J. King Saud Univ., Vol. 1, Eng. Sci. (1,2), pp. 85-94, Riyadh (1409/1989)

Evaluation of Light Crude Oil for Transformer Application

Abdulaziz A. El-Sulaiman, Abobakr S. Ahmed, M. Iqbal Qureshi, * Khalid A. Alrashood and **Saad I. Al-Huzeimi

*College of Engineering and *College of Pharmacy, King Saud University, P.O. Box 800, Riyadh 11421, and **SCECO East, Dhahran, Saudi Arabia*

Abstract. A sample of light distillate cut of crude oil of Saudi origin has been solicited and evaluated to be adopted as insulating oil. The sample was procured from a commercial local refinery. The conduction current (both quasi- and burst), gas liquid chromatography, IR spectroscopy analysis and the effect of an additive were investigated and compared with the result of a typical commercial transformer oil. It is shown that - after typical chemical treatment - this light distillate cut can be a potential base for producing insulating oils. Further laboratory tests are under examination.

1. Introduction

Electrical insulating oils have been refined - since World War I - from naphthnic crude petroleum oil. However, traditional naphthnic crude oils have become rare and there is a trend that the demand for insulating oils will exceed the supply. Synthesised fluids may be a solution but there are drawbacks to the use of synthetic oils [1], the most important of which is the relative low cost of petroleum mineral oil. Paraffinic crudes occur in much greater quantities and can be refined by much the same technique as naphthnic crude [2,3]. In producing electrical insulating oil from petroleum crude, particular attention is paid to obtain a "tailor made" product having optimum properties - to meet the necessary functional requirements, which depend largely on the degree of refining treatment [4]. Fortunately, the light Saudi Arabian crude oil is categorised chemically as a paraffinic/naphthnic product, *i.e.* it is mostly paraffinic with low sulfur content. So we have planned to evaluate experimental samples of certain light distillate cut acquired from local refineries. Evaluation of the samples will be carried out through a number of standard tests - mostly ASTM [5], but a good start would be the behaviour of the conduction current, gas liquid chromatography (GLC) and infrared spectrophotometry (IR). To our knowledge this is a new work to be adopted in the field of electrical insulation application.

It has up to now been difficult to establish a so called "oil index" for evaluating an oil. For this, several physico-chemical and electrical properties must be investigated according to current international standards. After that the oil must undergo several tests in actual transformer.

In this paper, the first set of results of evaluating a Saudi light distillate (Code: SJ01) is presented and discussed from the point of view of conduction current, burst current, GLC, cation content and a certain additive (Code: AD1).

2. Experimental Technique

Samples under investigation (SJ01) were carefully chosen from a local refinery so that the typical characteristic can be further tailored - through blending, treatment with other products - to produce electrical insulating oils having the target properties. Table 1 shows a comparison of some preliminary properties [5] of SJ01 and that of transformer oil type-I [6]. The sample was dehydrated by passing through one meter long chromatographic column containing non-absorbent silica gel. After dehydration it was filtered by passing through a sintered glass filter having porosity 16 to 40 μm (F3).

Table 1. Comparison of typical properties of the sample SJ01 and function property requirement of transformer oil type-I

Property	Sample SJ01 [5]	Transformer oil Type-I [6]	ASTM test
Specific gravity @ 15°C/15°C (max)	0.8681	0.91	D1298
Flash point, °C (min)	199	145	D92
Pour point, °C (max)	−18	−40	D97
Viscosity			
C St @ 40°C	18-21	12	D445
C St @ 100	3.89-4.2	3	
Colour	1	0.5	D1500
Sulfur, percentage weight	0.8	–	D1275

The experimental setup for conduction current is shown in Fig. 1. The point-plane electrode assembly with a gap fixed at 1.5 mm was immersed in the test cell containing the oil sample. The test cell and the electrodes assembly were cleaned

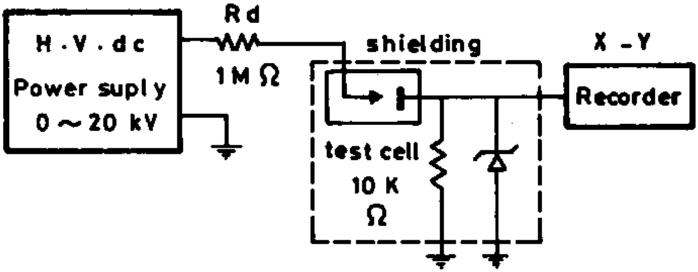

Fig. 1 . Experimental set-up

with n-haptane subjected to ultrasonic cleaner (Fisher Model: B-22-4) for 30 minutes. After cleaning, the test cell was dried inside the temperature chamber at 110°C for 30 minutes. The positive high voltage was applied to the point electrode, the plate copper electrode remained connected to the ground in all experimental observations. The conduction current was recorded on a Y-t recorder for more than 10 minutes (600 sec) duration, after the application of the stress for each run. Every possible measure and precaution was taken to avoid leakage currents. The additive (AD1) has a molecular weight of 142.2 and it was mixed thoroughly in SJ01 sample by a magnetic stirrer.

