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Research Paper

Simulation of Aromatic Compounds Extraction from Lube Cut in Rotating Disc Contactor

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1. ABSTRACT

Providing a reasonable and universal simulation method in the process design of reducing the aromatic content from lube oil cuts by solvent extraction can be of important industrial significance. These mixtures present very complex composition which makes difficult the description of the liquid–liquid equilibrium involved. In this investigation, the liquid-liquid extraction process of aromatics from SAE 30 lube oil by furfural using the calculated physical properties (density, specific gravity and refractive index) of pseudo-component (paraffinic, naphthenic and aromatic) by the standard ASTM experiments and the NRTL binary interaction parameters has been studied. The extraction temperature (328, 338, and 348 K) and the solvent to feed volume ratios (1, 4 and 7) were examined in order to determine their optimum values. The modeling results demonstrated that by increasing the solvent to feed ratio and the extraction temperature, decreasing the weight percentage of furfural and the yield of raffinate phase. The accuracy of the model was checked by simulating single-stage extractions using ASPEN HYSYS. Good agreement was found between predicted and experimental values of yield, furfural content, composition and physical properties for raffinates and extracts. The maximum errors between calculated and industry values of pseudo-component contents are less than 2%.

Keywords: Furfural, Liquid-Liquid Extraction, Lubricating Oil, Phase Equilibria, Rotating Disc Dontactor

2. INTRODUCTION

The separation of aromatic components from a lube-oil cut is carried out by liquid-liquid extraction with contacting the feed and solvent in an extraction column with a proper agitation rate and residence time. Rotating disc contactor (RDC) is one of the most efficient extractors for this process [1]. Lube oil cuts are composed of many complex compounds, so to describe such processes, complex compounds are considered as pseudo-component. Although several studies have been accomplished on predicting the thermodynamic properties using the pseudocomponent approach and by comparing the modeling results with experimental data, little research studies have been dedicated to analyze the effects of operating conditions on the performance of a production scale liquid-liquid extraction plant for aromatic removal. In addition, for increasing the accuracy of process simulation, the binary coefficients of the thermodynamic model are calculated based on the phase equilibrium data, which leads to a minimum deviation between the modeling results and industrial data.
In this work, a model was developed to describe the liquid-liquid equilibrium (LLE) established in the system furfural + SAE 30. The liquid phases (feed, raffinates, and extracts) were considered formed by three groups of pseudo-components (paraffinic (P), naphthenic (N), and aromatic (A)). In order to calculate pseudo-component physical properties (density (D), specific gravity (SG), and refractive index (RI)), the non-random two-liquid model (NRTL) parameters were calculated by correlating compositions of the different extraction experiments for the considered system at different temperatures and furfural/feed ratios. To check the accuracy of the proposed model, single-stage extraction experiments carried out with lube oil cut were simulated with ASPEN HYSYS.

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3. MATERIALS AND METHODS

Furfural and lube oil cut (SAE 30) were prepared from Tehran Lube Oil Refinery (Iranol Co. Tehran, Iran). The calculated composition and pseudo-component physical properties of the used lube oil cut are shown in Table 1. The experimental setup consisted of a 1 L cylindrical stirred glass mixer settler that was isolated from air oxygen by a Teflon bonnet. A stream of nitrogen was passed through the reactor to prevent furfural decomposition. The temperature was set by a thermostatic bath and controlled within ± 0.1°C. The feed and the solvent were kept in good contact by a continuous agitation for 1 h at 450 rpm. After the agitation operation, the phases were left to settle for another hour. The operating condition of the total solvent to feedstock ratio (1-7) and treating temperature (328-348K) was specified. The liquid density, specific gravity and refractive index of the resulting products and the feedstock were determined by means of the ASTM D-1298, ASTM D-2502, and ASTM D-1747, respectively [2]. Based on the measured values for D, SG, and RI, the values of aromatic, naphthenic, and paraffinic content were measured.

