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Viscosity Index Improvement of Lubricating Oil Fraction (SAE – 30)

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Abstract

An investigation was conducted for the improvement of viscosity index of a lubricating oil fraction (SAE – 30) obtained from vacuum distillation unit of lube oil plant of Daura Refinery, using solvent extraction process. In this study two type of extraction solvents were used to extract the undesirable materials which reduce the viscosity index of raw lubricating oil fraction, the first solvent was furfural which is un use today in the Iraqi refineries and the second was NMP (N-methyl, 2, pyrrolidone) which is used for the first time in this work to extract the lubricating oil fraction produced from Iraqi crude oils. The studied effecting variables of extraction are extraction temperature range from 70 to 110 oC for furfural and NMP extraction, solvent to oil ratio range from 1:1 to 5:1 (wt/wt) for furfural extraction and from 0.5:1 to 2:1 (wt/wt) for NMP extraction. 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 83 for NMP extraction at extraction temperature 110 oC and solvent to oil ratio 2:1, while the viscosity index reaches to 80 for furfural extraction at the same extraction temperature and solvent oil ratio. Higher viscosity index of lubricating oil fraction is obtained by using NMP instead of furfural under the same operating variables (extraction temperature and solvent to oil ratio). Further more, the results show that the viscosity, refractive index, and percentage yield of raffinate decreased as the extraction temperature or solvent to oil ratio increases for furfural and NMP extraction.

Introduction

With the increasing demands for high quality lubricating oils to withstand the severe operating conditions of the modern gasoline and diesel engines, it become apparent that the selected crudes were no longer sufficient in either quantity or quality to supply the demand. Therefore, it was obvious that the petroleum industry would have to resort to some means for separation of the desirable and undesirable component of lubricating oil stocks. Other than the heavy asphaltic materials and the normally solid paraffin waxes, which be removed by precipitation or by filtration at reduced temperatures, the undesirable components comprise those aromatic type hydrocarbons which possess low oiliness, low viscosity index, poor oxidation stability, high carbon residue, and poor color [1]. Solvent treating is the most widely used method of refining lubricating oils. These processes yield products that meet the requirements of a modern lubricant by removing from the charge material those undesirable constituents. The solvent – treated lubricating oils have higher viscosity indexes, greater resistance to gum and sludge formation by oxidation, and increased susceptibility to further improvement by addition of selective additives [2]. Although no solvent meets all of the requirements of the ideal extraction solvents have been proposed and used commercially. The major solvents in use today are N – methyl – 2 – pyrrolidone and furfural, with phenol and liquid sulfur dioxide being used to a lesser extent [3]. The present work deals with viscosity index improvement of lubricating oil fraction SAE – 30 obtained from vacuum distillation unit of lube oil plant of Daura Refinery, by extremely selective solvent extraction process using furfural and N – methyl – 2 – pyrrolidone solvents. This work includes the study of the effects of extraction temperature and solvent to oil ratio on the physical properties and the percentage yield of the produced lubricating oil.

Experimental Work

Feed Stock

A distillate lube oil fraction (SAE – 30 distillate) obtained from vacuum distillation unit of lube oil plant of Daura Refinery was used in this work. Atmospheric residue produced from mixed Iraqi crude oil (60 % of Basrah crude, 30 % of Kirkuk crude, and 10 % of Sharki – Baghdad crude) was the feed stock for vacuum distillation unit. Table (1) shows the properties of the lube oil fraction.

Table 1 Properties of lube oil fraction

No.	***Specification***	***Lube Oil Fraction***
1	Specific Gravity @ 60/60 ^oF	0.91705
2	Viscosity, Cst, @ 40 ^oC	118.00
3	Viscosity, Cst, @ 100 ^oC	9.39
4	Viscosity Index	26
5	COC Flash Point, ^oC	242
6	Pour Point, ^oC	25
7	Color ASTM – D 1500, @ 50 ^oC	5.5
8	Sulfur Content, % wt.	3.073

Solvents

Two solvents were used in this work. These solvents are furfural (Liaosin private limited company, China) and NMP (Fluka chemicals AG, Germany). Table (2) shows the measured properties of these solvent.

