-11} S/m. Electrical conductivity is a physical quantity to characterize the ability of transferring current. It must be determined precisely in evaluating the anti-static property of the oil.

II. Experimental procedure

Experimental setup is showed in Fig. 1. Charge is generated by a charge generator and conduct to the oil using a wire when the switch one (K1) is closed. The potential (U) of the oil is measured using an electrometer. The data of time (t) dependence of potential is collected and put to computer by an automatic data acquisition system (ADAS). The ADAS is designed to recorder the potential in each millisecond. The potential of the oil increases at an exponential rate and will reaches the max value (U_0) with 2 minutes. Then we open switch one (K1) and close switch two (K2). The charge in oil will be conduct to the ground at an exponential rate [1] as the Equation 1.

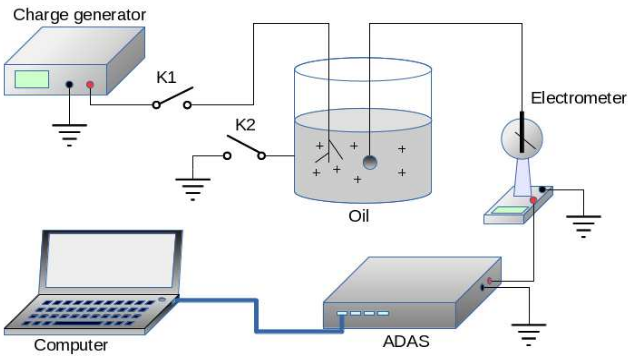

Fig. 1. Experimental setup

$$Q = Q_0 e^{-t\sigma/\varepsilon} \tag{1}$$

where Q is charge density in the oil, Q_0 is initial charge density, t is time, σ is liquid conductivity, ε is dielectric permittivity.

III. Results and Discussion

As the potential of the oil is proportional to charge, it will decrease also at an exponential rate as the Equation 2.

$$U = U_0 e^{-t\sigma/\varepsilon} = U_0 e^{-t/\tau} \tag{2}$$

where U is potential in the oil, U_0 is initial potential, t is time, τ is relaxation time constant. The ratio of dielectric permittivity to the liquid conductivity, ε/σ is referred to as the relaxation time constant, τ. The relaxation time constant is the time for a charge to dissipate to e^{-1} (approximately 37 percent) of the original value, if charge relaxation follows exponential decay. It gives an indication of the electrostatic accumulation relaxation time constant of typical liquids.

Usually there will be some background potential (U_B) left for the accumulated instrument errors under the different environment. So we use the revised Equation 3 instead of Equation 2. The background potential has no effect on relaxation time.

$$U = U_0 e^{-t\sigma/\varepsilon} + U_B = U_0 e^{-t/\tau} + U_B \tag{3}$$

Relaxation time constant τ is fitted from the data using Gnuplot software. Electrical conductivity is calculated using Equation 4.

$$\sigma = \varepsilon/\tau \tag{4}$$

where dielectric permittivity is easy to measure as the same order of magnitude. Charge relaxation of five different kinds of oils are measured using this experimental setup and relaxation time constant is fitted using Gnuplot[2] as shown in Fig. 2 to Fig. 5. All the experimental data are fitted well.

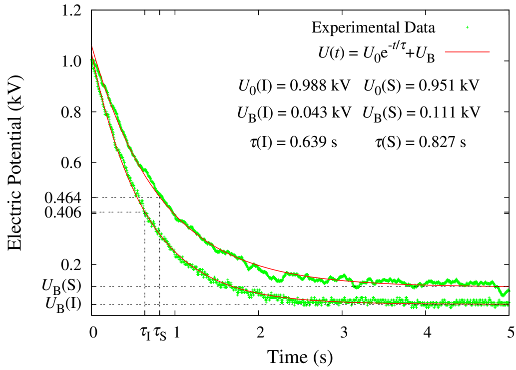

Fig. 2. Charge relaxation of crude oils. Two kinds of crude oil are measured, which are from Shengli oilfield and abroad oilfield. Both crude oils are desalted and dehydrated.

