Analysis and Comparison of Regenerative Technologies of Waste Lubricant

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Abstract: - Lubricant is one of the important resources that cannot be disposed of randomly due to the presence of pollutants. In response to economic efficiency and environmental protection, there is a growing trend of regeneration and reuse of waste lubricant. However, the technologies shall be compared to provide a useful reference for the use of waste lubricant. The major aim of this paper is to analyze and compare the regenerative technologies, thus laying a basis for the governmental bodies in policy-making of lubricant recovery as well as for industrial operators in deciding the recovery methods.

Key-Words: Regenerative Technologies, Waste Lubricant

1 Introduction

When additives and foreign substances, such as metal powder, chips and other grease, are mixed into the lubricant, aging, degrading and failure will likely occur, leading to mechanical fault and degraded performance. In such cases, the lubricant is replaced to improve the working efficiency.

The sales volume in the Taiwan lubricant market was registered separately as 400,000 kilolitres and 450,000 kilolitres in 2004, 2005, and the generation rate of vehicle waste lubricant and industrial waste lubricant was 90.6% and 55.6%, respectively. According to the "Planning and Rate Calculation of Waste Lubricant Recovery" formulated by the EPA in 1999, vehicle lubricant accounted for about 59.7%, and industrial lubricant for 40.3% of the Taiwan lubricant market. It is thus estimated that the annual yield of vehicle lubricant was about 240,000 kilolitres (45*59.7%*90.6%=24.3), and of industrial lubricant about 100,000 kilolitres (45*40.3%*55.6%=10.0) in 2005.

The efficient recycling of waste lubricant could help reduce both the environmental pollution and gas emission from greenhouses, thus creating a huge efficiency either from environmentally-friendly or economic levels. In addition, the imported lubricant can be cut down since only 1.6 kl of waste oil is required for lubricant extraction. As a two-win measure, waste lubricant recycling and regeneration not only save the cost of lubricant, but also contribute much to environmental protection.

2 Waste lubricant recycling

Analysis of pollutant sources of lubricant and disposal.

According to the investigation of CSCC, most of the waste lubricants in Taiwan are recycled and reused as secondary oil and fuel (approx. 94%), but the remaining portion leads to environmental pollution (Table 1).

2.1 Potential harmful substances in waste lubricants

The lubricant, mainly from oil refining, often generates aggregation, oxidation and acidification due to high-temperature catalysis with metal chips and water during operation. Thus, poly-nuclear aromatics and heavy metals contained in waste lubricant are carcinogenic, inflammable, harmful or corrosive substances (Table 2).

3 Evaluation of the recovery and reuse of waste lubricant in developed countries

The waste lubricant must meet environmentally-friendly and application criteria for recovery and reuse. Two key indicators include pollution level and viscosity index in this respect. In Europe, the regenerative oils are classified mainly according to the content of chlorides. Since chlorides are harmful to the human body, and complex finishing processes shall be required during the regeneration process, the chlorine content in reclaimed waste oil shall not exceed 50ppm in EU regulations.

A higher viscosity index of waste lubricant means a higher suitability for regeneration into lubricant. Viscosity is the most important consideration of choosing lubricants. The strength of the lubricant film is approximately proportional to its viscosity, so the higher viscosity indicates the stronger strength of the lubricant film. The viscosity index (VI) refers to the changing degree of viscosity dependent on temperature: the lower V.I means a higher viscosity change in the case of slight temperature change, and vice versa. Thus, in the case of a higher viscosity index, no finishing process shall be additionally required to improve V.I., making it more suitable for recovery and reuse with a relatively smaller operating cost.

4 Comparison of recovery rate between Taiwan and other regions in the world

In 2005, there is approx. 340,000 kiloliters of waste lubricant in Taiwan, so the recovery rate is about 4% if the audited statistical recovery yield of 14,000 kiloliters in the same year is divided by 340,000 kiloliters. As compared with European countries, it is found that Luxembourg had a recovery rate of 39%, and the average recovery rate of Europe was 50% in 2000.

Table 3 lists the predicted recovery rate of some European countries according to their consumption habits and distribution of lubricant. The predicted recovery is obtained by multiplying the consumption with this value. Then, the predicted recovery rate is obtained by dividing the recovery by the predicted recovery.

4.1 Discussion of regenerative technologies

The purpose of various regenerative technologies is to generate reusable lubricant by the following 4 steps.

4.1.1 De-water/de-fuel

The main components of light oil contain fuel and naphtha. These foreign substances are mainly leaked from vehicle engines into lubricant, and often disposed of according to their physical characteristics and the properties of the lubricant (boiling point, gravity and solubility).

4.1.2 De-asphalt

The solid foreign substances in waste lubricant derive from metal powder and additives during mechanical abrasion, and are often disposed of according to the physical characteristics (solubility and boiling point), or by chemical characteristics (by adding reagent). De-asphalting was previously performed by adding sulfuric acid or solvent, and is now done by means of thin film separation or thermal-finishing.

