

Modeling and Simulation of Used Lubricant Oil Re-refining Process

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ABSTRACT: Lubricating oils are widely used to reduce friction and wear by interposing a film of material between rubbing surfaces. However, the used lubricant oil does not evaporate and less subject to biodegradation. It requires proper treatment before it can be discharged to the environment. Recently, there is an increase tendency of using used lubricating oil as re-refining feedstock on a worldwide basis. Nevertheless, the activities of re-refining used lubricating oil in industrial scale do not occur in Malaysia. The main objective of this study is to model and simulate a used lubricating oil re-refining process by a conventional process simulator. A process model which tally the experimental results is developed. Next, an industrial scale of re-refining process model is built. This simulation model has successfully represented the real work for re-refining process and can be used as a base case study for industrial scale of re-refining process. Finally, the study is focused on the sensitivity analysis which then revealed the optimal operating condition of the solvent evaporation system in the re-refining process.

INTRODUCTION

Lubricant oils are used to reduce friction and wear by interposing a film of material between rubbing surfaces. Any classes of lubricating materials applied as fluid are considered as lubricating oils (Wills, 1980). It is made from the more viscous portion of crude oil in refinery. There is slight difference in term of elemental analysis depending on its source of crude oil derived from various wells throughout the world.

Modern lubricating oil mainly consists of two materials, which are the base oil and chemical additives (Gergel, 1992). With the addition of specific chemical additives, the properties of the lubricating oil is enhanced and the rate of undesirable changes taken place during operation is reduced.

Various types of additives are blended with base oil according to its grade and specific duty. Typical lubricating oil consists of few ppm to 30 % of additives as shown in Table 1 (Gergel, 1992).

Table 1 Composition of typical lubricating oil

Material	% weight
SAE 30 or 40 Base oil stock	71.5-96.2
Metallic Detergents	2.0-10.2
Ashless Dispersants	1.0-9.0
Zinc Dithiophosphate	0.5-3.0
Anti-oxidant/anti-wear	0.1-2.0
Friction modifier	0.1-3.0
Antifoam	2-15 ppm
Pour point depressant	0.1-1.5

In order to maintain the engines in good condition, it is advisable that the engine oil is drained and replaced by new oil after certain period of service. This is due to the changes occurred in the engine oil in its physical and chemical properties such that it cannot perform as its original performance. Typical composition of waste lubricating oil is shown in Table 2. Significant differences are observed with respect to the ash, bottom sediment, water, carbon contents and its viscosity, as well as the trace metal concentrations. This waste oil is normally somewhat acidic in nature.

Table 2 Comparison of virgin and waste lubricating oil properties (Gergel, 1992)

Properties	Virgin Lube Oil	Used Lube Oil
Physical Properties		
Specific gravity	0.882	0.910
Dynamic viscosity SUS @ 100°F	-	324.0
Bottom sediment and water, volume %	0	12.3
Carbon residue, wt %	0.82	3.00
Ash content, wt %	0.94	1.30
Flash point, °F	-	348.0
Pour point, °F	-35.0	-35.0
Chemical Properties		
Saponification number	3.94	12.7
Total acid number	2.20	4.40
Total base number	4.70	1.70
Nitrogen, wt %	0.05	0.08
Sulfur, % wt %	0.32	0.42
Lead, ppm	0	7,535
Calcium, ppm	1,210	4,468
Zinc, ppm	1,664	1,097
Phosphorus, ppm	1,397	931
Magnesium, ppm	675	309
Barium, ppm	37	297
Iron, ppm	3	205
Sodium, ppm	4	118
Potassium, ppm	< 1	31
Copper, ppm	0	29

* Average properties for 300 used oil sample

Used lubricant oil does not evaporate and less subject to biodegradation (Evdokimiv, 1991). Consequently, unregulated disposal of used oil could be a threat to human health and the environment (Franzmathes, 1988). There is an increase tendency of using used lubricating oil as re-refining feedstock on a worldwide basis. The driving force behind this is solely on the concept of resources conservation, besides minimizing environmental impact. Such commendable nobility must take into consideration the quality of the recycled product and its economic feasibility.