Table 2 Properties of furfural and NMP

No.	***Specification***	***Furfural***	***NMP***
1	Density (d_4^{25}), g/cm^3	1.1563	1.0270
2	Boiling Point, ^oC	161	202
3	Refractive Index (n_D^{25})	1.5235	1.4690
4	COC Flash Point, ^oC	68	95
5	Freezing Point, ^oC	-36.5	-24
6	Viscosity, cps, @ 25 ^oC	1.49	1.65

Extraction Experiments

Figure (1) shows the schematic diagram of the laboratory batch extraction unit. This unit consists of a bench scale jacketed glass column extraction apparatus with 50 mm ID, 700 mm length, 80 mm jacket ID and 2 mm wall thickness. The jacketed extractor was heated and controlled by circulating hot oil through the jacket. The solvent was stripped from the raffinate using distillation with nitrogen.

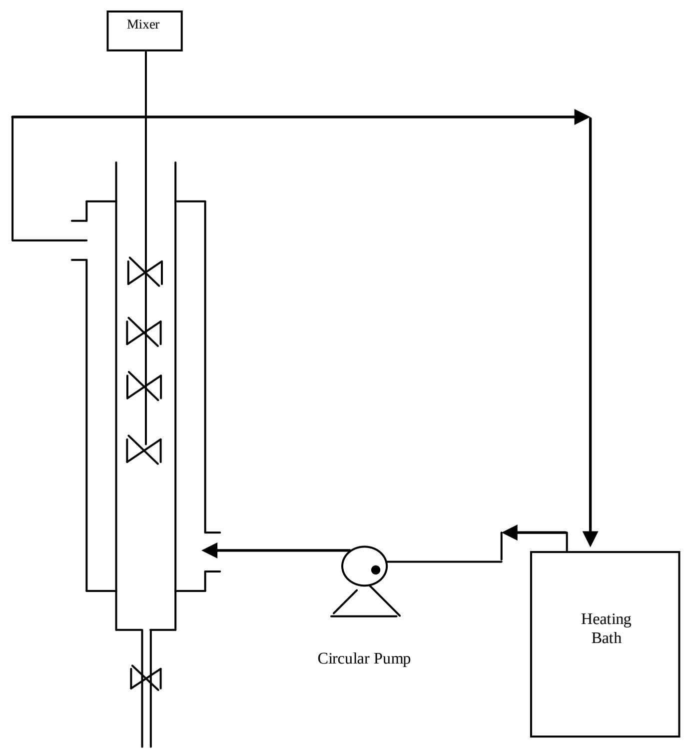

Fig.1: The schematic diagram of the laboratory batch extraction unit

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Extraction Experiments Conditions

In the present work, the experiments that applied on the extraction of lube oil distilled fraction were classified in to two categories. The first one was applied on furfural as extraction solvent. The operating conditions are extraction temperature range from 70 to 110 oC, solvent to oil ratio from 1:1 to 5:1 (wt. / wt.), and using atmospheric pressure. The second set of experiments applied on NMP as the extraction solvent. The extraction temperature was the same as for the first set but the solvent to oil ratio were reduced to 0.5:1 to 2:1 because of the higher solvent power of NMP than furfural [4].

Test Methods

1 - Viscosity

The viscosity of feed stock, and raffinate were determined by capillary U-tube viscometer according to ASTM D-445 [5].

2 - Viscosity Index

The raffinate viscosity index was determined by measuring the raffinate refractive index and from the data relating the refractive index to viscosity index tabulated in Table (3) (6), The refractive index was determined according to ASTM D-1747 [5].
The feed stock has a color greater than No. 4 according to ASTM color – D1500, therefore the viscosity index can not be determined by measuring the refractive index. Also the viscosity at 40 oC of waxy feed can not be measured, therefore The viscosity of the feed stock was measured at 80 and 100 oC to obtain the viscosity at 40 oC using the viscosity – temperature charts of liquid petroleum products according to ASTM – D341 (5).. The viscosity index of the feed stock fraction was calculated according to ASTM – D2270 (5) by applying the procedure for oils of zero to 100 VI. In this procedure Equation (1) was used.

$$VI = \frac{L - U}{L - H} \times 100 \qquad (1)$$

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).