4.1.3 Fractionation

Fractionation separates the substances using the different boiling points and characteristics. The lubricant products are usually a mixture of several organic compounds. So, fractionation is used to select or remove specific substance from the mixture.

4.1.4 Finishing

After the aforementioned processes, the finishing process shall be required to remove the remaining foreign substances, such as chlorine, nitrogen, oxygen and sulfur, etc. The finishing process generally comprises clay-finishing or hydro-finishing.

5 Comparison of regenerative technologies

The most commonly used regenerative technologies differ a lot from each other with respect to de-asphalting and finishing methods. The previously used technologies include the acid/clay process, the distillation process, and the solvent de-asphalting process, all of which generate acid sludge with secondary pollution. Therefore, reducing secondary pollution is a major consideration of new technologies.

Due to the different finishing methods, there are currently available many new technologies, such as Thin Film Evaporation (TFE), including: TFE + clay finishing, TFE + solvent finishing and TFE + hydro-finishing), Thermal De-Asphalt (TDA), TDA + clay finishing, and TDA + hydro-finishing. In addition, solvent extraction hydro-finishing is developed by means of hydro-finishing after the solvent de-asphalting process. These technologies are described below:

5.1 Acid/clay process

First, concentrated sulfuric acid is added into dehydrated waste oil, wherein the foreign substances (e.g. additives and sulfides) will form sludge, enabling 16~48 hour deposition and then separation from the waste oil. The foreign substances, colloid, organic acids and waxy substances are removed by clay (porcelain clay or aluminum silicate) and de-colored. Next, such oil is filtered to yield reusable base oil (Figure 1).

5.2 Distillation process

The operating principle of the distillation process is to further purify the waste oil by vacuum distillation prior to the acid/clay process, with its flow process similar to the acid/clay process (Figure 2).

5.3 Solvent de-asphalting process:

The propane is used as a solvent to separate insoluble suspended substances such as asphalt, metallic compounds, and resin in the waste oil, with its flow process similar to method 2, other than the solvent extraction and vaporization steps.

In addition to propane, organic solvents, such as propanol and supercritical ethane, can also be used for the solvent de-asphalting process (Figure 3).

5.4 TFE + hydro-finishing

This method is used to separate oil and foreign substances via a thin film, and purify it through hydro-finishing to avoid secondary pollution. Firstly, the moisture and light oil contained in the waste oil are removed through hydro-finishing, and then vacuum distillation of free components is required to allow for subsequent separation of a high-temperature thin film. Finally, the oil is subjected to hydro-finishing to remove chlorine, nitrogen, oxygen, and sulfur compounds (Figure 4).

5.5 TFE + clay finishing

This method is used to separate oil and foreign substances via a thin film, and purify it by clay. As compared with TFE + hydro-finishing, the only difference is that the clay is used for absorption in lieu of hydro-finishing (Figure 5).

5.6 TFE + solvent finishing

This method is used to separate oil and foreign substances via a thin film, and apply the solvent to finishing, with the flow process similar to TFE + hydro-finishing (Figure 6).

5.7 Solvent extraction hydro-finishing

This method combines solvent extraction and hydro-finishing by removing the foreign substances by solvent and then improving oil quality by hydro-finishing. Firstly, the moisture is removed, and the waste oil is separated through propane extraction. Then the mixture of propane and waste oil is subjected to hydro-finishing to remove sulfur, nitrogen and oxygen for purification purposes (Figure 7).

5.8 TDA + clay finishing and TDA + hydro-finishing

The dehydrated waste oil is vacuum-heated at 360^{o}. The ash remains at the bottom, and the oil is divided into 3 types: i.e. vacuum gas oil (VGO); base oil (as lubricant); and asphalt residue. Next, the base oil is subjected to hydro-finishing or clay-finishing under high-pressure (100 bar) for subsequent utilization (Figure 8).

6 Manufacturers for waste lubricant recovery

The world-wide leading manufacturers specialized in waste lubricant recovery are listed below:

They are well-proven with long-term development expertise.

(1) KTI –focused on TFE + hydro-finishing, with factories in Greece, Tunisia and the U.S.
(2) CEP/MOHAWK.--focused on TFE + hydro-finishing, with 2 factories in America.
(3) SAFETY-KLEEN-focused on TFE + hydro-finishing, with factories in the U.S. and Canada.
(4) Agip Petroli/VISCOLUBE-focused on Thermal De-Asphalt (TDA) and clay-finishing, with factories in Italy.
(5) IFP--focused on solvent extraction hydro-finishing, with factories in Greece.
(6) SNAM PROGETTI-.focused on solvent extraction hydro-finishing, with factories in Italy.

Well-proven but with little development expertise, are:

(1) UOP DCH-laboratory test.
(2) New Meinken technology-under development.

7 Comparison and discussion

In view of the relative advantages, these regenerative technologies are analyzed comparatively in terms of operational, economic and environmentally-friendly aspects, as listed in Table 4~6. The relational chart of regenerative technologies is depicted in Figure 9, wherein the relationship is explained according to their intersection—based on de-asphalting and finishing technologies. For example, both the distillation and solvent de-asphalting processes employ clay-finishing, so there is an intersection with the acid/clay process, and so on.

