

## The Effect of Solvent Extraction of Light Lubricating Oil on Viscosity Index and Chemical Composition

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### Abstract

An investigation was conducted for the improvement of viscosity index of light lubricating oil fraction (40 stock) obtained from vacuum distillation unit of lube oil plant of Daura Refinery, using solvent extraction process.

In this study furfural solvent was used to extract the undesirable materials which reduce the viscosity index of raw lubricating oil fraction.

The studied effecting variables of extraction were extraction temperature range from 70 to 110°C, and solvent to oil ratio range from 1:1 to 4:1 (wt/wt).

The n-d-M method was used for calculation of carbon distribution and structural group analysis of the raffinate produced from furfural extraction.

Also the three component phase diagram for a mixed-base oil and furfural at different temperature was drawn.

The results of this investigation show that the viscosity index of lubricating oil fraction increases with increasing extraction temperature and increasing the solvent to oil ratio and reaches 115.6 at extraction temperature 110°C and solvent to oil ratio 4:1.

Further more, the results show that the viscosity, refractive index, density, sulfur content and percentage yield of produced raffinate were decreased as the extraction temperature or solvent to oil ratio increases for extraction process.

**Keywords:** solvent extraction, lubricating oil, furfural.

### Introduction

Since the beginning of the petroleum industry, solvent extraction has been interest to refiners as a means of removing polyaromatics and other undesirable constituents from lubricating oils(1). The most important properties of a lubricating oil which solvent extraction is meant to improve are viscosity-temperature characteristics, stability toward oxidation, and carbon residue. The improvement of these properties is accomplished almost entirely by the extraction of aromatics(2).

A strong temptation to produce high viscosity index lubes has led to a prolific growth of solvent extraction. Solvents widely used for this affair are furfural, phenol, mixture of cresols and propane. Many other solvents like aniline, sulfur dioxide are enlisted; but with out much

use(3). Although there are technical advantages for each of these solvent's, furfural remain the solvent of choice in many parts of the world. The major factors favoring its use are low toxicity, cost, availability, history of commercial experience, adaptability to extraction of gas oil and better selectivity in the extraction of these lube stocks which exhibit excellent refining response at low solvent to oil ratios(1). In the 1990s, a world wide trend began to manufacture higher-viscosity index VI, lower-volatility, paraffinic base oils for automotive applications. These new paraffinic base oils, in the 110-140 VI range, are expected to become more readily available and more commonly used to blend lubricants in the 21st century(4).

The improvement in the properties of an oil gained by solvent refining is some what dependent on the properties of the original stock as well as the type of kind of solvent employed, and since base oils differ widely in molecular

composition and physical properties due to the crude source, hence each refiner must satisfy himself by laboratory tests and studying in detail the selected fraction of lubricating oil.

The purpose of this investigation is to improve the viscosity index of light lubricating oil fraction (40 stock) obtained from vacuum distillation unit of lube oil plant of Daura Refinery, by extremely solvent extraction process using furfural. The present study includes a detail investigation of the effect of extraction temperature and solvent to oil ratio on physical properties, sulfur content, chemical composition, and the percentage yield of the product lubricating oil. In addition, the three-component phase diagram of the extraction process was drawn at different temperatures.

## Experimental Work

### Feedstock

In this work a light lube oil distillate fraction (40 stock) with boiling point range 316-326°C obtained from vacuum distillation unit of lube oil plant of Daura Refinery was used. The feedstock for vacuum distillation unit was atmospheric residue produced from mixed Iraqi crude oils (60 % of Basrah, 30 % of Kirkuk and 10 % of Sharki-Baghdad). Table 1 shows the properties of the light lube oil fraction.

Table 1 Properties of the Light Lube Oil Fraction (40 stock).

No.	Specification	Values
1	Viscosity, cSt, @ 40°C	15.773
2	Viscosity, cSt, @ 100°C	30.336
3	Viscosity index	66
4	Specific gravity@ 60/60 °F	0.91
5	COC flash point, °C	168
6	Pour point, °C	18
7	Sulfur content, % Wt	2.6015
8	Color, ASTM-D1500, at 25°C	5
9	Refractive index ( $n_D^{25}$ )	1.4971

### Solvent

The solvent used in this work is furfural (Liaosin Private limited Company, China). Table 2 shows the properties of this solvent.

Table 2 Properties of Furfural

No.	Specification	values
1	Boiling point, °C	161
2	Freezing point, °C	-36.5
3	Viscosity, cPS, @25°C	1.49
4	Density ( $d_4^{25}$ ), g/cm <sup>3</sup>	1.1563
5	COC flash point, °C	68
6	Refractive index ( $n_D^{25}$ )	1.5235

## Extraction Experiments

### 1. Contacting Step

In the present work a laboratory batch extraction unit was used. Figure 1 shows the process flow diagram of the laboratory extraction unit. This unit consists of a bench scale Hiter, 3-necks Pyrex flask extraction apparatus. The middle flask neck was connected with the mixer; the second neck was connected with recycle condenser and the third neck was connected with thermometer.

Electrical mixer was used to mix the feedstock with the extraction solvent inside the flash extractor with 45 mm diameter paddle. The flask extractor was heated and controlled by using an oil bath (with heater and thermostat) in which the flask extractor is immersed. The lube oil fraction was mixed with the extraction solvent in the extractor at controlled specified temperature.

Mixing the two materials at the specified temperature was continued for a period of 30 min then the mixture was left at the specified temperature for 30 min to be separated in to two phases. The upper liquid phases is light raffinate solution and the bottom liquid phase is heavier extract solution. After steady state indicated by constant interface level, the two phases were separated by using a separating funnel.

The two solutions were weighted to ensure material balance closure.

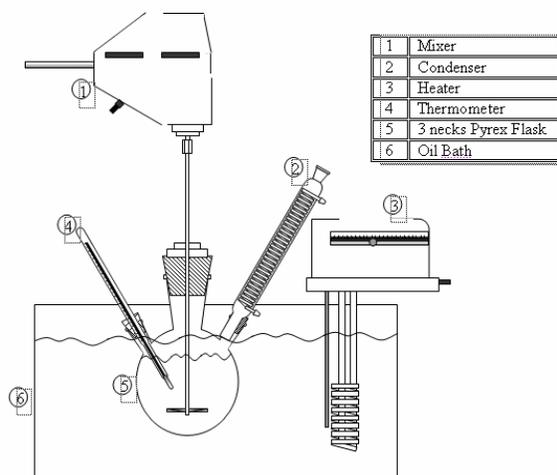


Figure 1 Flow Diagram of the Laboratory Extraction Unit.

### 2. Solvent Recovery

The solvent was stripped from the raffinate solution by distillation under vacuum about (0.2 bar) to avoid decomposition, and from the extract solution by atmospheric distillation. Figure 2 shows the process flow diagram of the laboratory vacuum distillation unit.