Table 3 Raffinate refractive index and viscosity index [6]

RI	***VI***	***RI***	***VI***
1.4560	103	1.4690	86
1.4565	102	1.4700	85
1.4570	101	1.4708	84
1.4575	100	1.4715	83
1.4580	99	1.4720	82
1.4590	98	1.4730	81
1.44600	97	1.4740	80
1.4610	96	1.4745	79
1.4625	94	1.4765	77
1.4630	93	1.4770	76
1.4640	92	1.4780	75
1.4650	91	1.4790	74
1.4655	90	1.4795	73
1.4665	89	1.4805	72
1.4675	88	1.4815	71
1.468	87	1.4820	70

Results and Discussion

Effect of Operating Variables and Solvent Type on Raffinate Viscosity

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

In the present work the effect of extraction temperature and solvent to oil ratio on raffinate kinematic viscosity at 100 oC were studied.

Figures (2 and 3) show the effect of extraction temperature on raffinate viscosity for furfural and NMP extraction respectively, while Figures (4 and 5) show the effect of solvent to oil ratio on raffinate viscosity for furfural and.

In general, the viscosity of raffinate produced from furfural or NMP extraction decreased with increasing the extraction temperature or increasing the solvent to oil ratio and that is due to the extraction of aromatic materials especially polycondensed aromatics from the raw lubricating oil fraction.

The aromatics have the higher viscosity among the hydrocarbons that presented in raw lubricating oils and the extraction of these materials decrease its content in the produced raffinate and increase the paraffins content which have a viscosity relatively lower than that of aromatics as mentioned by Kosters [7].

Figures (2 and 3), clearly indicate that the extraction temperature slightly affect the viscosity of raffinate produced from furfural and NMP extraction for a given solvent to oil ratio. Figures (4 and 5) show that the increase in solvent to ratio for a given extraction temperature have higher effect in decreasing the raffinate viscosity obtained by furfural and NMP extraction. The viscosity of the raffinate produced from NMP extraction is slightly lower than that produced from furfural extraction using the same operating variables, because of the higher activity and high solvent power of NMP than furfural [4].

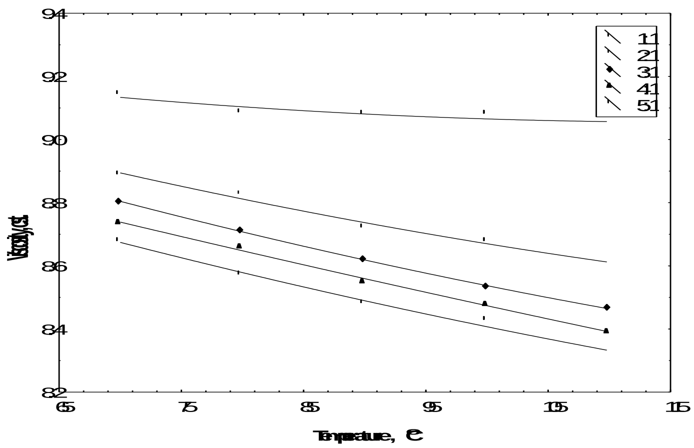


Fig.2: Effect of extraction temperature on raffinate viscosity at different solvent to oil ratio for furfural extraction

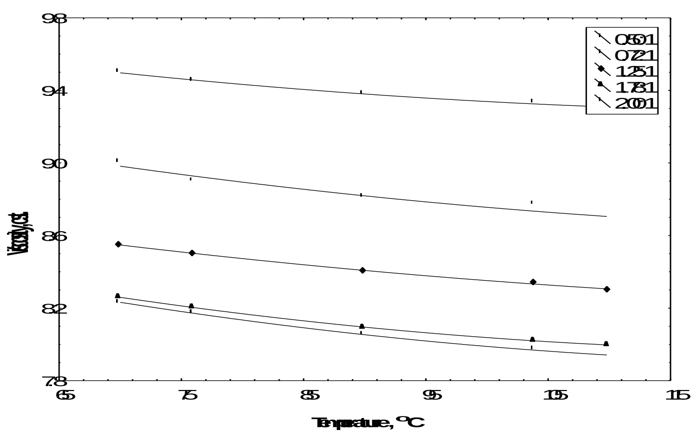


Figure (4) Effect of solvent to oil ratio on raffinate viscosity at various extraction temperature for furfural extraction