For the GLC, the samples were diluted with cyclohexane (10% dilution) and run against a standard sample C6 to C40 using a Varian 3700 instrument. The following conditions were employed:

Column: 3% OV-17-Chrom. (W.H.P.);
Temperature programming: being from 50°C then increased to 250°C at 10°C/min; *Carrier gas:* N_2 at 30 ml/min.

and

Sample size: 0.5 µl.

The IR spectra were recorded on a Perkin Elmer Spectrophotometer 580B using a scan from 625 to 4000 cm^{-1}

3. Results and Discussions

3.1. Electrical

Quasi-steady state conduction current

The variation of the quasi-steady state conduction current i_q with time lapse t is shown in Fig. 2 for the sample SJ01 and typical transformer oil. Generally, the trend of the sample SJ01 is very similar to the behaviour of a transformer oil. The current i_q versus time t can be fitted to the general relation:

$$i_q = C\, t^{-m}$$

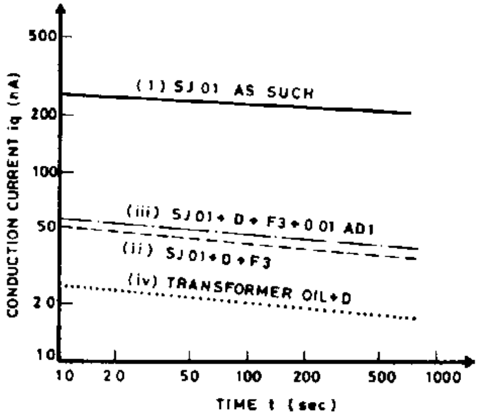

Fig. 2. Time dependence of the quasi-steady state current I_q for the sample SJ01 and typical transformer oil

where C and m are constants and 10s ≤ t ≤ 600s. The slopes of lines (m) are almost the same, however dehydration and filtration reduce the current by about 75% for the SJ01 sample.

For comparison, the trend in a dehydrated aged transformer oil is also shown in Fig. 2. This result represents the highest magnitude of current which is obtained when the positive voltage is applied to the copper plane electrode in a point-plane configuration [7]. Still the current in the SJ01 sample is twice as much in the aged transformer oil. Further dehydration and filtration may improve the conduction current characteristics through the removal of impurities and moisture content.

Fig. 3 shows the variation of the quasi-steady state current with molar concentration of the additive AD1 at 10 kV and 12 kV and after 10s of voltage application. It is seen that the current increases with molar concentration at low levels - around 0.001 molar - to a certain maximum then it starts decreasing upon further increase of concentration. At molar concentration of 0.01, the conduction current becomes very near to that of the sample without additive, which may be considered the optimum molar concentration $M_o = 0.01$. It is interesting to note that similar optimum concentration phenomenon of organic additives at which gas evolution is minimum has been reported in insulating liquids [8]. With naphthalene as additive, the concentration corresponding to the peak and minimum breakdown voltage of degassed transformer oil occurs at 0.05 and 0.01 molar respectively [9].

An increase of the molar concentration up to 0.001 mole may enhance the formation of charge carriers, resulting in increase in conduction current. However,

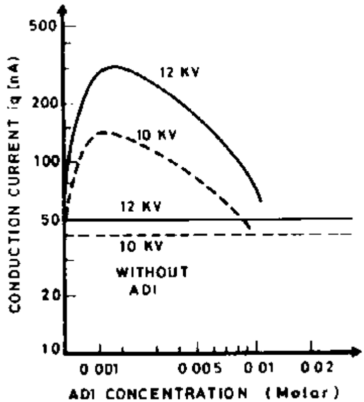

Fig. 3 . Effect of additive concentration on the quasi-steady current i_q

increasing the additive concentration leads its action as a gassing inhibitor, consequently, the current starts decreasing. Moreover, the trend of the curve indicates that a certain optimum concentration of the additive is reached, at which the current is minimum.

This phenomenon of optimum concentration supports the hypothesis that all the additives in general possess resonance structures. Two different reactions between the additive and the free radicals occur; the first is gas absorbing whilst the second is gas evolving which increases with increasing concentration [8]. A point is reached at which the volatile molecules dissolve in the oil at greater rates which correspond to the optimum concentration of the additive.

Burst current activity

Figure 4 illustrates the burst current at a field strength 10 kV with 0.001, 0.005 and 0.010 molar concentration of the additive in the sample.

