A review on treatment methods of used lubricating oil

Article *in* International Journal of Civil Engineering and Technology · December 2018

Temitayo Oladimeji
Covenant University Ota Ogun State, Nigeria

Jacob Sonibare
Obafemi Awolowo University

James Abiodun Omoleye
Covenant University Ota Ogun State, Nigeria

International Journal of Civil Engineering and Technology (IJCIET)
Volume 9, Issue 12, December 2018, pp. 506–514, Article ID: IJCIET_09_12_056
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=12
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

A REVIEW ON TREATMENT METHODS OF USED LUBRICATING OIL

Temitayo E. Oladimeji
Department of Chemical Engineering, Covenant University, Ota, Ogun state, Nigeria

Jacob A. Sonibare
Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria

James A. Omoleye
Department of Chemical Engineering, Covenant University, Ota, Ogun state, Nigeria

Moses E. Emetere
Department of Physics, Covenant University, Ota, Ogun state, Nigeria.

Francis B. Elehinafe
Department of Chemical Engineering, Covenant University, Ota, Ogun state, Nigeria

ABSTRACT

Disposing used lubricating oil (ULO) through local means has been found to lead to air, land and water pollution. This pollution lowers the lifespan of inhabitants due to spread of diseases. Treatment of used oil is one of the easiest way to avoid pollution as observed in literatures. Aside preventing pollution, another advantage is majorly turning waste to wealth. In this paper, an indebt review was done on the various methods for treating used lubricating oil. The advantages and shortcomings of each method were highlighted for further study.

Keywords: used lubricating oil, methods, treatment, pollutants.

Cite this Article: Temitayo E. Oladimeji, Jacob A. Sonibare, James A. Omoleye, Moses E. Emetere and Francis B. Elehinafe, A Review on Treatment Methods of Used Lubricating oil, International Journal of Civil Engineering and Technology, 9(12), 2018, pp. 506–514

http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=9&IType=12

1. INTRODUCTION

Lubricating oil majorly helps in reducing friction, dust, corrosion, protection against wear and tear and provision of heat transfer medium in various equipment or machineries. (Shri et al., 2014). In the process of usage of lube oil, temperature build up occurs which breaks down the oil and weakens its properties which include pour point, flash point, specific gravity, viscousity etc. (Udonne and Bakare, 2013). The oil becomes unsuited for normal usage due to the build-up of contaminants in the LO such as water, metals, carbon residue, ash, water, gums, varnish, e.t.c. and chemical changes in the oil such as thermal degradation or oxidation. These contaminants are impurities which decrease the lubricating oil performance and turn it into used oil/ Waste oil.

Poor management and careless disposal of used Lube oil can affect the environment negatively (Lam et al., 2016). As reported by UN (2016), about six million deaths resulted from air pollution yearly. The burning of the waste lubricant contributes to the aerosol or green houses in the environment. Scientists have reported that in some geographical region e.g. West Africa, the dispersion of the air pollutants could travel at a speed of 10 -12 m/s (Emetere, 2017). The implication of this report is that air pollution from the burning of waste lubricant is not localized to the source of pollution but could travel with time to other locations. For example, it was recently reported that black soot covered a metropolitan city of Port Harcourt while the remote sources were at the suburb settlement (about 22 km away from city).

Recycling of used oil is therefore important in that; it takes less energy and cost compared to refining of crude oil, it helps to mitigate air, land or water pollutions in the environment. The most prefered option by expert is the reuse of the used oil generated by consumers (Jafari and Hassanpour, 2015). In this study, a detailed review on various treatment methods of used oil starting from the generic methods to the most recent methods and their limitations was discussed; future development of this field was also highlighted.

2. CONVENTIONAL/ GENERIC TREATMENT METHODS OF USED LUBRICATING OIL

2.1. Acid-clay

Evaluation of the different recycling processes showed that acid-clay process has the highest environmental risk as well as the lowest cost. The process involve treatment of used oil with acid and clay (Udonne and Bakare, 2013; Ellela et al., 2015; Hamawand et al., 2013). The clay serves as an adsorbent to remove the odour and dark colour. Factors which distinguishes acid-clay from other methods include; simple process, low capital investment, low operating cost and requires no skilled operators (Giovanna et al., 2012; Nwachukwu et al., 2012).