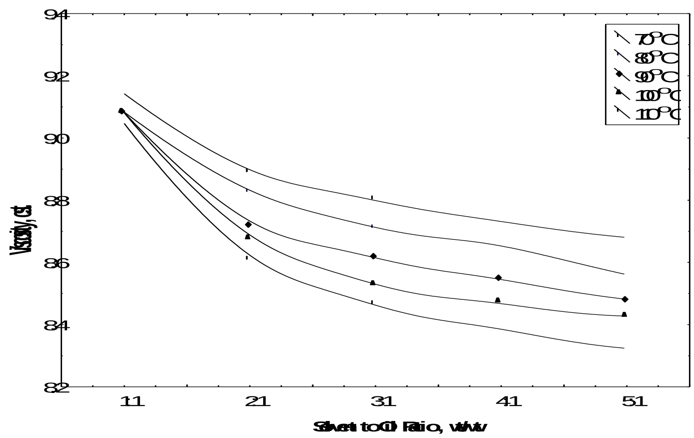


Fig.4: Effect of solvent to oil ratio on raffinate viscosity at various extraction temperature for furfural extraction

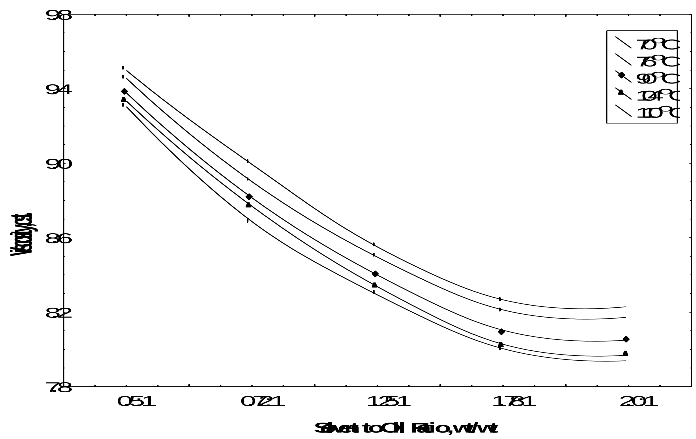


Fig.5: Effect of solvent to oil ratio on raffinate viscosity at various extraction temperature for NMP extraction

Effect of Operating Variables and Solvent Type on Raffinate Viscosity Index

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

Figures (6 and 7) show the effect of extraction temperature on raffinate viscosity index for furfural and NMP extraction respectively at various solvent to oil ratio.

Figures (8 and 9) show the effect of solvent to oil ratio on raffinate viscosity index for furfural and NMP extraction respectively at various extraction temperature.

The increase in extraction temperature will encourage the solubility of undesirable materials especially polycondensed aromatics (which reduce the viscosity index of lubricating oil) in extraction solvent. It is obvious from Figures (6 and 7) that the viscosity index of lubricating oil fraction increase with increasing the extraction temperature. The increase of extraction temperature 10 oC will increase the viscosity index one point for a given solvent to oil ratio using furfural and NMP as extraction solvents.

Figures (8 and 9) indicate that the increasement in solvent to oil ratio has a high effect on increasing the viscosity index of lubricating oil fraction compared with extraction temperature in furfural and NMP extraction. In case of using furfural as extraction solvent, the significant solvent to oil ratio is higher than 1:1 because of the constancy of the viscosity index on a fixed value using different extraction temperatures and that is due to the saturation of this amount of furfural with undesirable materials.

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.

The higher solvent power of NMP compared with furfural gave higher viscosity index using the same operating variables. These results are in agreement with those obtained by Sequeira and Sherman (4) which approved that the solvent power is better (solvent to oil ratio is lower) for NMP than for furfural.