For 0.001 molar, the burst activity is not vigorous and characterised by few large unidirectionally increasing bursts, of the order of 140 nA peak. As the molar concentration is increased to 0.005 the burst activity becomes more vigorous but of lesser amplitude of the order of 70 nA. Further increase of molar concentration to 0.010 results in less burst activity and smaller burst current.

Comparing Fig. 4b and Fig. 4d shows that the burst activity has been suppressed after removal of the wax deposited on electrode surface. This implies that the wax plays an important role in the sample and has to be removed for achieving similar burst characteristics of transformer oil. It is noted that the burst amplitude and duration are of the same order as previous finding in transformer oil [10].

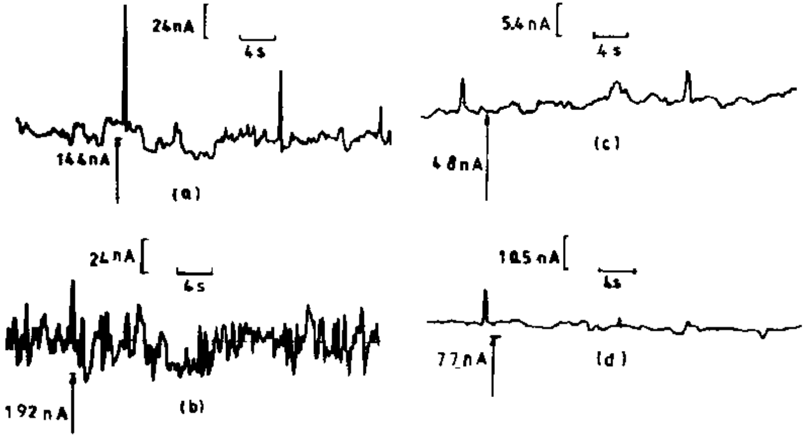

Fig. 4 . Effect of additive concentration on burst current at 10 kv for sample SJ01: (a) 0.001 molar, (b) 0.005 molar, (c) 0.01 molara, (d) removing the deposit wax in the electrode

3.2. Chemical

The IR of the filtered oil cut studied here was compared with that of fresh oil. The two spectra showed some similarity, revealing the presence of open chain aliphatic, alicyclic and also showed aromatic hydrocarbon, Fig. 5.

The GLC run of the oil cut sample showed the chain of hydrocarbons starting from C10 to C21. When compared with the spectra of fresh oil, generally we found that they bear some similarity which makes this oil cut a potential candidate for making transformer oil. Obviously this cut needs a proper refining process such as solvent extraction, dewaxing and adding certain additives, Fig. 6.

The cation content of this oil cut revealed a relatively high content of ferric and copper but reasonable amount of lead in comparison with that of fresh oil, Table 2. This high content of Fe^{3+} and Cu^{3+} metals is reflected in the behaviour conduction of the oil.

Table 2. Cation content of the sample and fresh transformer oil

Element	Total element in sample (ppm)	Fresh Transformer oil
Cu^{2+}	0.35	0.60
Fe^{3+}	0.45	Nil
Pb^{2+}	0.3	1.2