The unit consists of a 500 ml, 2 necks Pyrex flask, the middle flask neck was connected with thermometer (to indicate vapour temperature) and double wall condenser. At the end of condenser there is a receiver which is connected with a trap and vacuum pump with a vacuum gage pressure. The second flask neck was connected with thermometer (to indicate the solution temperature). The raffinate and extract solutions were heated in the flask using heating mantle with a regulator to control heat supply. The stripped raffinate was weighted and the raffinate yield was obtained.

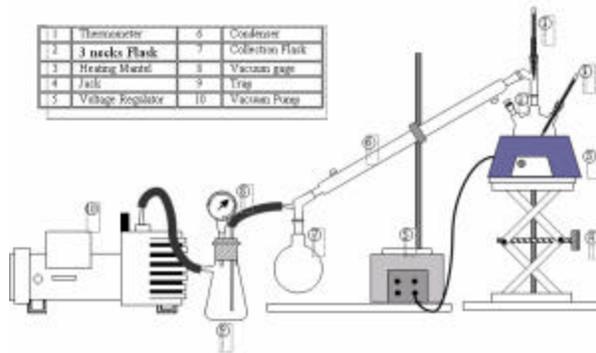


Figure 2 Flow Diagram of the Vacuum Distillation Unit

## Extraction Experiment Conditions

The operating conditions of the set of experiments that applied on the extraction of light lube oil distillate fraction (40 stock) by furfural were extraction temperature range from 70 to 110°C, and solvent to oil ratio range from 1:1 to 4:1 (wt./wt.). The pressure was kept constant at atmospheric pressure. Table 3 shows the details of extraction experiments.

Table 3 Details of Extraction Experiment

No.	Temperature, °C	Solvent to Oil Ratio (wt/wt)
1	70	1:1
2	70	2:1
3	70	3:1
4	70	4:1
5	80	1:1
6	80	2:1
7	80	3:1
8	80	4:1
9	90	1:1
10	90	2:1
11	90	3:1
12	90	4:1
13	100	1:1
14	100	2:1
15	100	3:1
16	100	4:1
17	110	1:1
18	110	2:1
19	110	3:1
20	110	4:1

## Test Methods

### 1. Density and Specific Gravity

The density and specific gravity of lubricating oil were measured according to ASTM-D1481 (5).

Density is defined as mass per unit volume and specific gravity of the test liquid is obtained by dividing its density by the density of water at the test temperature (6,7). The liquid was drawn into the bicapillary pycnometer through the removable siphon arm and adjusted to volume at the temperature of test, in such a manner that there is practically no drainage in the unfilled tubing. After equilibration at the test temperature, liquid levels were read, and the pycnometer was removed from the thermostated bath, cooled to room temperature, and weighted. From the weight of the sample and the volume at the test temperature density is calculated (5).

The density of the petroleum product reduces by 0.00062 per Celsius degree of temperature rise (7). Specific gravity at the test temperature is converted to specific gravity at 60/60°F by using Figure which relates the specific gravity at 60/60°F with the specific gravity at other temperature (8).

### 2. Viscosity

The viscosity of lubricating oil was measured according to ASTM-D445 (9). This test method specifies a procedure for the determination of the kinematic viscosity,  $V$ , of liquid petroleum products, both transparent and opaque, by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary U-tube viscometer (5). The lube oil distillate fraction and raffinate oil sample is charged in the viscometer, and then the viscometer is immersed in an oil bath which maintained at a constant temperature of 100°C (to measure the viscosity at 40°C it immersed in a water bath which maintained at constant temperature of 40°C). After 20 minutes to achieve thermal equilibrium between the sample and the bath temperature, the sample dragged then the time in second is recorded for flow of oil sample between the two levels in the capillary tube. The kinematic viscosity can be calculated by applying Equation 1.

$$V = c \hat{t} \quad (1)$$

$c$  = constant factor of the calibrated viscometer.

$t$  = time in second.

$V$  = kinematic viscosity measured in mm<sup>2</sup>/s (centiStoke, cSt).

### 3. Viscosity Index

The viscosity index of lube oil distillate fraction and raffinate oil were calculated according to ASTM-D2270 (9), by applying the procedure for oils of zero to 100 VI. In

this procedure the kinematic viscosity of lube oil at 40 and 100°C is measured and equation 2 was used.

$$VI = \frac{L - U}{L - H} \times 100 \quad (2)$$

Where

U= kinematic viscosity at 40°C of the oil whose viscosity index to be calculated (cSt).

L= kinematic viscosity at 40°C of an oil of zero viscosity index having the same kinematic viscosity at 100°C as the oil whose viscosity index is to be calculated (cSt).

H = kinematic viscosity at 40°C of an oil of 100 viscosity index having the same kinematic viscosity at 100°C as the oil whose viscosity index is to be calculated (cSt).

The value of L and H can be obtained from Tables.

For oils having a viscosity index greater than 100, another viscosity index scale has been created.

For this index, the oil is only compared with a reference oil of the H family having the same viscosity at 100°C, and by applying equation 3 (7).

$$\text{Viscosity index} = \left[ (10^N - 1) / 0.00715 \right] + 100 \quad (3)$$

Where

$$N = \frac{\log H - \log U}{\log B}$$

B= the kinematic viscosity of the oil at 100°C

#### 4. Refractive Index

The refractive index of lubricating oil was measured according to ASTM-D1218 (5). The refractive index is measured by the critical angle method with a Bausch and Lomb precision Refractometer using monochromatic light. This method is used for hydrocarbons having an ASTM color less than 4 and it is limited to measuring refractive indices between 1.33 and 1.50, for temperature between 20 and 30°C (7).

#### 5. Color

The color of lubricating oil was measured according to ASTM-D1500 (5), by using a standard light source, a liquid sample is placed in the test container and compared with colored glass disks ranging in value from 0.5 to 8.0 when an exact match is not found and the sample color falls between two standard colors, the higher of the two colors is reported.

#### 6. Sulfur Content

The sulfur content of lubricating oil was measured according to ASTM-D2622(5), with a fluorescence analyzer of xrays. This method uses to measure sulfur levels in the 0.001-5.000% range (6).

A sample is placed in an xray beam, and the peak intensity of the sulfur  $k\alpha$  line at 5.373Å is measured. The background intensity, measured at 5.190Å is subtracted from the peak intensity. The resultant net counting rate is then compared to a previously prepared calibration curve or equation to obtain the sulfur concentration in mass percent.

#### 7. Molecular Weight

Molecular weight is a fundamental physical constant that can be used in conjugation with other physical properties to characterize pure hydrocarbons and their mixtures (5).