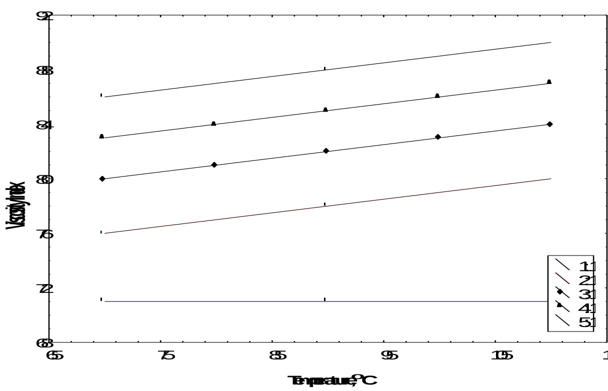
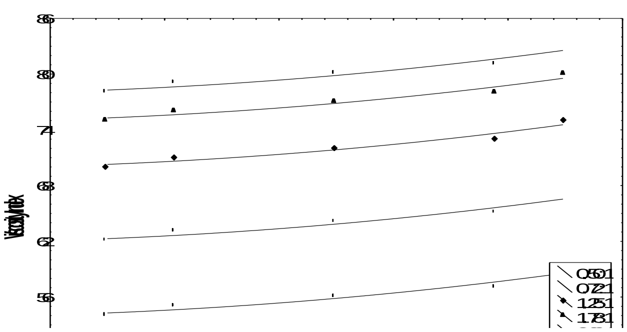


Fig.6: Effect of extraction temperature on raffinate viscosity index at various solvent to oil ratio for furfural extraction



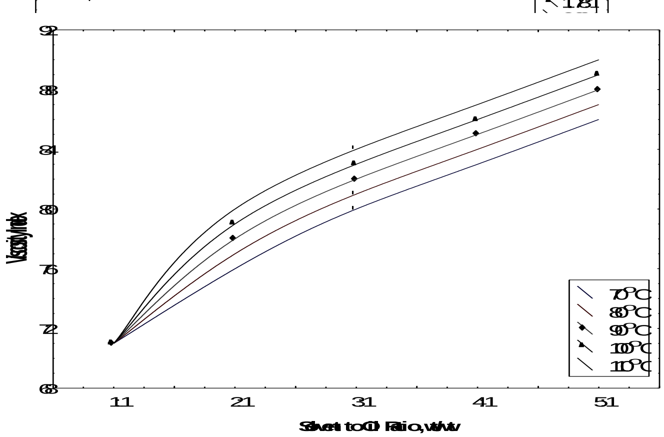


Fig.7: Effect of extraction temperature on raffinate viscosity index at various solvent to oil ratio for NMP extraction

Fig .8: Effect of solvent to oil ratio on raffinate viscosity index at various extraction temperatures for furfural extraction

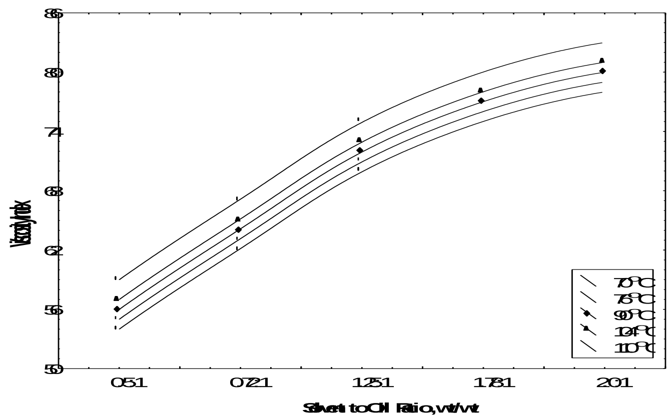


Fig .9: Effect of solvent to oil ratio on raffinate viscosity index at various extraction temperatures for NMP extraction

Effect of Operating Variables and Solvent Type on Raffinate Yield

Many factors controlling the convential operating conditions of solvent extraction. One of these important factors affecting the overall process performance is the lubricating oil yield.

Figures (10 and 11) show the effect of extraction temperature on raffinate yield at various solvent to oil ratio for furfural and NMP extraction. It appears from these figures that the yield percentage decreases as the extraction temperature increased but that effect is some what little in comparison with the effect of solvent to oil ratio.

Figures (12 and 13) show the effect of increasing solvent to oil ratio on decreasing the raffinate yield percentage at various extraction temperatures for furfural and NMP extraction respectively.