8 Conclusions

In a move to achieve environmental protection or sustainable utilization of mineral resources in Taiwan, the recovery rate of waste lubricant should be further improved. In fact, there is much room in this respect according to the economic and technological feasibility aspects. However, the technical feasibility, economic and energy efficiency, as well as possible environmental hazards should be taken into account in any case. Owing to the fact that waste lubricant is possibly disposed at an individual's own will, or put into the market as new lubricant, it is urgently required to collect the methods and advantages/disadvantages of existing regenerative technologies, establish the recovery and utilization system (for repair depots and factories), formulate the regulatory laws and auditing system as well as the production and consumption system. This would facilitate the planning and management of recovery and sustainable utilization of waste lubricant.

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Table 1□Distribution and hazards of waste lubricant in Taiwan.

Distribution	Common purpose	Percentage	Hazards
Recycling dealer	Secondary oil and fuel	79.5%	Inferior reclaimed oil, leading to mechanical damage
Factories	Furnace fuel	14%	Inclusive of heavy metal, improper incineration leading to serious pollution
Secondary lubricating in construction	De-molding	2.5%	Pollution transfer
Random dumping		4%	Serious environmental pollution

Table 2□Potential harmful substances in waste lubricant.

Organic pollutants	Possible sources	Range
polynuclear aromatics	Basic oil components	(μ g/L)
Benzopyrene		360~62,000
Dimethylbenz anthracene		870~30,000
Pyrene		1,670~33,000
Alkyl naphthalene	Basic oil components	900,000
Albocarbon	Basic oil components	440,000
Chlorine solvent	Cleaning agents in degreasing	(mg/kg)
1,1,1- trichloroethane		18~1,800
Trichloroethane		18~2,600
Tetrachlorethylene		3~1,300
Metal elements		
Barium	Additive	60~690
Zinc		630~2,500
Aluminum	Engine or metal chips	4~40
Chrome		8~24
Lead	Oil	3,700~114,000

Table 3□Recovery rate of lubricant in European regions.

Region	Consumption(t)	Predicted recoverable rate (%)	Predicted recovery(t)	Actual recovery	Predicted recovery rate (%)
Austria	102,400	44	45,000	33,500	74
Belgium	173,608	44	76,388	60,000	79
Denmark	71,416	65	46,420	35,000	75
Finland	89,194	54	48,165	38,532	80
France	888,771	49	435,498	242,500	56
Germany	1,076,149	50	538,075	460,000	85
Greece	88,000	68	60,000	22,000	37
Ireland	38,900	51	19,839	17,062	86
Italy	681,100	40	272,440	200,395	74
Luxemburg	10,150	50	5,075	2,000	39
Netherlands	154,685	54	83,530	60,000	72
Portugal	113,200	55	62,260	39,620	64
Spain	496,141	55	223,263	105,000	47

Sweden	146,847	54	79,297	63,438	80
Great Britain	803,667	51	409,870	352,500	86
Europe	4,934,228	49	2,405,120	1,731,546	49

Table 4□Comparison of regenerative technologies (operational level).

Regenerative technology	Process				Water consumption	Operating temperature
	De-water/de-fuel	De-asphalt	Fractionation	Finishing		
Acid/clay process	Vacuum distillation/centrifugation	Adding sulfuric acid and clay	N/A	N/A	Little	Low
Distillation process	Vacuum distillation	Adding clay and a few acids for vacuum distillation	N/A	N/A	Little	High
Solvent de-asphalting process	Vacuum distillation	Adding solvent separation oil and ash	Vacuum heating fractionation	Clay-finishing	Little	High
TFE + hydro-finishing	Vacuum distillation	Thin film separation (High-temperature/-pressure)	Vacuum heating fractionation	Hydro-finishing	Moderate	High
TFE + clay finishing	Vacuum distillation	Thin film separation (High-temperature/-pressure)	Vacuum heating fractionation	Clay-finishing	Moderate	High
TFE + solvent finishing	Vacuum distillation	Thin film separation(High-temperature/-pressure)	Vacuum heating fractionation	Solvent-finishing	Moderate	High
Solvent extraction hydro-finishing	Vacuum distillation	Adding solvent separation oil and ash	Vacuum heating fractionation	Hydro-finishing	Moderate	High
TDA	Vacuum distillation	Thermal finishing	Vacuum heating fractionation	Hydro-or clay-finishing	Much	High

Table 5□Comparison of regenerative technologies (economic level).