A knowledge of molecular weight is necessary for the application of a number of correlative methods (such as in n-d-M method in the present work) that are useful in determining the gross composition of the heavier fractions of petroleum (5).

The molecular weight of petroleum fractions in the 70-350 range can be approximated from boiling points and density (10). The molecular weight of lube oil was determined by using equation 4 (11).

$$M = T_{A,^{\circ}C} / sp.gr.^{0.4} \quad (4)$$

Where

M= molecular weight g/gmol.

TA,°C= molal average boiling point of lube oil fraction.

sp.gr.= specific gravity at 60/60°F of lube oil.

#### Calculation of Carbon Distribution and Structural Group Analysis of Lube Oils by the n-d-M Method

N-D-M method was applied on lube oil distillate fraction and raffinate oil according to ASTM-D3238 (12). This method covers the calculation of the carbon distribution and ring content of lube oils from measurements of refractive index, density and molecular weight.

The refractive index and density of the oil are determined at 20°C. These data are then used to calculate the carbon distribution (%CA, %CN, %Cp) or the ring analysis (RA, RN) using the appropriate set of the following equations:

$$v = 2.51(n_D^{20} - 1.4750) - (d_4^{20} - 0.8510) \quad (5)$$

$$w = (d_4^{20} - 0.8510) - 1.11(n_D^{20} - 1.4750) \quad (6)$$

Where

V And W are factors

$d_4^{20}$  = relative density at 20°C

$n_D^{20}$  = refractive index at 20°C

To calculate the percentage of aromatic carbon (%CA):

$$\text{If } V \text{ is positive: \% CA} = 430V + 3660/M \quad (7)$$

$$\text{If } V \text{ is negative: \% CA} = 670V + 3660/M \quad (8)$$

Where

M= molecular weight

To calculate the percentage of carbon in total aromatic and naphthenic) ring structures (%CR):

$$\text{If } W \text{ is positive: \% CR} = 820W - 3S + 10000/M \quad (9)$$

$$\text{If } W \text{ is negative: \% CR} = 1440W - 3S + 10600/M \quad (10)$$

Where

S= weight % sulfur

To calculate the percentage of naphthenic carbon (%CN) and the percentage of paraffinic carbon (%Cp):

$$\% \text{CN} = \% \text{CR} - \% \text{CA} \quad (11)$$

$$\% \text{CP} = 100 - \% \text{CR} \quad (12)$$

To calculate the average number of aromatic rings per molecule (RA):

$$\text{If } V \text{ is positive: RA} = 0.44 + 0.055M V \quad (13)$$

$$\text{If } V \text{ is negative: RA} = 0.44 + 0.080M V \quad (14)$$

To calculate the average total number of rings per molecule (RT)

$$\text{If } W \text{ is positive: RT} = 1.33 + 0.146M(W - 0.005S) \quad (15)$$

$$\text{If } W \text{ is negative: RT} = 1.33 + 0.180M(W - 0.005S) \quad (16)$$

To calculate the average number of naphthene rings per molecule (RN)

$$\text{RN} = \text{RT} - \text{RA} \quad (17)$$

## The Triangular Coordinate Graphical Method

When solvent extraction is employed for the removal of undesirable constituents from petroleum products, such as in the present work the extraction of aromatics from lubricating oil by furfural, the equilibria involved cannot be represented exactly by any simple means. Exact representation can be obtained only by the use of complex methods involving a comprehensive knowledge of the constituents of such petroleum products (13).

The resulting oil-solvent system may be treated as a simple ternary system and equilibrium relations represented on triangular coordinates in terms of solvent, extract (naphthenic), and raffinate (paraffinic). The equilibrium diagram can be constructed from the experimental results obtained by the single-stage batch extraction of an oil with different volumes of solvent (13).

In order to represent the equilibrium relations in an oil-solvent system, it is necessary only to record by some suitable means the following information (13):

Amounts of the two phases in equilibrium.

Amount of solvent in each phase at equilibrium.

A physical property of the oil present in each phase at equilibrium (in this work specific gravity at 60/60°F was used).

Item 2 and 3 of this information can be recorded by a single point on a triangular graph of which one vertex represent pure solvent and one side, opposite this vertex, is scaled into units representing the required physical property of the solvent-free oil.

The equilibrium resulting between a lubricating oil (of the present work) and furfural at 90°C is shown in Table 4. These equilibrium relationships are plotted on the triangular graph, Figure 3.

The specific gravity of the solvent-free oil in the raffinate layer from experiment 1 of Table 4 is given by point A on this diagram (Figure 3). If raffinate oil of this, specific gravity was mixed with an amount of furfural such that the total mixture contained 16.4 volume percent of furfural, the actual raffinate layer should be obtained. Therefore by joining point A to the apex of the triangle representing 100 percent of furfural and locating the point on this line where the furfural content is 16.4 volume percent, point a representing the composition of the raffinate layer can be obtained. This may be shown in another way by starting with the raffinate layer of composition a and removing all the solvent present, point A would be obtained on the diagram, which is solvent-free oil of specific gravity 0.8925. The composition of the various raffinate and extract layer is therefore easily ascertained and is indicated on Figure A-1 by points *a, b, c, d* and *a', b', c', d'* for the experimentals 1, 2, 3, and 4 quoted in Table 4. Returning again to experiment 1, the composition of the raffinate and extract layers in equilibrium are given by points *a* and *a'*. These two solutions are conjugate and hence may be joined by the tie line *aa'*.

Mixtures of oil and furfural whose compositions fall within the two-phase region under the curve will separate into two layers whose composition are shown by the ends of the tie lines labeled *aa'*, *bb'*, *cc'*, and *dd'*. The four tie lines represent experimental data, but additional tie lines can be estimated as necessary.

The completed isothermal binodial curve and tie lines represented the equilibrium relations for lube oil-furfural system at 90°C was shown in Figure A-3.