Re-refining methods of used lubricating oil

During the early development of re-refining industry, acid-clay treatment was regarded as one of the prominent methods in this category. Meinken re-refining process (Ali and Hamdan, 1995) is a typical acid-clay treatment process. It is very attractive economically but was drastically reduced due to the disposal problem of acid sludge and growing difficulty in separating contaminants of used oil with high additive content.

Reis and Jeronimo (1988) in their study on the performance of different solvents in the extraction process revealed that alcohol is a promising solvent to remove sludge from the used oil. However, these alcohols will only act as effective flocculating agents, if other types of solvent were added to form a composite solvent. Percentage sludge removal (PSR) is defined as the mass of dry sludge per 100 gram used oil separated when this mass of oil is treated by a certain amount of solvent and the dispersion settles during 24 hours under gravity action. Pilot plant study by Reis and Jeronimo (1990) also revealed that a combination of n-hexane and 2-propanol should be considered for industrial usage due to low solvent/oil ratio and high sludge removal capabilities.

Process simulation

Computer-aided process design tools have been used in the chemical process industries for over four decades to facilitate process analysis, evaluation and optimization with a good degree of success (Petrides et al., 1998). Trainhamit (1994) stated that an effective process modeling and simulation will increase the market value of a company.

Process simulator is able to model different processes in more detail and to trace the flows of different elements during production, use and recycling. Radgen (1998) used Aspen Plus to determine a sensitivity study and an optimization run for recycling strategies for carbon based materials. In this study, the systematic analysis of process chains using modeling and simulation prove to be a valuable tool to minimize material and energy consumption as well as to reduce emission.

Due to multiple inter-relationships and parameter, process chains are complex in nature. As such, computer tools are used to analyze the problem. The flexibility of a process simulator to recalculate the same process chains for different mass flows, combinations of raw materials and the possibility of conducting sensitivity studies for changing reaction yields improves the understanding of the complex relationship between the different mass flows.

There are three basic types of solution algorithm for process simulators: sequential modular, equation solving (simultaneous non-modular) and simultaneous modular (Westerberg et al., 1979). In the sequential modular approach, the equations describing the performance of equipment units are grouped together in modules. The process is then started from one equipment to another. In the equation solving, or simultaneous non-modular technique, all the relationships for the process are written together and then the resulting matrix of nonlinear simultaneous equation is solved to yield the solution. The final technique is the simultaneous modular approach, which combines the modularizing of the equations relating to specific equipment with the efficient solution algorithms for the simultaneous equation solving technique (Turton et al., 1998).

Among these three types of solution algorithm, the sequential modular approach is by far the most widely used (Turton et al., 1998). In this method, each piece of equipment is solved in sequence, starting from the first then followed by the second, and so on. We assume that all the input information required to solve each piece of equipment has been provided. Therefore, the output from a given piece of equipment, along with specific information of the equipment, becomes the input to the next piece of equipment in the process. Figure 1 showed the general strategy for process simulation (Turton et al., 1998).

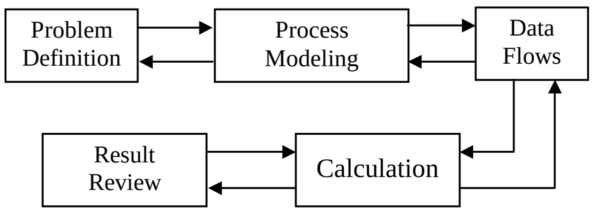

Figure 1 General simulation strategy

In this study, a conventional process simulator, i.e. Aspen Plus is used to model and simulate the used oil recovery process. Trainhamit (1994) reported that this commercial process simulator is highly efficient and provide reliable results. A flowsheet similar to the real plant can be model and simulate by using suitable thermodynamic data, operating conditions and unit operation models. This modular based software includes various conventional unit operations which can be combined to model any process flowsheet.

Re-refining of used lubricant oil by solvent extraction and clay adsorption process

Many studies have been carried out in the research center to develop an environmental friendly used lubricant oil recovery process (Chua, 1999; Nimir, *et. al*, 1999; Lim, 2000; Foo, 2000; Balachandran, 2001). This has been contributed as the base case for comparison in this study.

A process flow diagram of the recovery process is shown in Figure 2. First stage of the used oil recovery process is solvent extraction which consists of three-steps of physical processes. The initial step is the solution of base oil into the solvent and followed by rejection of particles and polymeric additives from the mixture. The extraction process is completed when the flocs grow into sizes large enough to allow for sedimentation and consolidation.