Regenerative technology	Technology maturity	Energy demand	Recovery rate	Quality of reclaimed oil	Equipment demand	Operating cost	Scale (kt/y)
Acid/clay process	Plant scale	Low	63%	Poorer*	Low	Low	Small(2~10kt)
Distillation process	Plant scale	High	50%	Poorer*	Moderate	Low	Middle(25kt)
Solvent de-asphalting process	Plant scale	High	65-70%	API GROUP I	High	High	Middle(25kt)

TFE + hydro-finishing	Plant scale	High	72%	API GROUP II	High	High	Big(50~80kt)
TFE + clay finishing	Plant scale	High	72%	API GROUP II	High	High	Big(100kt)
TFE + solvent finishing	Plant scale	High	72%	API GROUP II	High	High	Big(100kt)
Solvent extraction hydro-finishing	Plant scale	High	74%	API GROUP II	High	High	Middle(60kt)
TDA	Plant scale	High	74-77%	API GROUP II	High	High	Big(100~180kt)

*Acid/clay and distillation processes were developed previously. The regenerated substances couldn’t meet the present criterion of base oil.

Table 6□Comparison of regenerative technologies (environmental-friendly level).

Regenerative technology	Acid sludge	Residual oil sludge	Harmful chemicals	Secondary pollution
Acid/clay process	Much	Much	Sulfuric acid	Yes
Distillation process	Little	Many	Sulfuric acid	Yes
Solvent de-asphalting process	Little	Much	Sulfuric acid and volatile organic solvent	Yes
TFE + hydro-finishing	N/A	Little	N/A	Few
TFE + clay finishing	N/A	Little	N/A	Few
TFE + solvent finishing	N/A	Little	Volatile organic solvent	Few
Solvent extraction hydro-finishing	N/A	Little	Volatile organic solvent	Few
TDA	N/A	Little	N/A	Few

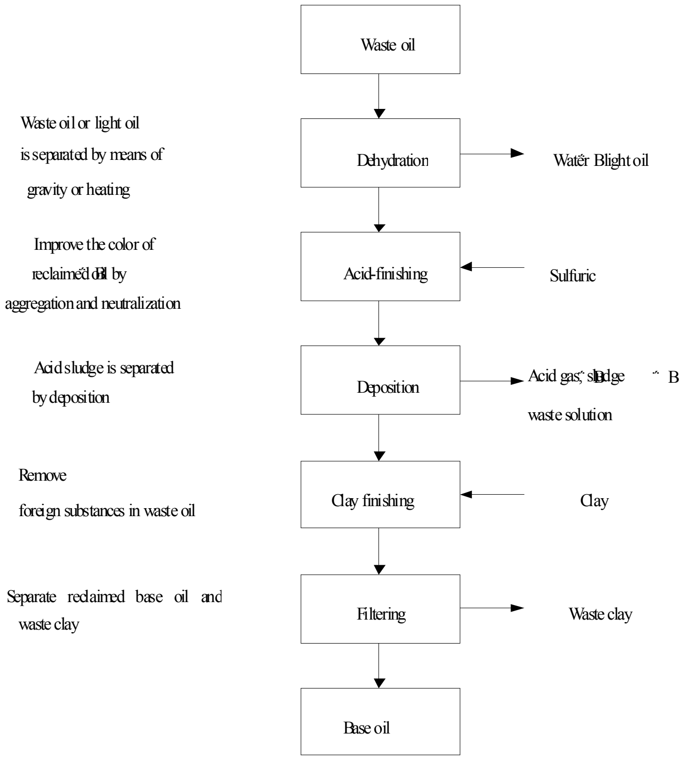


Fig.1□Schematic diagram of the acid/clay process.

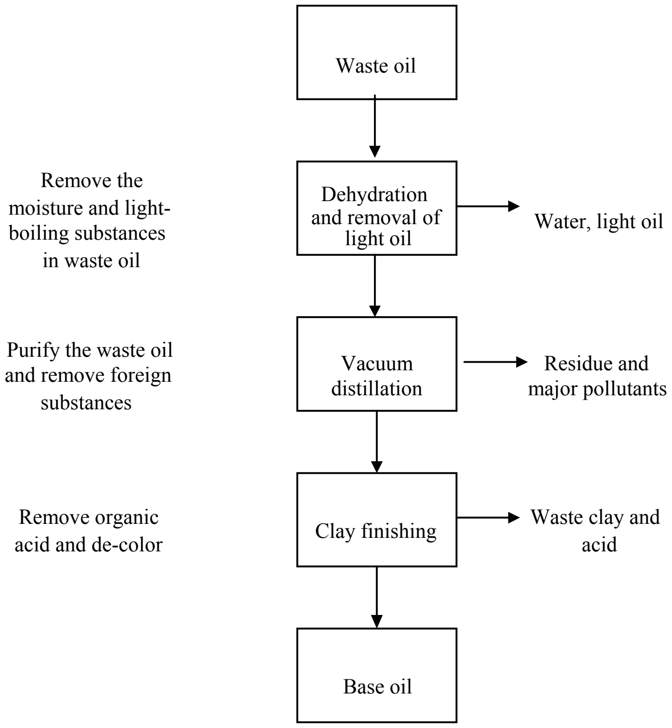


Fig.2□Schematic diagram of the distillation process.