To minimize the harzadous waste generated from this process; the acid treatment stage of the process can be conducted under the atmospheric pressure to remove the acidic products, oxidized polar compounds, suspended particles and additives (Falah & Hussien, 2011). Princewill & Sunday (2010) observed that high recovery rate of treated LO from used oil depend largely on the used oil source, pretreatment steps, level of contamination, and grade of acid used. He also added that volume of adsorbent (clay) used could affect the rate at which contaminants are removed and the percentage of recovery of the process.

In Ellela et al., (2015) work, used motor oil was treated with phosphoric acid, sulphuric acid, methanoic acid and acetic acid. Also, methanoic acid, sulphuric acid and acetic acid have great changes on the kinematic viscosity while phosphoric acid is not affected by ULO. Therefore, treatment with acetic showed better results than formic acid- clay.

Nguele et al. (2014) identified three main lube oil degradation causes as wear, carbonyl oxidation and sulfate oxidation. The above itemized processes are the principal reasons of additive depletion in lubricants. Hence, the effective way for determining the most effective process for the treatment of used oil can be adopted from known models e.g. activated sludge model 1 (ASM1). ASM1 enables the simulation of the purification of used lubricating oil via the adoption of thirteen process components, eight biochemical processes and nineteen kinetic parameters. The mathematical representation of the ASM1 is shown below

$$r_o = \overbrace{\frac{1-\gamma_H}{\gamma_H}\mu_H\left(\frac{\rho(S_s)}{K_s+\rho(S_s)}\right)\left(\frac{\rho(S_o)}{K_{O,H}+\rho(S_o)}\right)\rho(X_{B,H})}^{heterotrophs}$$

$$-\overbrace{\frac{4.57-Y_A}{Y_A}\mu_A\left(\frac{\rho(S_{NH})}{K_{NH}+\rho(S_{NH})}\right)\left(\frac{\rho(S_o)}{K_{O,A}+\rho(S_o)}\right)\rho(X_{B,A})}^{autotrophs}$$

WhereK_s, $K_{O,H}$, K_{NH}, and $K_{O,A}$ are saturation constants for biodegradable organics, oxygen in heterotrophs, ammonia and oxygen in autotrophs respectively. $\rho(S_s)$, $\rho(S_o)$, $\rho(X_{B,H})$, $\rho(X_{B,A})$ and $\rho(S_{NH})$ are the densities of biodegradable organics, oxygen, heterotroph biomass, autotroph biomass and ammonia respectively. γ_H And Y_A are the yield coefficients of heterotroph and autotroph respectively. μ_H And μ_A are maximum growth rate of the heterotroph and autotroph respectively.

2.2. Solvent Extraction (SE)

Solvent Extraction produces good quality base oils and lower rate of pollution. On the contrary, it operates at higher pressure and reqires skilled operating systems and personnel. (AERCO, 1995). Several solvent have been used for solvent extraction which include 2-propanol, 1-butanol, MEK, ethanol, Toluene and acetone, Sterpu et al., (2012); Katiyar and Husain (2010) and Hassan et al., (2012) found out that MEK has the highest performance due to its low oil percent losses and high sludge removal while Aremu et al., (2015) and Hussein et al., (2014) stated extraction using butan-1-ol solvent produced the highest sludge removal rate best. In the study of Oladimeji et al., (2018), a composite and single solvent was used. Single solvent used were methyl ethyl ketone (MEK) and propan-2-ol while the composite consist 75% MEK and 25% propan-2-ol. From the result obtained MEK gave the highest yield. It was also discovered that Solvent to oil ratio had a greater effect on the properties of the oil than temperature.

In the findings of Durani et al., 2011; Osman et al., 2017 and Kamal and Khan, 2009, SE and adsorption was confirmed to be more an effective processes for recycling of waste lubricating oils. Osman et al., 2017 examined blends of two or more solvent and activated alumina adsorbent. The higher the solvent - oil ratios, the higher the PSR. Mohammed et al., 2013 investigated the use of adsorbent materials which includes almond shell, eggshell, walnut shell and locally prepared acid activated clay. Khan (2009) added that due to low cost, availability and best adsorbing performance, magnesite can be chosen as a sorbent. Hydrocarbon solvent can also be used which include stabilized and liquefied petroleum gas (LPG) condensate (Hamad et al., 2005). This process reduced asphaltene content, ash content and carbon residue of the lubricating oil. Kamal and Khan (2009) reported that solvents selection can be done using Burrel's classification which says that alcohols are solvents with high capacity, Ketones, solvent with moderate capacity and hydrocarbons are low capacity solvent. These solvents are basically used due to their ability to form hydrogen bond