Table 4 The Equilibrium Data of Three-Component System of a Mixed-Light Lube Oil Fraction (40 stock) and Furfural at 90°C

Expt.	Solvent to Oil Ratio wt/wt	Raffinate Layer		Extract Layer	
		Specific Gravity at 60/60°F of Oil in Layer	Vol.% Solvent in Layer	Specific Gravity at 60/60°F of Oil in Layer	Vol.% Solvent in Layer
1	1:1	0.8925	16.40	1.0000	75.3
2	2:1	0.8785	13.10	0.9825	81.0
3	3:1	0.8537	10.11	0.9700	85.0
4	4:1	0.8400	9.770	0.9578	85.6

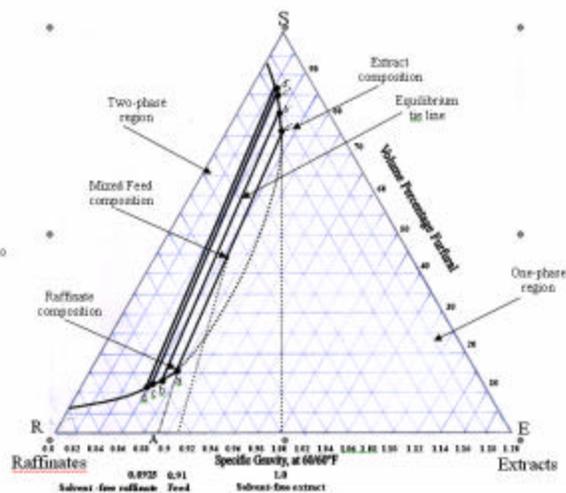


Figure 3 Three-Component Phase Diagram for a Mixed-Light Lube Oil Fraction (40 stock) and Furfural at 90°C

## Results and Discussion

### The Effect of Extraction Temperature and Solvent to Oil Ratio on Raffinate Viscosity and Viscosity Index

The viscosity of lubricating oil fraction is very important factor in the manufacture of lubricating oils, and the correct operation of the equipment depends upon the appropriate viscosity of the lubricating oil being used.

The ability of lube oil viscosity to vary with temperature reflects the viscosity index of lubricating oil.

In the present work the effect of extraction temperature and solvent to oil ratio on raffinate kinematic viscosity measured at 40 and 100°C was studied.

Figures 4 and 5 show the effect of extraction temperature on raffinate viscosity measured at 40 and 100°C, respectively at various solvent to oil ratio, while Figures 3 and 4 show the effect of solvent to oil ratio on raffinate viscosity measured at 40 and 100°C, respectively, at various extraction temperatures.

In general, the viscosity of raffinate produced from extraction decreases with increasing the extraction temperature or increasing the solvent to oil ratio. This is due to the extraction of high molecular weight aromatic materials, especially, polycondensed aromatics from the raw lubricating oil fraction.

The high molecular weight aromatics have the higher viscosity among the hydrocarbons that presented in raw lubricating oils and the extraction of these materials decreases its content in the produced raffinate and increases the paraffins content which have a viscosity relatively lower than that of aromatics as mentioned by Kusters (14).

Figures 4 and 5 clearly indicated that the extraction temperature slightly effect on the produced raffinate viscosity measured at 40 and 100°C for a given solvent to oil ratio.

Figures 6 and 7 show that the increase in solvent to oil ratio for a given extraction temperature has higher effect on decreasing the raffinate viscosity measured at 40 and 100°C, respectively because of the high removing of aromatic compounds with increasing solvent to oil ratio.

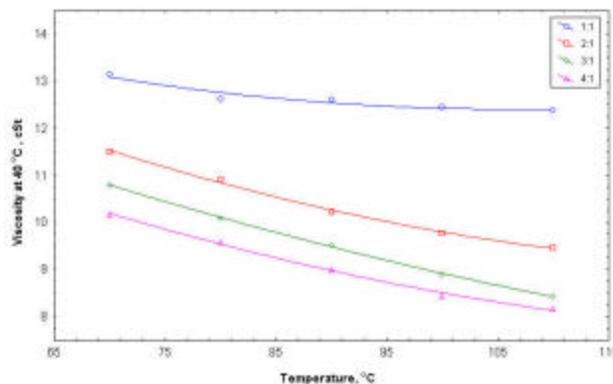


Figure 4 Effect of Extraction Temperature on Raffinate Viscosity at 40°C at Various Solvent to Oil Ratio

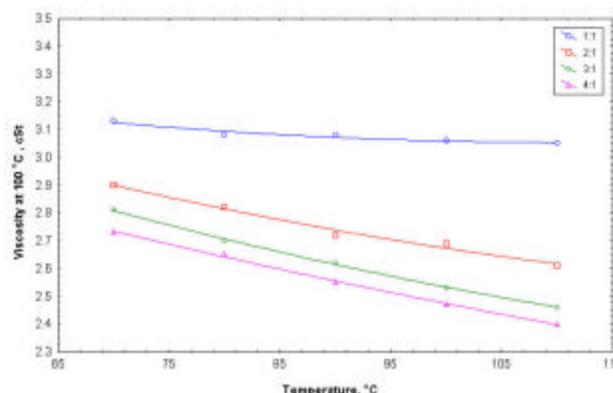


Figure 5 Effect of Extraction Temperature on Raffinate Viscosity at 100°C Using Different Solvent to Oil Ratio.

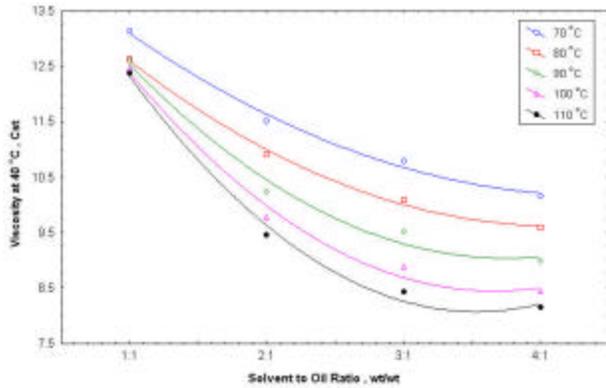


Figure 6 Effect of Solvent to Oil Ratio on Raffinate Viscosity at 40°C at Various Extraction Temperatures

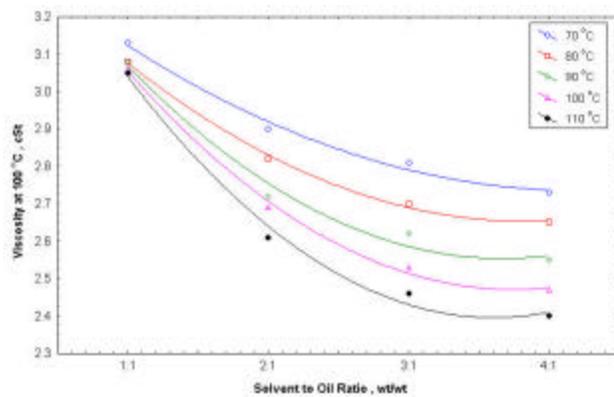


Figure 7 Effect of Solvent to Oil Ratio on Raffinate Viscosity at 100°C at Various Extraction Temperatures

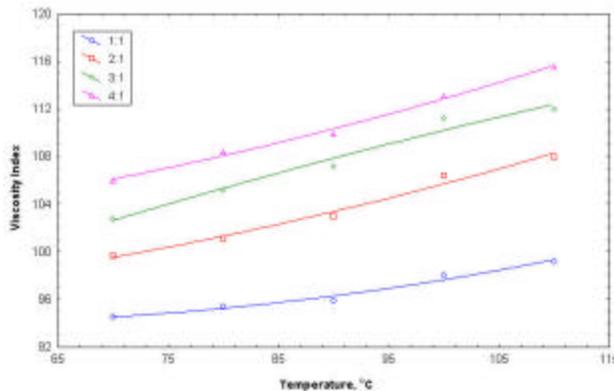


Figure 8 Effect of Extraction Temperature on Raffinate Viscosity Index at Various Solvent to Oil Ratio

Figure 8 shows the effect of extraction temperature on raffinate viscosity index at various solvent to oil ratio, while Figure 9 shows the effect of solvent to oil ratio on raffinate viscosity index at various extraction temperatures.