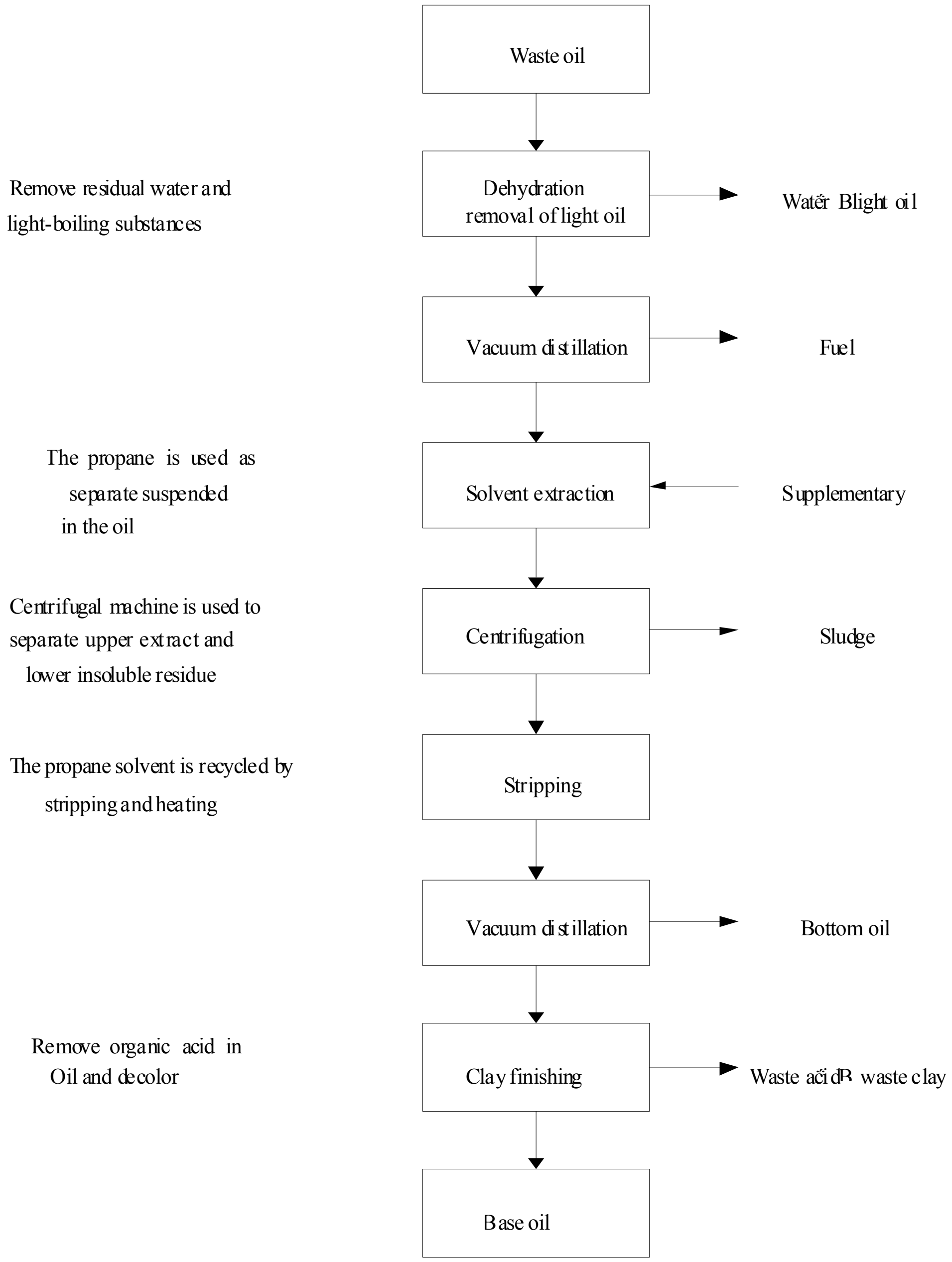


Fig.3□Schematic diagram of the solvent de-asphalting process.