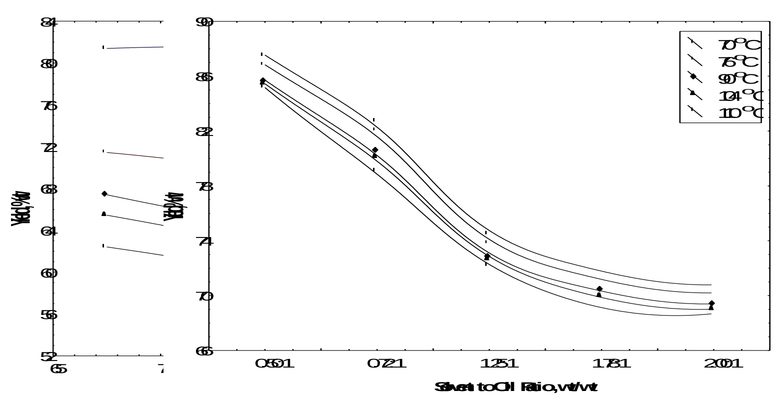


Figure (10) Effect of extraction temperature on raffinate yield at various solvent to oil ratio for furfural extraction

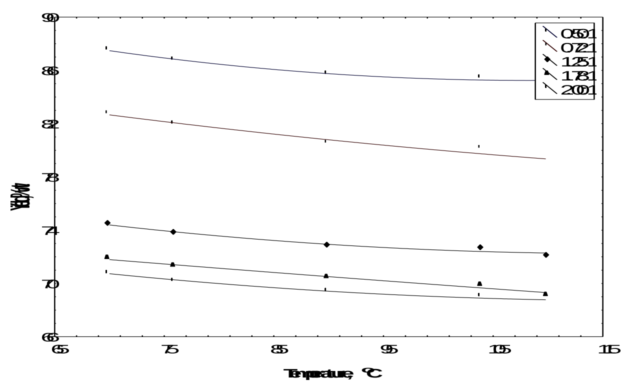


Figure (11) Effect of extraction temperature on raffinate yield at various solvent to oil ratio for NMP extraction

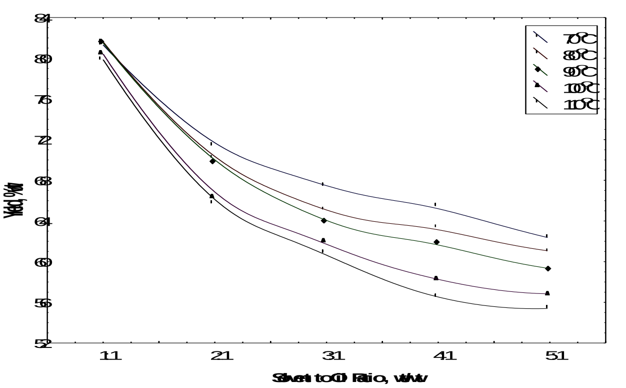


Figure (12) Effect of solvent to oil ratio on raffinate yield at various extraction temperatures for furfural extraction

Figure (13) Effect of solvent to oil ratio on raffinate yield at various extraction temperatures for NMP extraction

Comparison of Furfural and NMP Extraction

For the purpose of selecting the most efficient solvent for the extraction of undesirable materials presented in raw lubricating oil fraction used in this study, a comparison between the viscosity index and percentage yield of raffinates produced from furfural and NMP extraction process were included in this investigation.

The comparison was taken place at extraction temperature of 90 oC and solvent to oil ratio in the range 1:1 to 2:1 for furfural and NMP extraction.

Figure (14) show the effect of increasing the solvent to oil ratio on raffinate viscosity index for furfural and NMP extraction at 90 oC, while Figure (15) shows the effect of increasing solvent to oil ratio on raffinate yield for furfural and NMP extraction at 90 oC.

Figure (14) indicates that the raffinate viscosity index produced from furfural extraction is slightly higher than that produced from NMP extraction in solvent to oil ratio lower than 1.5:1, above this ratio the viscosity index of NMP becomes higher than that of furfural extraction and reaches 80 for NMP raffinate and 77 for furfural raffinate at 2:1 solvent to oil ratio.