The increase in extraction temperature will encourage the solubility of undesirable materials in extraction solvent especially polycondensed aromatics which reduces the viscosity index of lubricating oil.

It is obvious from Figure 8 that the viscosity index of lubricating oil fraction increases with increasing the extraction temperature.

Figure 9 indicates that the increase in solvent to oil ratio has a higher effect on increasing the viscosity index of lubricating oil fraction than the effect of increasing the extraction temperature.

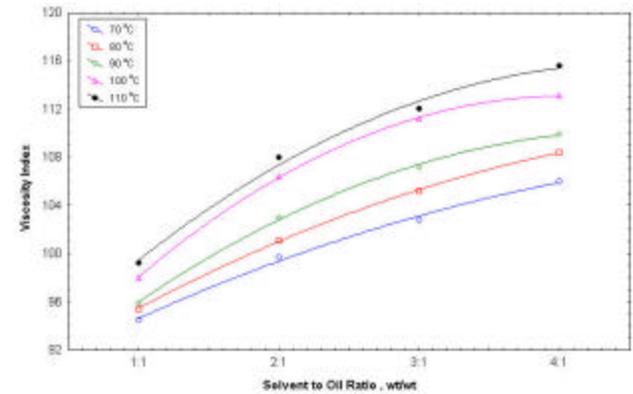


Figure 9 Effect of Solvent to Oil Ratio on Raffinate Viscosity Index at Various Extraction Temperatures

### The Effect of Extraction Temperature and Solvent to Oil Ratio on Raffinate Yield

Figure 10 explains the effect of extraction temperature on raffinate yield at various solvent to oil ratio, while Figure 11 shows the effect of solvent to oil ratio on raffinate yield at various extraction temperatures.

Usually, on raising the temperature the solvent power is increased but the selectivity is decreased, resulting in deeper extraction but a lower yield of raffinate (15).

It appears from Figure 10 that the yield percentage decreases as the extraction temperature increases but that effect is some what little in comparison with the effect of solvent to oil ratio.

Figure 11 shows the effect of increasing solvent to oil ratio on decreasing the raffinate yield percentage at various extraction temperatures.

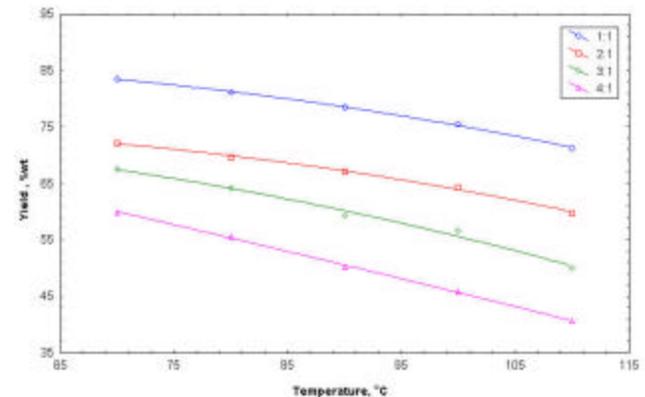


Figure 10 Effect of Extraction Temperature on Raffinate Yield at Various Solvent to Oil Ratio

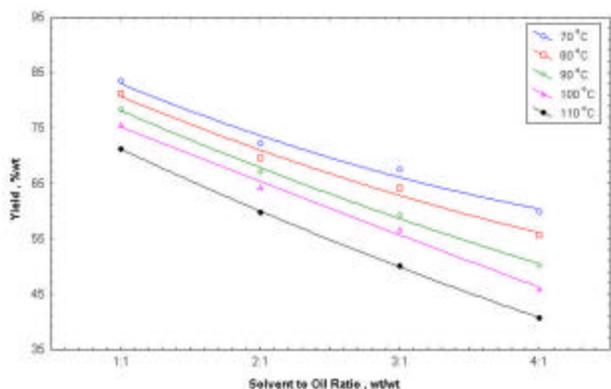


Figure 11 Effect of Solvent to Oil Ratio on Raffinate Yield at Various Extraction Temperatures

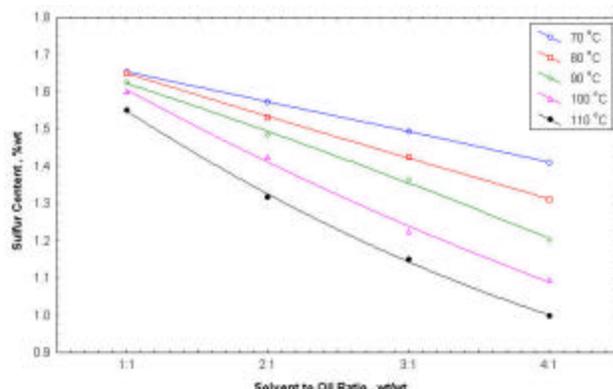


Figure 13 Effect of Solvent to Oil Ratio on Raffinate Sulfur Content at Various Extraction Temperatures

### The Effect of Extraction Temperature and Solvent to Oil Ratio on Raffinate Sulfur Content

Sulfur species are reactive and corrosive and can be reduced by solvent extraction process by removing the heteroaromatics which are typically multi-ring aromatics that contain one or more atoms of sulfur, oxygen or nitrogen (6).

Figure 12 shows the effect of extraction temperature on raffinate sulfur content at various solvent to oil ratio, while Figure 13 shows the effect of solvent to oil ratio on raffinate sulfur content at various extraction temperatures. It is obvious from Figure 12 that the sulfur percentage in raffinate produced by solvent extraction decreases with increasing the extraction temperature for a given solvent to oil ratio.

Figure 13 shows that the increase in solvent to oil ratio has higher effect on decreasing the sulfur percentage of the raffinate obtained by solvent extraction compared with the effect of extraction temperature.