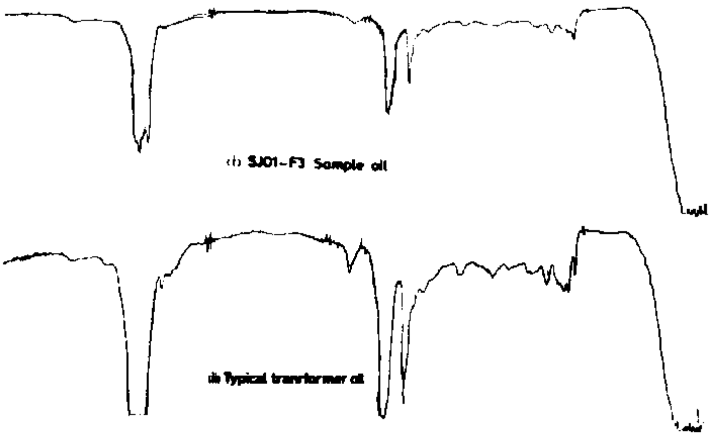

Fig. 5 . (i) IR spectra of SJ01 sample, (ii) typical transformer oil

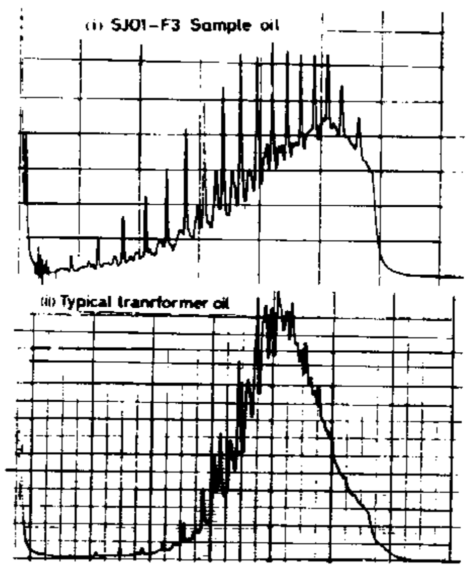

Fig. 6 . (i) GLC spectra of SJ01 sample (ii) typical transformer oil

4. Conclusion

The investigation of conduction current and chemical spectroscopy of a light distillate cut solicited from Saudi local refinery indicates that this cut can be a potential base for making transformer oil. Further dehydration, filtration and treatment will improve the conduction current to be comparable with a typical transformer oil. Certain additive shows optimum concentration value similar to cited literature. GLC and IR spectroscopy run of the oil cut sample shows the chain of the hydrocarbons starts from C10−C21 which is similar to the spectra of a transformer oil. Further characteristics are under investigation.

Acknowledgement: The authors wish to thank the Board of Research Center, College of Engineering, King Saud University, for financing this project, the Research Center of College of Pharmacy for their facilities and Mr. A. Sherif for running the GLC and IR. We are also indebted to Saudi Petromin of Jeddah for providing oil distillate samples.

References

[1] **Rouse, T.** "Evaluation of alternate mineral oil for use in transformer and other electrical apparatus." *IEEE Intrn. Sym. Elect. Insul.*, June (1978), 250–260.

[2] **St-Jean, G.; Costonguay, J.; Landry, M.; Pugh, D.R.**, and **St-Onge, H.** "Comparative performance of paraffinic & naphthenic insulating oils under arc-quenching conditions." *IEEE Trans. Power App. and Syst.*, **PAS-99**,6 (1980), 2439–2447.

[3] **Modunga, M.; Kobono, Y.** and **Ohmori, T.** "Results tests on paraffinic insulating oils." 12*th JEIC* (1975), 224–228.

[4] **Wilson, A.C.M.** *Insulating Liquids: Their Uses, Manufacture and Properties.* London: The IEE press, 1975.

[5] **Private Communication with Saudi Petromin of Jeddah.**

[6] **ASTM D 3487–81.** *Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.* Annual Book of ASTM Standards, Part 40, 1981.

[7] **El-Sulaiman, A.A.** "Effect of point cathode and point anode on conduction and burst current in an inhomogeneous field for inservice transformer oil." *IEEE Conf. on Electr. Insul. and Dielectric Phenomena, Buffalo*, Oct. 20–24, New York (1985), 67–72.

[8] **Zaky, A.A.** and **Megahed, I.Y.** "Effect of organic additives, gas phase, stress, and temperature on gassing characteristics of insulating liquids." *IEEE Trans. on Electr, Insul.*, Vol. EI-7, No. 3 (1972), 145–153.

[9] **Zaky, A.A.** *et al.* "The effect of organic additives on the breakdown and gassing properties of mineral oils." *J. Phys. D. Appl. Phys.*, **9** (1976), 841–850.

[10] **El-Sulaiman; Abdulaziz, A.; Ahmed, Abobakr S.** and **Qureshi, M. Iqbal** "Quasi-Steady and burst current in aged transformer oil under high direct field." *IEEE Transactions on Electrical Insulation*, **EI-16**, 5 (1981), 453–457.

(*Manuscript Received:* 13-5-1987; *Accepted:* 23-12-1987)

تقويم زيت خام خفيف للاستعمال في المحولات

عبدالعزيز عبدالله السليمان، أبو بكر سلطان أحمد، محمد إقبال قريشي، خالد الرشود*
وسعد إبراهيم الحزيمي**

*كلية الهندسة و*كلية الصيدلة، جامعة الملك سعود، ص.ب ٨٠٠،*
*الرياض ١١٤٢١ و**شركة الكهرباء الموحدة، المنطقة الشرقية؛*
المملكة العربية السعودية

ملخص البحث: تم اختيار عينة من الزيت الخام الخفيف ذات منشأ سعودي وذلك لتقويم إمكانية تطويره لأغراض العزل الكهربائي. وقام الباحثون بدراسة وتحليل تيار التوصيل شبه المستقر والنتوءات، كروماتوجراف الغاز السائل، تحليل طيف الأشعة تحت الحمراء، تأثير الإضافات الكيميائية وكذلك مقارنة النتائج مع زيت محولات تجاري مستورد ولقد بينت الدراسة بعد المعالجة الكيميائية اللازمة أن هذه العينة من الزيت السعودي يمكن أن تكون أساسا لإنتاج زيوت عازلة. ومع ذلك فإنه لا زال هناك اختبارات أخرى تحت البحث والدراسة.