Figure (15) show that the raffinate yield produced from furfural extraction is higher than that produced from NMP extraction but at solvent to oil ratio 2:1 an equivalent yield was obtained from furfural and NMP extraction.

If the extraction temperature increase to 110 oC, the raffinate yield for NMP extraction becomes higher than that for furfural extraction at solvent to oil ratio above 1.5:1 and the raffinate viscosity index reaches to 83 for NMP extraction and 80 for furfural extraction at 2:1 solvent to oil ratio.

From the above mentioned discussion it may be concluded that NMP was the most efficient solvent for the extraction of lubricating oil fraction used in this study because of the following:

Low solvent to oil ratio can be used to produce the same raffinate viscosity index.

An equivalent or higher raffinate yield obtained from NMP extraction at solvent to oil ratio higher than 2.0:1.0.

Low solvent toxicity.

Better heat stability because of high boiling point.

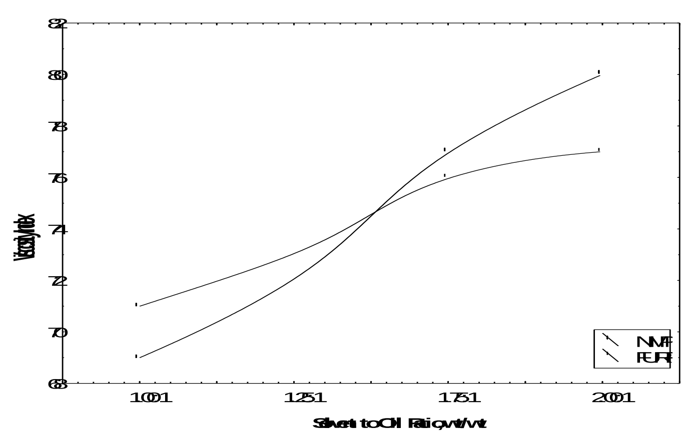


Figure (14) Effect of solvent to oil ratio on raffinate viscosity index for furfural and NMP extraction at 90 oC

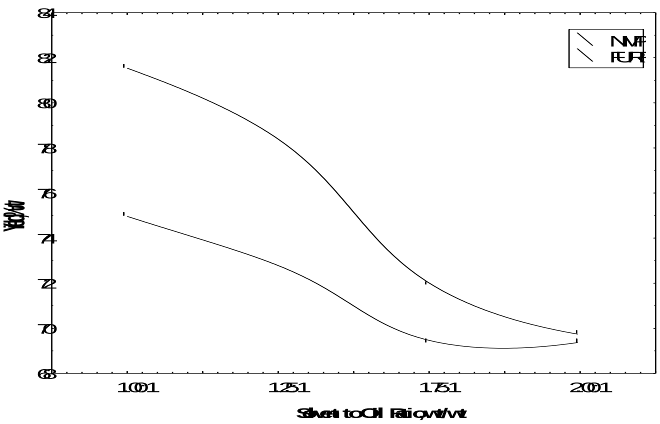


Figure (15) Effect of solvent to oil ratio on raffinate yield for furfural and NMP extraction at 90 oC

CONCLUSIONS

1. the viscosity index of lubricating oil fraction increases from 26 to 71 as a minimum for furfural extraction at 70 oC and 1:1 solvent to oil ratio and reaches 90 as a maximum at 110 oC and 5:1 solvent to oil ratio.
2. the viscosity index of lubricating oil fraction increases to 54 as a minimum for NMP extraction at 70 oC and 0.5:1 solvent to oil ratio and reaches 83 as a maximum at 110 oC and 2:1 solvent to oil ratio.
3. The raffinate viscosity index produced from NMP extraction was higher than that produced from furfural extraction at the solvent to oil ratio higher than 1.5:1 and reaches 83 and 80 for NMP and furfural extraction respectively at 2:1 solvent to oil ratio and 110 oC extraction temperature, while the raffinate yield is 68.69 % wt. and 65.66 % wt. for NMP and furfural extraction respectively using the same operating variables. A compromise should be performed between the desired viscosity index and lubricating oil yield.
4. The solvent to oil ratio has the higher influence on increasing the raffinate viscosity index and decreasing yield, viscosity, and refractive index for furfural and NMP extraction than extraction temperature.

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