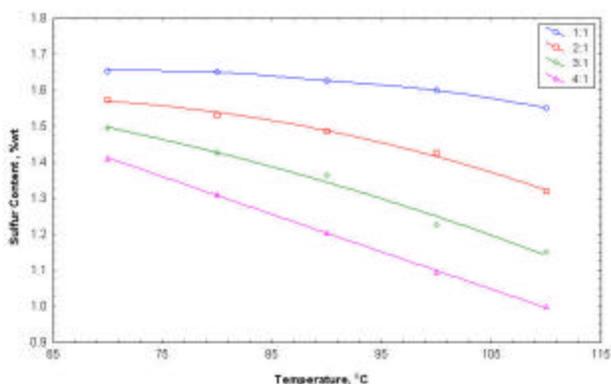


Figure 12 Effect of Extraction Temperature on Raffinate Sulfur Content at Various Solvent to Oil Ratio

### The Effect of Extraction Temperature and Solvent to Oil Ratio on Other Properties

Refractive index and density are a fundamental physical properties that can be used in conjunction with other properties to characterize the composition of lubricating oils (16, 17).

The lower values of refractive index are associated with paraffins and higher values with aromatics (15).

Figure 14 shows the effect of increasing extraction temperature on decreasing the raffinate refractive index at various solvent to oil ratio, while Figure 15 shows the effect of increasing solvent to oil ratio on decreasing the raffinate refractive index at various extraction temperatures.

It may be concluded that the most important factor affecting the reduction in raffinate refractive index is the solvent to oil ratio and that reflects the best quality of raffinate.

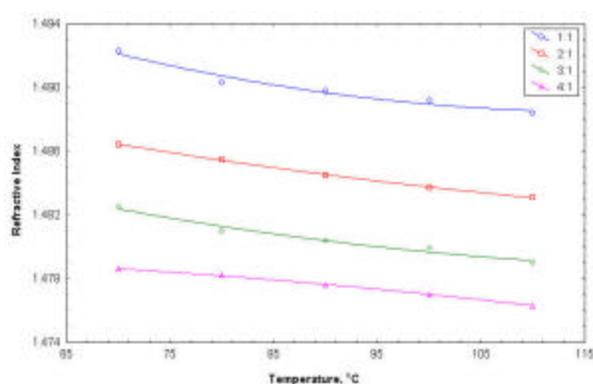


Figure 14 Effect of Extraction Temperature on Raffinate Refractive Index at Various Solvent to Oil Ratio

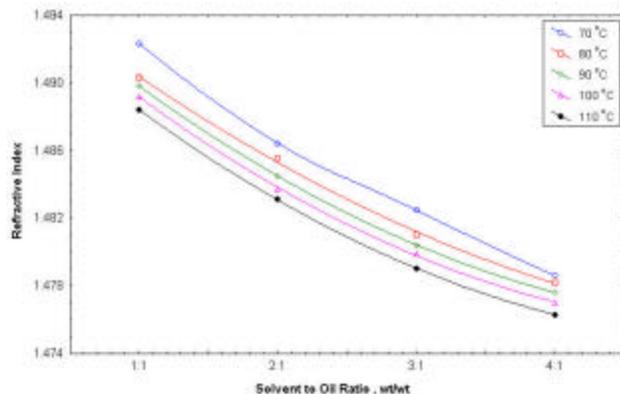


Figure 15 Effect of Solvent to Oil Ratio on Raffinate Refractive Index at Various Extraction Temperatures

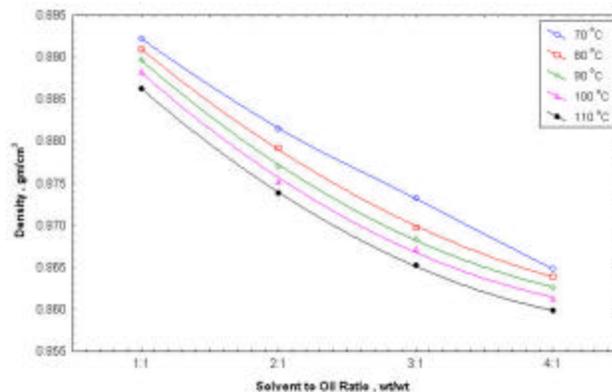


Figure 17 Effect of Solvent to Oil Ratio on Raffinate Density at Various Extraction Temperatures

In general, the density of raffinate produced from extraction decreases with increasing the extraction temperature or increasing the solvent to oil ratio and this is due to the extraction of aromatic materials which have the higher density among the hydrocarbons that presented in raw lubricating oils.

Figure 16 shows the effect of increasing the extraction temperature on decreasing the raffinate density at various solvent to oil ratio, while Figure 17 shows the effect of increasing solvent to oil ratio on decreasing the raffinate density at various extraction temperature.

Figure 17 indicates that the increase in solvent to oil ratio for a given extraction temperature has higher effect on decreasing the raffinate density compared with the effect of increasing the extraction temperature.

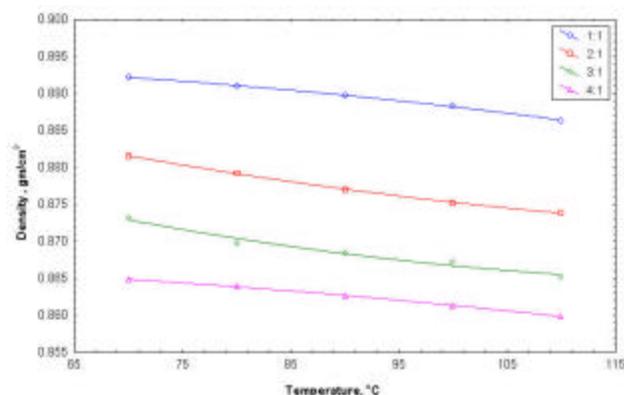


Figure 16 Effect of Extraction Temperature on Raffinate Density at Various Solvent to Oil Ratio

The color is important since it is readily observed by the customer (16). The color of a new oil depends on its degree of refining, and its content of aromatics (7).

### The Effect of Extraction Temperature and Solvent to Oil Ratio on Hydrocarbon Composition

The qualities required for a lubricating oil base-stock are usually determine by measuring of either the product viscosity index or saturates content. The increase in raffinate viscosity index related to the reduction in naphthene-aromatic and polar aromatic content and the increase in saturates content in the produced raffinate (6).

Alternatively, the composition of hydrocarbons may be expressed in term of a carbon distribution, that is the percentage of the total number of carbon atoms that are present in aromatic ring structures (%CA), naphthene ring structures (%CN), and in paraffin chains (%CP) (18).

In the present work the carbon distribution and structural group analysis of produced raffinate was calculated by the n-d-M method.

Figures 18 and 19 show the effect of increasing extraction temperature on decreasing the percentage of the total number of carbon atoms present in aromatic ring structures (%CA) and naphthene ring structures (%CN) of produced raffinate respectively at various solvent to oil ratio, while Figure 20 shows the effect of increasing extraction temperature on increasing the percentage of the total number of carbon atoms present in paraffin chains (%CP) of produced raffinate at various solvent to oil ratio.