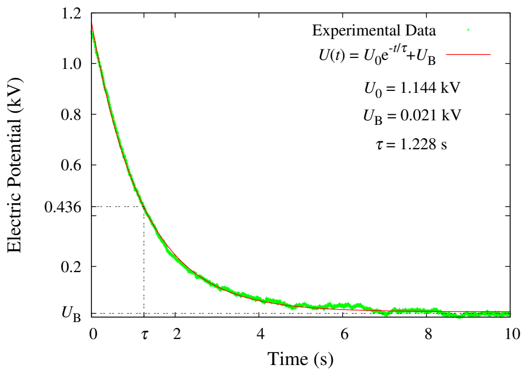

Fig. 3. Charge relaxation of gasoline oil.

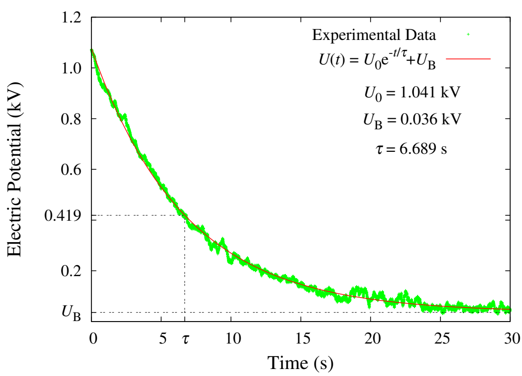

Fig. 4. Charge relaxation of jet fuel oil.

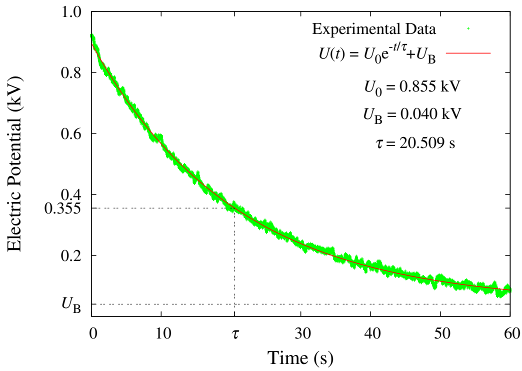

Fig. 5. Charge relaxation of diesel oil.

It takes less than 1 second for charge decaying to 37% for two kinds of crude oil with grounding for the high conductivity, while takes more than 20s for diesel oil for the low conductivity of 0.961 pS/m, as shown in Table 1.

TABLE 1: DIELECTRIC PERMITTIVITY, RELAXATION TIME CONSTANT AND CONDUCTIVITY OF FIVE KINDS OF OIL

	this work			API 2003[1]	
Oil type	ε (pF/m)	τ (s)	σ (pS/m)	τ (s)	σ (pS/m)
Shengli crude oil	25.9	0.827	31.3	<0.018	>1000
Imported crude oil	23.9	0.639	37.4	<0.018	>1000
Gasoline oil	18.9	1.228	15.4	1.8-0.006	10-3000
Jet fuel oil	18.1	6.689	2.71	>0.36	<50
Diesel oil	19.7	20.509	0.961	0.5-50	36-0.36

The crude oils in this work are desalted and dehydrated. They have a low conductivity less than 50 pS/m. Usually the original crude oil with salt and water has very a high conductivity more than 1000 pS/m, according to the API report shown in Table 1[1]. The conductivity of gasoline, jet fuel and diesel got in this work are quit consistent with the report.

The accuracy of the ADAS is 1 ms. Considering there are three variables to fit, more than three experimental data are needed. To keep the basic precision, not less than 10 experimental data are reasonable for fitting. That means the minimal relaxation time constant is 10 ms and the maximal conductivity is about 1800 pS/m. This is the upper limit for this setup. Besides ADAS, it also depends on the insulating property between the tank and the high insulating poly methyl methacrylate (PMMA), and the insulation between the tank and the air. It is necessary to keep the air dry around the tank and oil. In theory, there is no lower limit for this setup. Considering the long time to charge and relax the oil, 0.001 pS/m of conductivity will be the lower limit of this setup.

IV. CONCLUSION

A kind of measurement of electrical conductivity of high insulating oils is proposed using charge decay. It extends the measurement accuracy from 1pS/m to 0.001 pS/m.

REFERENCES

[1] American Petroleum Institute. API 2003: Protection against ignitions arising out of static, lightning, and stray currents. 1998(SIXTH EDITION).

[2] Thomas Williams, Colin Kelley. *Gnuplot 4.6: An Interactive Plotting Program*[Online]. 2008-3-8. Available: http://gnuplot.info/docs_4.6/gnuplot.pdf.