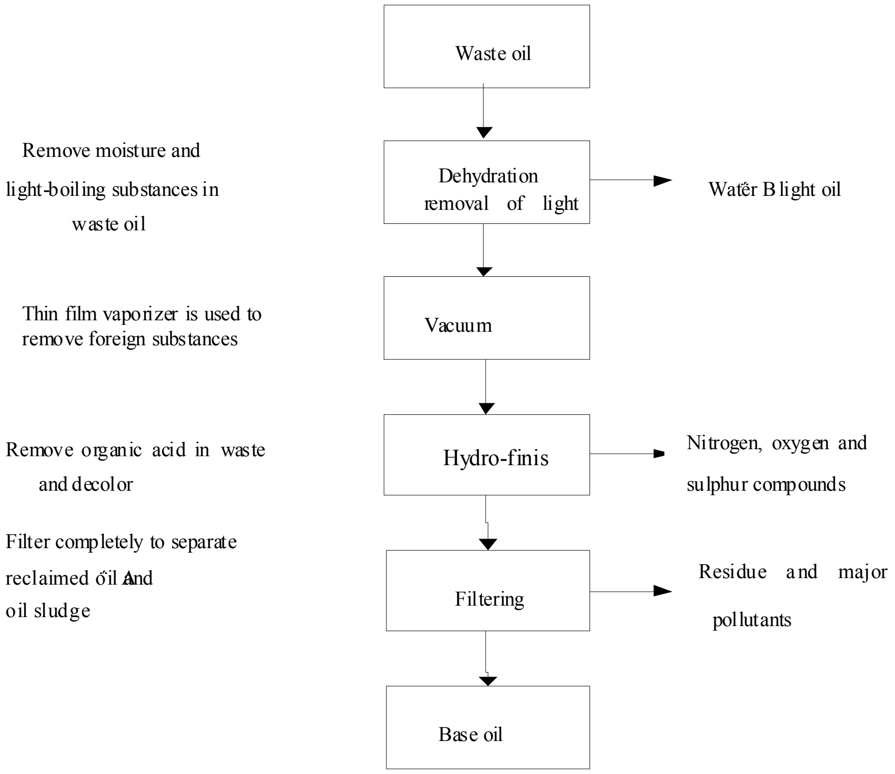


Fig.4 Schematic diagram of TFE + hydro-finishing.

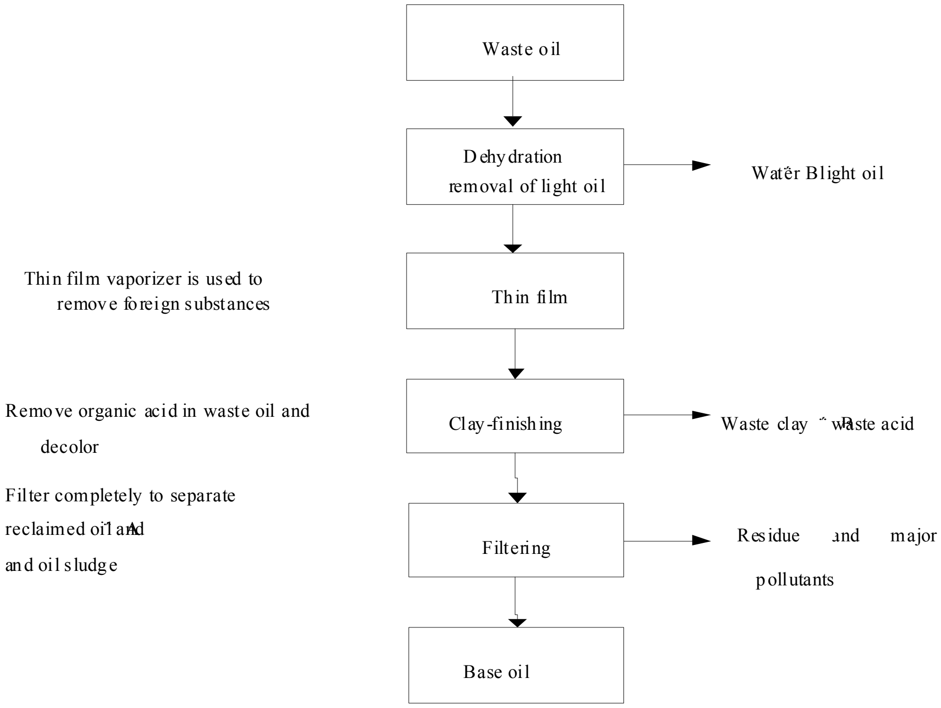


Fig.5 Schematic diagram of TFE + clay finishing.