Figures 21 and 22 show the effect of increasing solvent to oil ratio on decreasing the percentage of the total number of carbon atoms present in aromatic ring structures (%CA) and naphthene ring structures (%CN) of produced raffinate, respectively, at various extraction temperatures, while Figure 23 shows the effect of increasing solvent to oil ratio on increasing the percentage of the total number of carbon atoms present in paraffin chains (%CP) of produced raffinate at various extraction temperatures.

It is obvious from Figures 21, 22 and 23 that the solvent to oil ratio have the higher effect compared with the effect of extraction temperature shown in Figures 18, 19 and 20.

By comparison the results of Figures 18-23 with those in Figures 8 and 9, it obvious that the viscosity index increases with increase the percentage of the total number of carbon atoms present in paraffin chains and decrease the percentage of the total number of carbon atoms present in aromatic and naphthene ring structures.

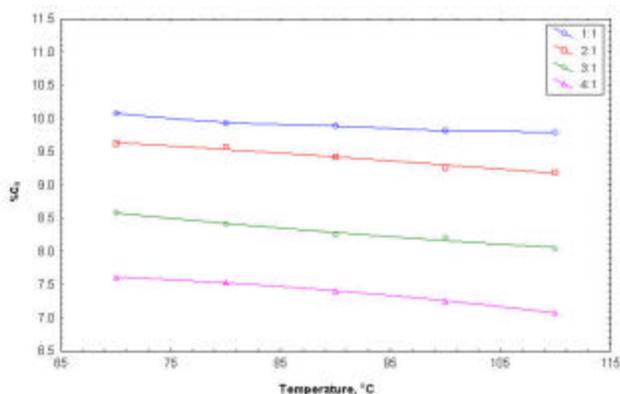


Figure 18 Effect of Extraction Temperature on The Percentage of the Total Number of Carbon Atoms Present in Aromatic Ring Structure (%CA ).

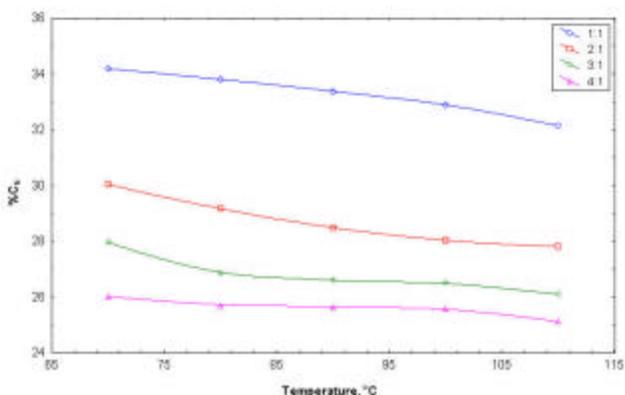


Figure 19 Effect of Extraction Temperature on The Percentage of the Total Number of Carbon Atoms Present in Naphthene Ring Structure (%CN).

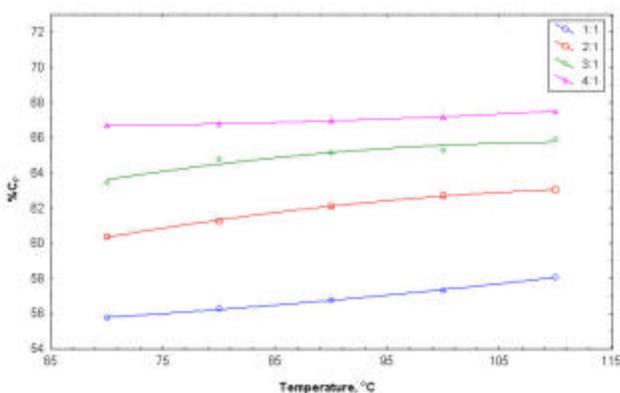


Figure 20 Effect of Extraction Temperature on The Percentage of the Total Number of Carbon Atoms Present in Paraffin Chains(%CP).

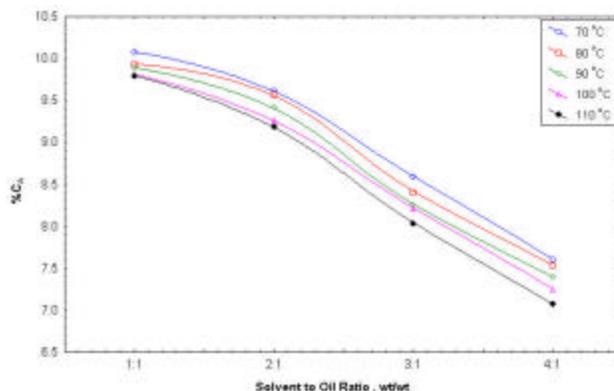


Figure 21 Effect of Solvent to Oil Ratio on the Percentage of the Total Number of Carbon Atoms Present in Aromatic Ring Structure (%CA).

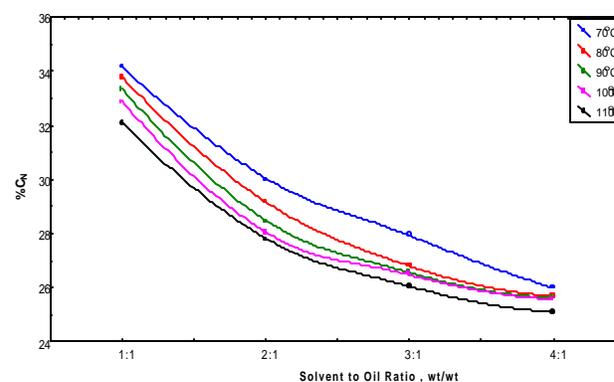


Figure 22 Effect of Solvent to Oil Ratio on The Percentage of the Total Number of Carbon Atoms Present in Naphthene Ring Structures (%CN).

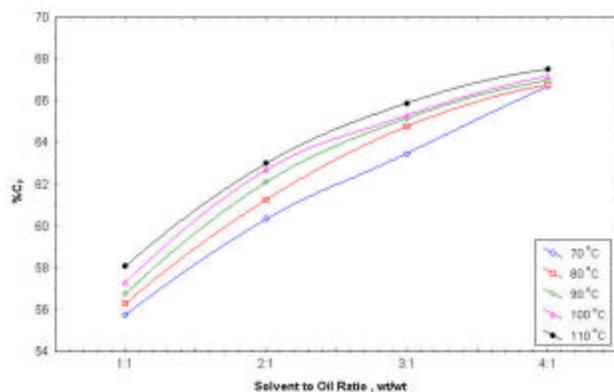


Figure 23 Effect of Solvent to Oil Ratio on The Percentage of the Total Number of Carbon Atoms Present in Paraffin Chains(%CP).

The composition of complex petroleum fractions is often expressed in terms of the proportions of aromatic rings (RA), naphthene rings (RN) and paraffin chains (CP) that would comprise a hypothetical mean molecule (12).