Chua (1999) reported that the increase of 2-propanol composition in the composite solvent of 2-propanol and n-hexane tends to force the polymer into rather extensive configuration, which encourages more particles to be absorbed on its surface and form larger flocs. The author concluded that the optimum of the composite solvent should be at the ratio of 60% 2-propanol and 40% n-hexane.

Nimir *et. al* (1999) and Lim (2000) observed that the optimum ratio of the same solvent to oil ratio as 4:1. Foo (2000) suggested that with the addition of 1.5 gram potassium hydroxide (KOH) into the composite solvent, the sludge sedimentation rate will increase. Duration of 30 to 45 minutes is expected for a 60 gram of used oil sample.

At the second stage, an adsorption process would take place. Activated clay is used to adsorb the awful color of the extracted base oil at the temperature of 80ºC. This will then add the economical value of the re-refined oil. Balachandran (2001) recently reported that the used oil decoloring process would take place in a packed column. 80 gram of activated clay is used to perform the best result for a 60 gram of oil sample.

Lastly, the adsorbed oil is then sent to an evaporation system to separate the composite solvent from the recovered base oil. No laboratory study has been conducted so far on the reuse of recovered composite solvent. Thus, this study will address this solvent reuse opportunity in more detail.

A steady state model is developed by the sequential modular algorithm using Aspen Plus simulator. The extraction and adsorption process are represented by the separator model in Aspen Plus. Two additional flash models are added to represent the drying process of wet sludge and spent activated clay in the real case. A process flowsheet in the Aspen Plus interface is shown on Figure 3.

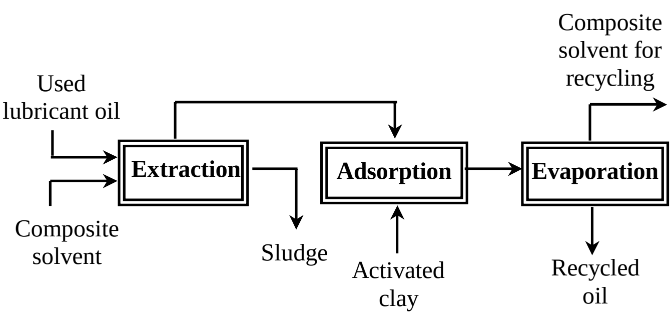

Figure 2: Process re-refining of used lubricant oil

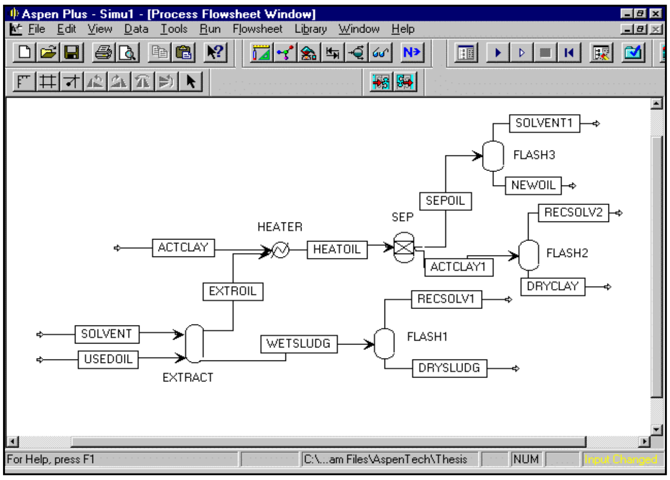

Figure 3 Process flowsheet of used lubricant oil re-refining process in Aspen Plus

RESULTS AND DISCUSSIONS

From a design point of view, numerous different optimization targets can be identified when investigating a process, depending on the objective of the optimization. In this case, the minimum cost for raw materials, which are the composite solvent being use for the extraction process and the activated clay use for adsorption process are investigated. The amount of heat duty needed to operate this re-refining process is also another objective function of the study.