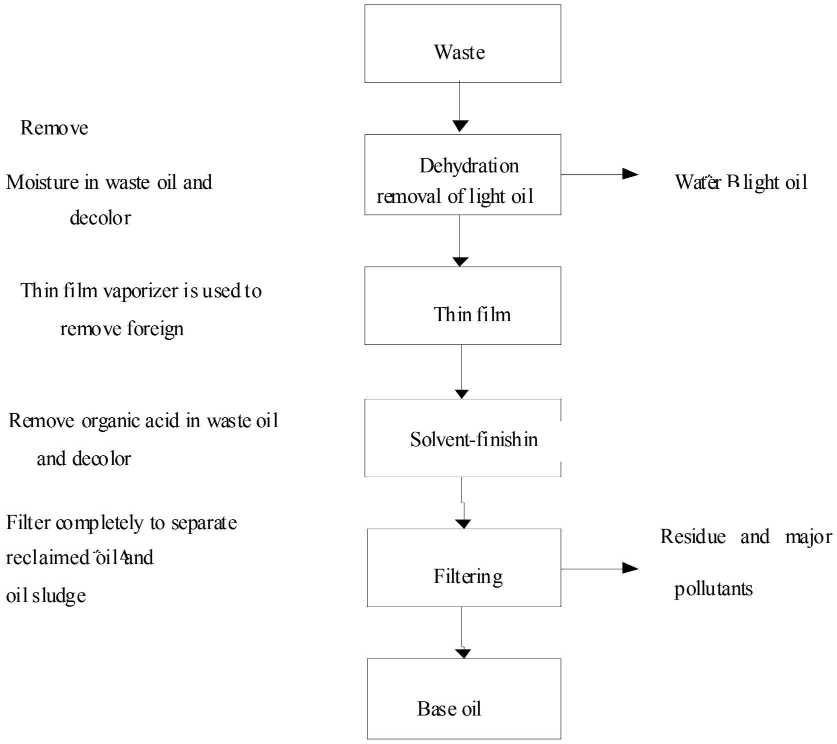
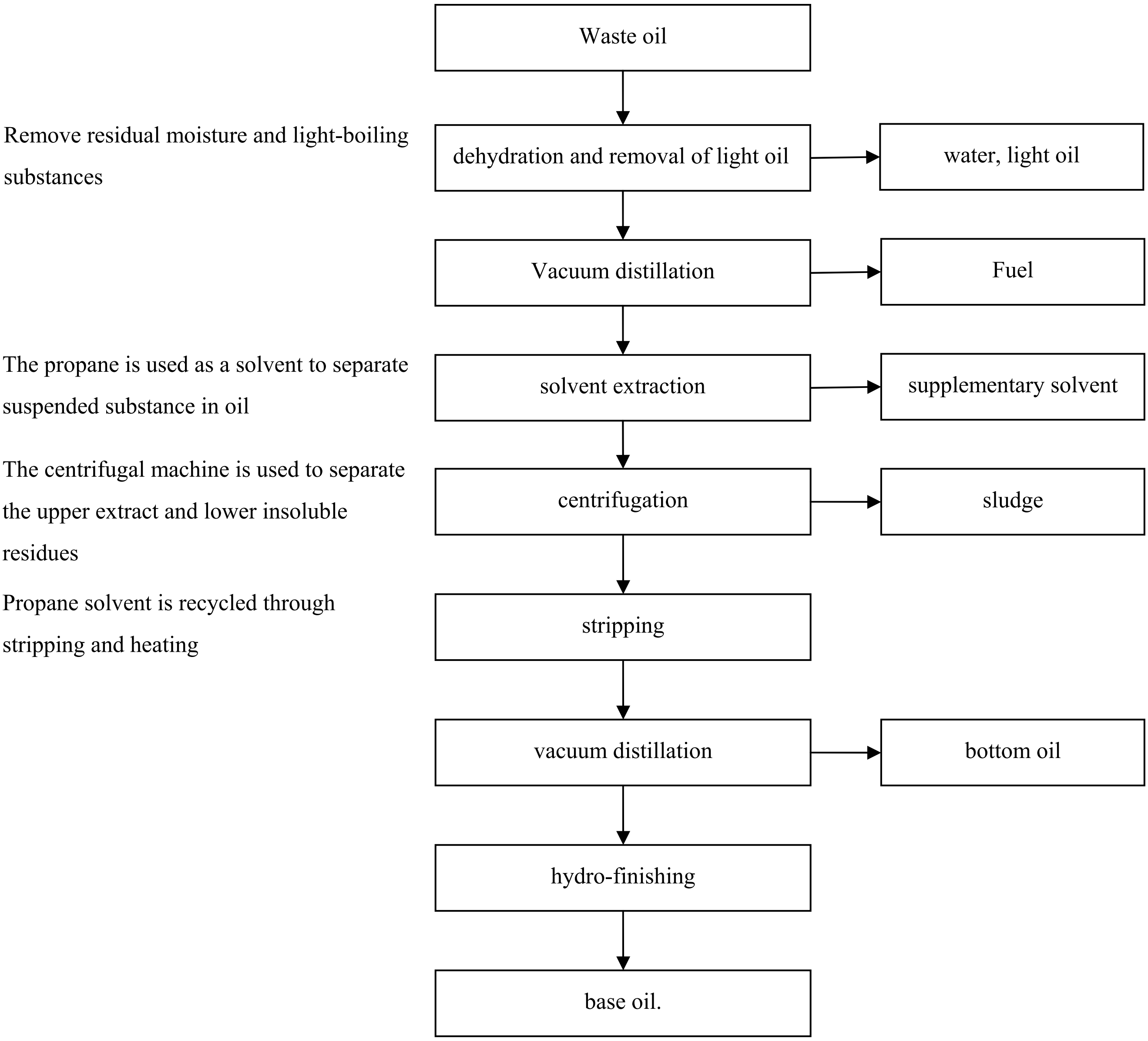


Fig.6□Schematic diagram of TFE + solvent finishing.



Remove residual moisture and light-boiling substances

The propane is used as a solvent to separate suspended substance in oil

The centrifugal machine is used to separate the upper extract and lower insoluble residues

Propane solvent is recycled through stripping and heating

Fig.7 Schematic diagram of solvent extraction by hydro-finishing.