Figures 24 and 25 show the effect of increasing the extraction temperature on the average number of aromatic

rings per molecule (RA) and the average number of naphthene rings per molecule (RN) of produced raffinate, respectively, at various solvent to oil ratio.

Figures 26 and 27 show the effect of increasing the solvent to oil ratio on the average number of aromatic rings per molecule (RA) and the average number of the naphthene rings per molecule (RN) of produced raffinate, respectively, at various extraction temperature.

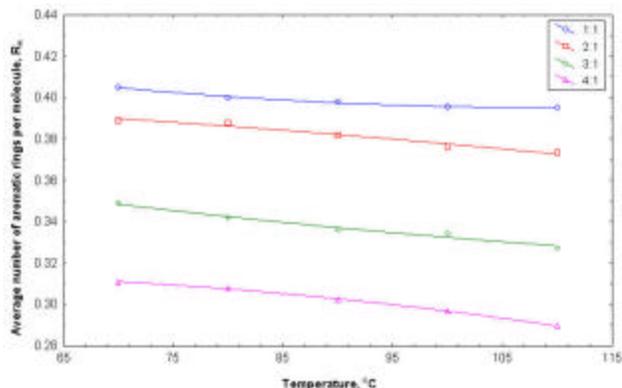


Figure 24 Effect of Extraction Temperature on The Average Number of Aromatic Rings Per Molecule, (RA).

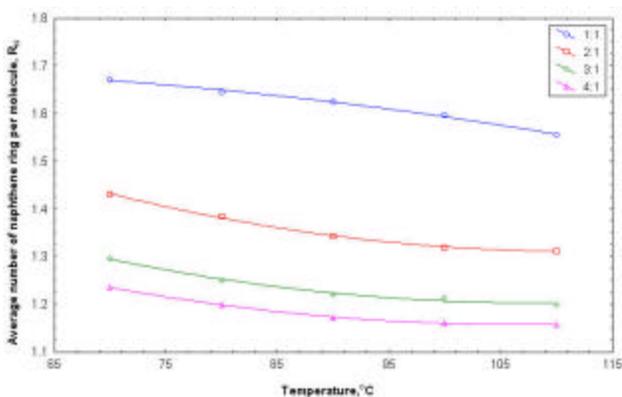


Figure 25 Effect of Extraction Temperature on The Average Number of Naphthene Rings Per Molecule, (RN).

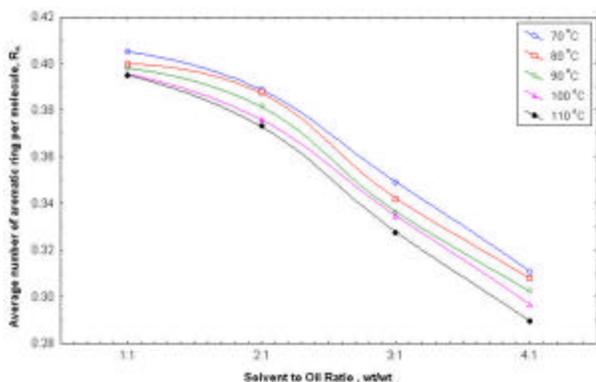


Figure 26 Effect of Solvent to Oil Ratio on The Average Number of Aromatic Rings Per Molecule, (RA).

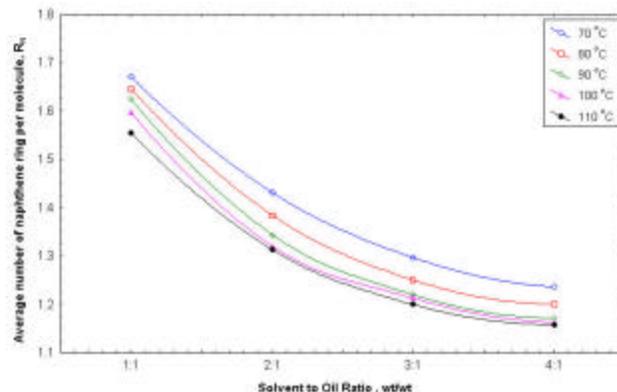


Figure 27 Effect of Solvent to Oil Ratio on The Average Number of Naphthene Rings Per Molecule, (RN).

### Ternary Phase Diagram for Extraction of Lubricating Oil with Furfural at Different Temperatures

Ternary phase diagram, triangular coordinate, is used to represent the isothermal equilibrium data of three-component systems.

In the present investigation, ternary liquid-liquid equilibrium data were obtained and three-component phase diagram were drawn for the system mixed-light lube oil fraction (40 stock) and furfural at different temperatures.

Figure 28 shows the effect of changing extraction temperature on the liquid-liquid equilibria of the system.

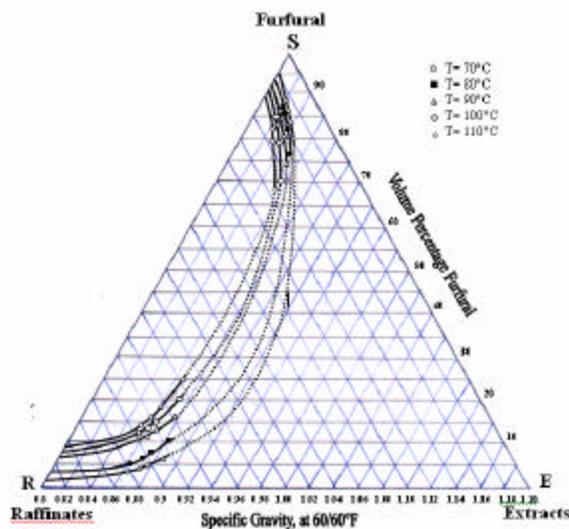


Figure 28 Effect of Extraction Temperature on the Liquid-Liquid Equilibrium of Mixed-Light Lube Oil Fraction (40 stock) and Furfural System

## Conclusions

1. The viscosity index of lubricating oil fraction increases from 66 to 94.5 as a minimum by extraction at 70°C and 1:1 solvent to oil ratio and reaches 115.6 as a maximum by extraction at 110°C and 4:1 solvent to oil ratio.
2. The solvent to oil ratio has the higher influence on increasing the raffinate viscosity index and decreasing viscosity, density, refractive index, sulfur content, color, and yield.
3. The sulfur content of the raffinate decreases with increasing extraction temperature and solvent to oil ratio, the lower sulfur content obtained was 0.9983%wt at 110°C and 4:1 solvent to oil ratio.
4. The area under the bimodal curve which representing two liquid layers in the three component phase diagram decreases as the temperature of extraction increases.
5. The percentage of the total number of carbon atoms present in aromatic and naphthene ring structures decreases while the percentage of the total number of carbon atoms present in paraffin chain increases with increasing extraction temperature and solvent to oil ratio.

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