Quality of the recovered composite solvent

In order to fulfill the above mentioned targets, a recycle stream is built at the overhead stream of the evaporator in order to feed the composite solvent back to the extraction process. The base case simulation shows that about 94% of the solvent fed to the system will be recovered by the evaporation process. With the recycling stream, the demands for the new composite solvent feed will then be reduced from 0.24kg/hr to 0.02kg/hr, which is a reduction of 92% (Table 2). The remaining 8% of composite solvent loses during the sludge disposal and trapped in the used activated clay.

Table 2 Comparison between the uses of composite solvent

Re-refining Process of Used Lubricant Oil	Quantity of New Composite Solvent (kg/hr)	Reduction (%)
Without Recycle Stream	0.2400	0.0
With Recycle Stream	0.0158	93.4

Besides, a comparison of the composite solvent composition between the new and recovered solvent is presented in Table 3. Results show that a slight decrease of n-hexane volume is found in the recovered solvent, while the potassium hydroxide which acts as a flocculating agent has also diminished during the recycling process. The original quality of the composite solvent could be easily fine tuned by adding the sufficient amount of n-hexane and potassium hydroxide during the solvent recycling.

Table 3 Comparison of the new composite solvent and the recycled composite solvent

Composition	New Composite Solvent (wt%)	Recycled Composite Solvent (wt%)	Difference (wt%)	Difference (%)
2-propanol	0.5963	0.6148	+ 0.0165	2.69
n-hexane	0.3975	0.3847	- 0.0105	-2.71
Potassium Hydroxide (KOH)	0.0062	0.0000	- 0.0062	-100.00

Extraction process

Simulation result on the extraction process is compared with the laboratory study by Chua (1999). Table 4 shows the result in term of Percent Sludge Removal (PSR) done for both laboratory test and the simulation.

Table 4 Results for extraction process

Composite Solvent/Oil = 4:1	Sample, W_0 (gm)	Dry Sludge, W_d (gm)	PSR (%)
Laboratory Results	20.0000	1.2700	6.33
Simulation Results	20.0000	1.3428	6.71

Table 4 shows that a difference of 0.43 for Percent Sludge Removal (PSR) is found between laboratory test and the simulation. It is due to the significant loss of the composite solvent in the wet sludge stream, which has led to the increase of the total dry sludge for the simulation result.

Composition of the dry sludge after the evaporation system is presented in Table 5. Noted that most of the sludge composition is made up from polar component which originated from the lubricant oil. These polar content are mainly the additives been added to enhance the quality of the lubricant oil, such as polymer alkhyaromatic, polymer olefin and polar ester. Some trace amount of composite solvents are also found in the sludge. These loses are mainly due to solvent trapped in the oil sludge during the sedimentation process.

Table 5 Composition and quantity in the dry sludge

Composition	Quantity (% weight)
Composite Solvent	
2-propanol	0.09928
n-hexane	0.02415
Potassium hydroxide (KOH)	0.01216
Lubricant Oil	
Saturated hydrocarbon	0.03359
Aromatic	0.01683
Polar	0.81390

Adsorption process

With respect to the laboratory results carried out by Balachandran (2001), a comparison with the simulation results on the metal contents is presented in Table 6.

Table 6 Metal contents adsorbed in the adsorption process

Metal Components	Laboratory Result (ppm)	Simulation Result (ppm)	Difference (%)
Magnesium (Mg)	10.875	11.000	1.14
Lead (Pb)	0.194	0.199	2.51
Sodium (Na)	0.396	0.400	1.00
Ferum (Fe)	0.086	0.086	0.00
Zinc (Zn)	0.049	0.049	0.00

Both the laboratory and simulation results showed that high quantity of magnesium is adsorbed in the activated clay as compared to other types of metals. There is also a slight difference of 1.14% between the results, as shown in Table 6. The large amount of magnesium content in the used lubricant oil is mostly contributed by the additives added for the performance improvement of the lubricant oil.

Table 6 also showed a slight difference in the composition of other trace metals. Lead recorded a difference of 2.51% while sodium 1.00% between the laboratory and the simulation results. Ferum and the zinc contributed the least content in the used lubricant oil which are both less than 0.09 ppm. The result for ferum is 0.086 ppm and zinc is 0.049 ppm. This is the same for both laboratory and simulation tests.