Table 1. Properties and composition of pseudo-component for SAE-30 lubricating oil

Property	Paraffin	Naphthene	Aromatic
Composition (wt.%)	69.93	21.54	8.52
Density at 20 °C (g/cm^3)	0.7840	1.2499	0.9935
Specific gravity (SG) at 15 °C	0.8253	1.9253	0.9920
Refractive index (RI) at 20 °C	1.4291	1.5890	1.5832

The liquid-liquid extraction was carried out in the RDC of Iranol Company with the characteristics (column diameter: 4.1 m, number of discs: 32, column height: 22.2 m, feed entry: disc 32 (bottom), and solvent entry: disc 1 (top)) was simulated by a single-stage extraction column, using Aspen Hysys 8.3 and the pseudo-component properties and the parameters estimated for the thermodynamic model. Figure 1 summarizes the scheme of application of the generalized model.

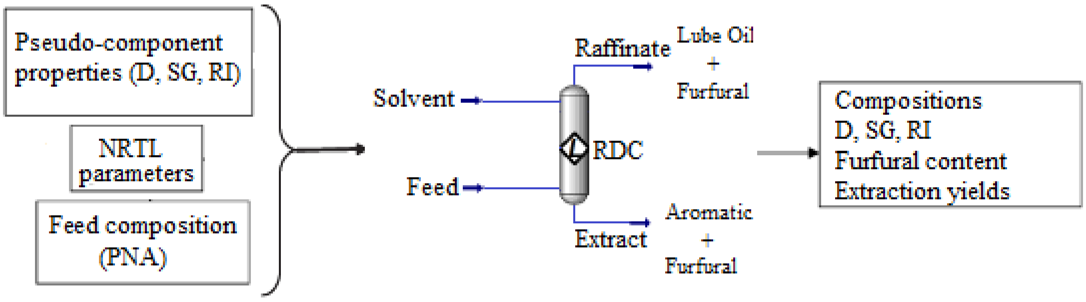

Figure 1. Scheme of calculations and simulation of the single-stage extraction process

4. RESULTS AND DISCUSSION

The effects of solvent to feed ratio and extraction temperature on the extraction system performance as well as the quality of lubricating oil are presented in Table 2. At a constant solvent to feed ratio, by increasing the extraction temperature, the amount of furfural in the raffinate stream is increased due to the fact that the solubility of furfural in lube oil is increased at higher temperatures [3]. At a constant temperature, increasing the solvent to feed ratio leads to a decrease in the amount of aromatic contents in the raffinate stream. This effect is due to the high solubility of aromatic compounds in furfural [4]. Furthermore, at a constant temperature, by increasing the solvent to feed ratio, the value of the refractive index decreases. Generally, by increasing both the extraction temperature and the solvent to feed ratio, the refractive index as well as the density of the raffinate phase decrease. This is mainly due to the extraction of aromatic contents which have a higher density among the other hydrocarbons existed in the feed [5]. Moreover, it can be concluded that the influence of the solvent to feed ratio on the refractive index is higher in comparison with the effect of temperature. The results show that the yield percentage decreases by increasing both the solvent to feed ratio and the extraction temperature. It can be concluded that by increasing the extraction temperature, both the solvent power and the furfural selectivity toward aromatic contents increase, resulting in the lower yield of raffinate. In addition, it can be conceived that the effect of solvent to feed ratio is more than the temperature effect on the raffinate yield.

Experimental and calculated values are compared in Figure 2. Reasonable agreement was obtained in the whole range, with the highest deviations for the highest values of the different properties. Absolute average deviation values were 0.007, 0.014, 0.003, 0.009 and for D, SG, RI, and furfural content, respectively. The obtained deviations for extraction yields (0.012) were less than other previously reported (2-5 %).

5. CONCLUSION

In this study, the four-component system of lube oil cut and furfural was simulated by ASPEN HYSYS software and the results were compared with the experimental results. The results indicated that by increasing the solvent to feed ratio and the extraction temperature, the yield of raffinate phase is decreased. Also, the obtained deviations for extraction yields (1.2 %) were less than the other previously reported [4].