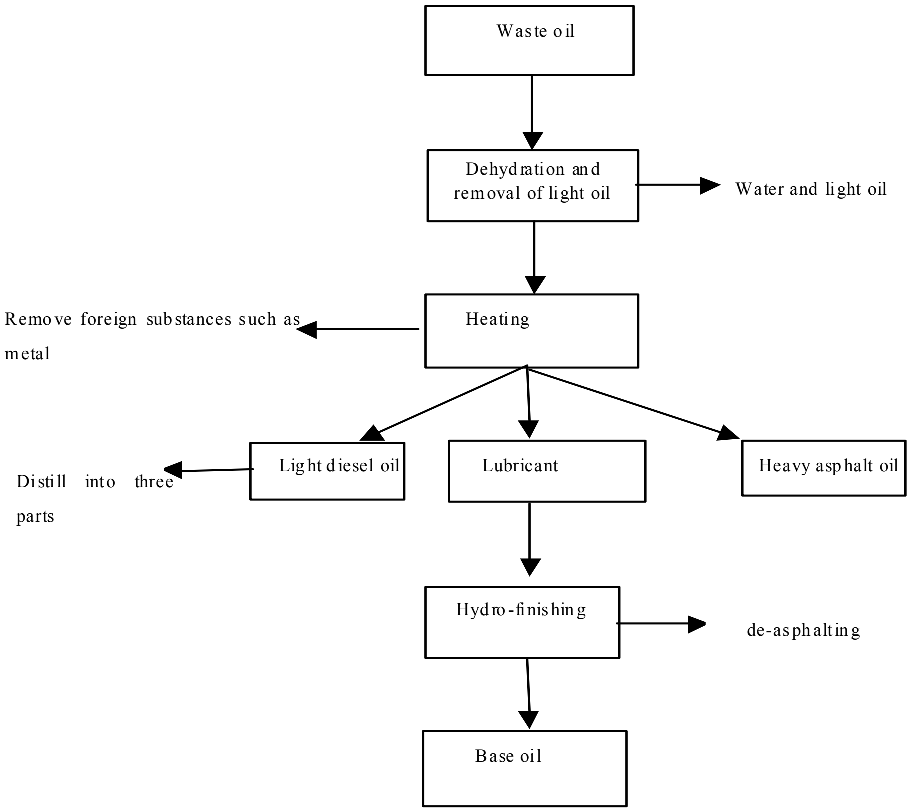


Fig.8 Schematic diagram of TDA finishing process.

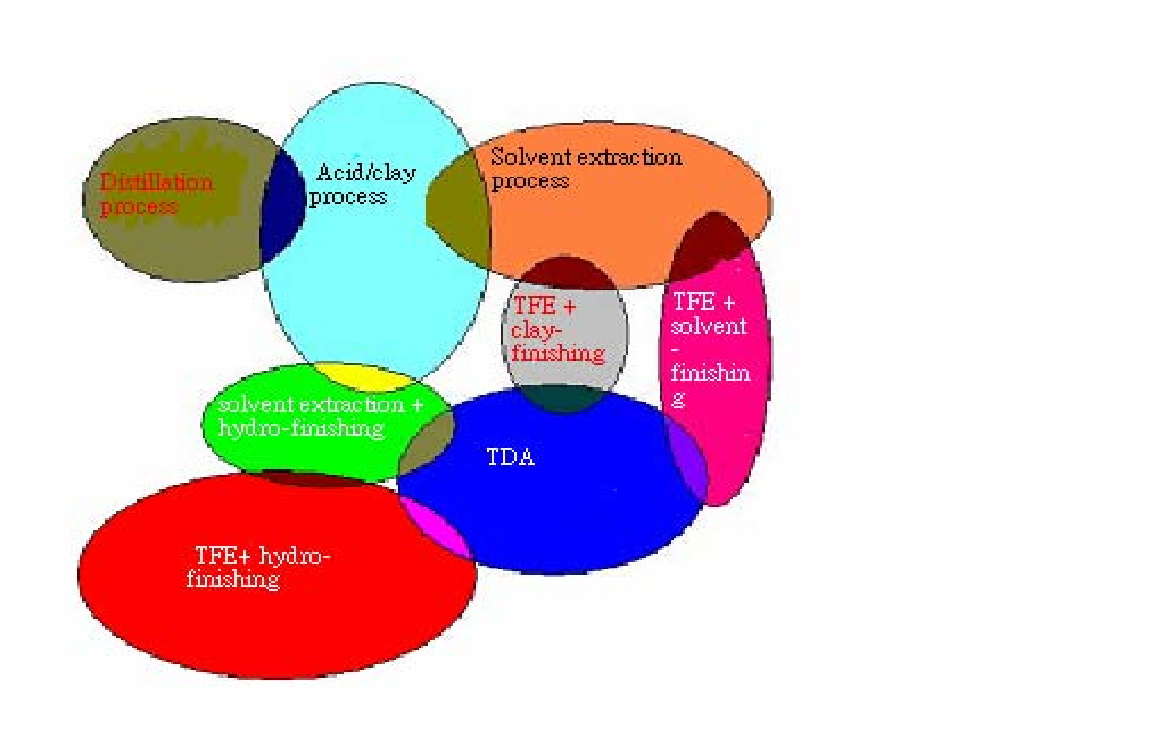


Fig.9 Relational chart of regenerative technologies.