Simulation of an industrial scale re-refining process

A 5000 MTA lubricant oil re-refining plant is simulated in Aspen Plus based on the base case simulation model. The simulation model reveals that the amount of composite solvent needed to process 571 kg/hr of used lubricant oil is 39 kg/hr (with recycling). Meanwhile, activated clay needed is 760 kg/hr (without recycling). Result of PSR for this industrial scale re-refining process is found to be 6.42%, which is consistent with the PSR value in the base case study. Result of this simulation is presented in Table 7.

Table 7 Input for re-refining of 5000MT/yr of used lubricant oil

Input	Base case study (kg/hr)	Industrial scale re-refining process (kg/hr)
Used lubricant oil	0.0600	571
Composite solvent	0.0158	39
Activated clay	0.0800	760

Sensitivity analysis

The most energy intensive unit operation in the process is found in model Flash 3, where a large amount of heat is required to evaporate the composite solvent from the recovered oil. Thus, a sensitivity analysis has been carried out on the operating temperature of this model with respect to the quality of composite solvent. This is to recover the best quality of composite solvent at the lowest temperature range.

The sensitivity analysis has been studied based on 3 variables, i.e. the heat duty (Watt), mass flow (kg/hr) for 2-propanol and n-hexane. Mass flow of composite solvent in other sense also represents its concentration in the stream. The results are shown in Figure 4 and Figure 5.

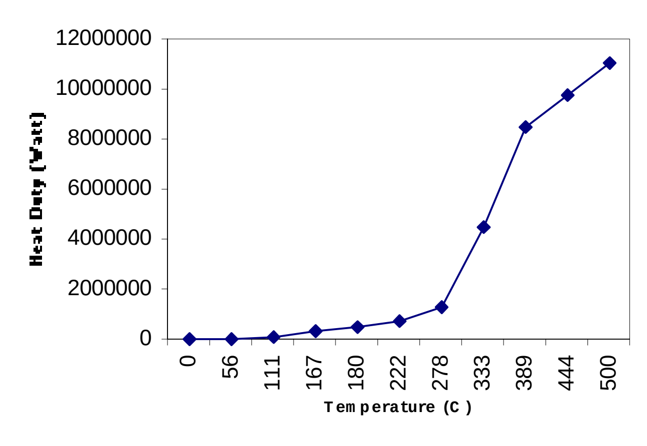

Figure 4 Sensitivity analysis of unit operation Flash3 (**°C**) wrt heat duty (Watt)

Figure 4 shows that the heat duty used is at an exponential function to the temperature of the unit operation. At the temperature of 111°C, the mass flow of both 2-propanol and n-hexane in the composite solvent are at the highest point with a low heat duty needed. When the temperature is increased, the mass flow of composite solvent is increased proportionally and kept at a constant flowrate.

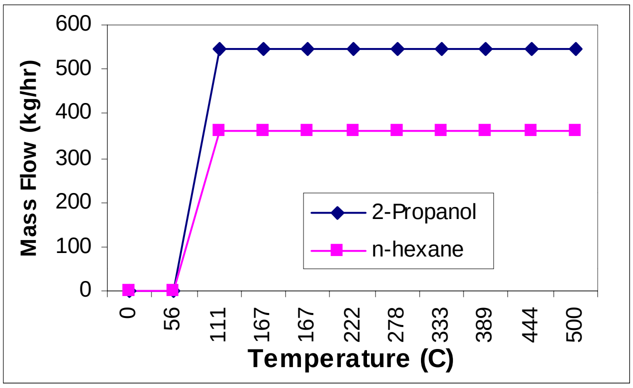

Figure 5 Sensitivity analysis of unit operation Flash3 (°C) wrt mass flow (kg/hr) of composite solvent

Result from sensitivity analysis reveals that the best operating temperature for Flash 3 is 111°C in which the mass flows for both 2-propanol and n-hexane is maximised. Meanwhile, the least quantity of oil composition is obtained along the recycled composite solvent, which is 0.009 in weight percent. The heat duty needed for this operation is reported at 348 kW.

CONCLUSION

A simulation model is successfully built in Aspen Plus simulator to represent the re-refining process. The simulation results which tally the experimental results has shown that this model is reliable to represent the real re-refining process. Subsequently, an industrial scale of re-refining process is successfully carried out. The results from this simulation can be used as a base case for the real scale process. Finally, the sensitivity analysis carried out has revealed the optimal operating condition of the evaporation system in the re-refining process.

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