Table 2. Experimental results for the extraction of the aromatic compounds

Fraction	Furfural/Feed (v/v)	T_{ext} (k)	Furfural (w%)	Yield (wt%)	D (g/cm^3)	SG	RI
R-1	1	328	10.7	74.3	0.8447	0.8829	1.4691
R-2	4	328	9.0	53.2	0.8214	0.8599	1.4551
R-3	7	328	7.4	43.8	0.8132	0.8518	1.4496
R-4	1	338	13.1	71.2	0.8553	0.8951	1.4765
R-5	4	338	9.9	47.3	0.8445	0.8835	1.4704
R-6	7	338	8.6	35.9	0.8355	0.8756	1.4643
R-7	1	348	16.0	67.9	0.8452	0.8834	1.4693
R-8	4	348	11.4	41.6	0.8187	0.8572	1.4531
R-9	7	348	10.4	28.0	0.8095	0.8482	1.4481

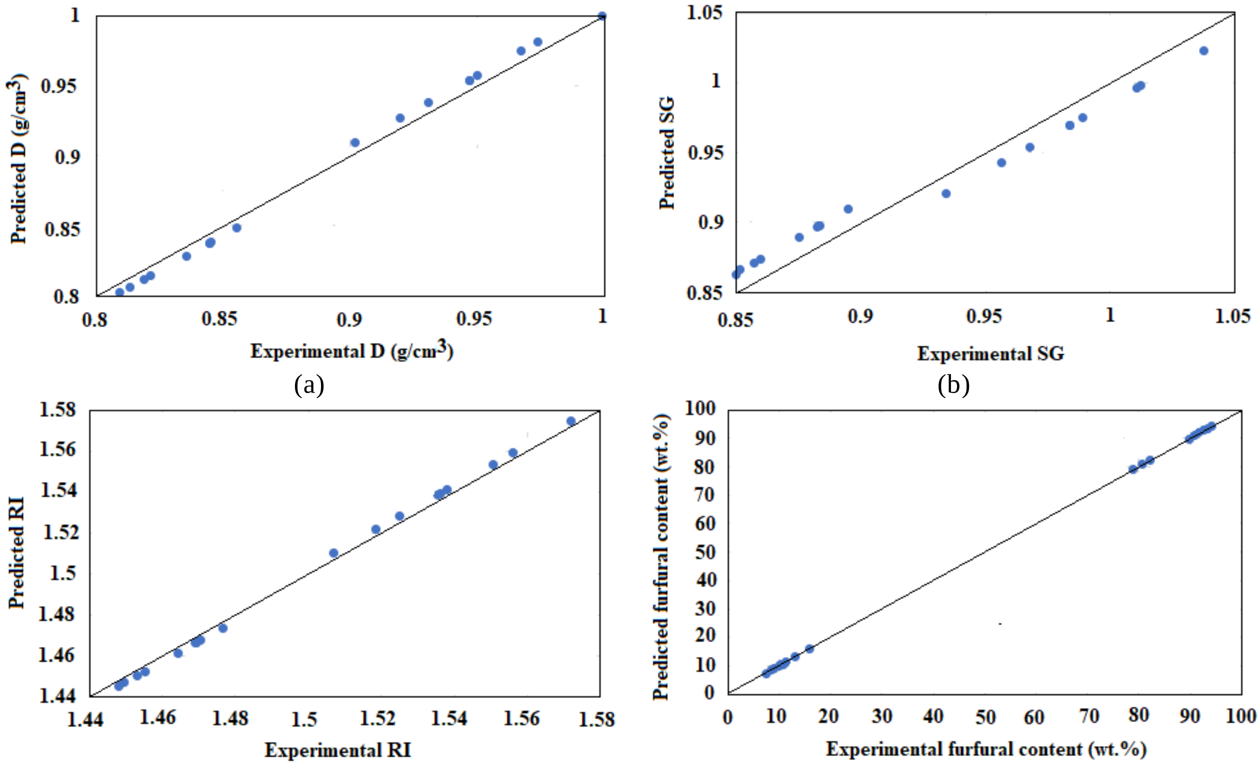

Figure 2. Comparison between experimental and predicted properties: (a) density, (b) specific gravity, (c) refractive index, and (d) furfural content

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