2.3. Vacuum distillation (VD)

Several work have been done on VD of used oil which include, Hamawand et al., 2013; Bridjanian and. Sattarin, 2006; Emam and Shoaib, 2013. The basic steps in VD are, pretreatment of oil to remove impurities which can result to fouling and corrosion of the equipment followed by distillation, where water and light hydrocarbons are separated (Gorman, 2005), then vacuum distillation using thin film or a conventional vacuum column. (Assuncao et al., 2010). Vacuum distillation is followed by hydrotreating of distillate with high pressure and temperature in the presence of catalyst for the purpose of removing chlorine, sulphur, nitrogen and organic components. Hydrotreated oil is further fractionated under high vacuum into components of industrial, hydraulic and motor oil. The resulting residue from the VD treatment can be used for road and roof bitumen production (Giovanna et al., 2003).

2.4. Hydrogenation

The process involve in hydrogenation can be summarized thus, Used oil and hot hydrogen was heated and mixed in a pressurized mixing chamber. The mixture was transferred to a separator routed to a residue stripper (Basel Convention, 2002). And processed in a catalytic reactor to remove soluble metals and passed through hydro-finishing reactor for dechlorination, desulphurization and other processes. The treated hydrocarbons resulted in products of improved odour, chemical properties and colour. The residue resulting from the process is a high boiling range of hydrocarbon product fractionated into neutral oil products with varying viscosities which can also be used to blend LO (Basel Convention, 2002).

3. COMBINED TECHNOLOGIES

These are advanced technology which combines two or more generic methods in its process. Due to the complexity of recycling of used oil, using a single method is difficult to achieve a standard emission controlled process. Some companies developed specific processes for recycling waste oils (Brinkman, 2010; Basel Convention, 2002), these methods require sophisticated equipment and processes. Some of these technologies are detailed below;

KTI process has its first re-refinery plant established in 1992 in Greece. It combines the technology of vacuum distillation and hydrofinishing process (Havemann, 197roces8). The process involve; atmospheric distillation, for removal of water and light components, vacuum distillation at 250°C temperature and finally hydrogenation which eliminates the sulphur, nitrogen and oxygenated compounds. (Puerto-Ferre and Kajdas, 1994).

STP is another advanced technology which combines vacuum distillation and hydrofinishing process (Basel Convention, 2002). It release less harmful pollutants therefore its environmentally friendly (Khelifi, 2003). The basic steps of the STP process includes; dehydration, vacuum distillation, separation of the lubricating fraction and hydrofinishing base oil is seperation from the residue.

The Vaxon process is one of the treatment process commonly used in Denmark, Germany, Saudi Arabia and Spain. Its advantage over other processess is the special VD unit called Vacuum Cyclone Flash Evaporator, where less cracking of oil takes place. Vaxon process involves chemical treatment, using alkali-hydroxides which removes metals, chlorides, acidic compounds, acidic compounds and additives and then solvent refining units using solvents such as, dimethyl-formamide, n-methyl-2-pyrrolidone, etc to seperate polycyclic aromatic hydrocarbons and lastly vacuum distillation, where the raffinate are seperated into varying viscosity grade base oils (Brinkman, 2010). .

Axen/Viscolube (revivoil) technology is a process that involve high pressure catalytic hydrogenation. It involve three basic steps; dehydration, to seperate water and light hydrocarbon; thermal de-asphalting, where distillation takes place at high temperature to remove asphaltic and bituminous products and hydrofinishing, where chlorine, sulphur and other contaminants are removed (Kajdas, 2006).

IFP Technology/Snamprogetti is the “Institut Français du Petrole”, it combines vacuum distillation and hydrogenation process. IFP process has the following basic steps; the first stage is atmospheric distillation which helps to remove light hydrocarbon and water while the second stage include Vacuum distillation and extraction of the oil-containing part using propane (Kajdas, 2006). Lastly, hydrogenation, where propane, Asphaltic compounds, oxidized hydrocarbons and solids are seperated.

Proterra recycling technology has two major processess which include solvent extraction and vacuum distillation. By-products resulting from this process are, light oils, vacuum residues, extracts, vapour that cannot be condensed and effluent water (Basel Convention, 2002).

4. CURRENT TREATMENT METHODS

Used oil tends to have a high concentration of potentially hazardous pollutants and heavy metals which could be deleterious to the earth. Therefore, development of environmentally safe, sustainable and cost-effective solution is required for recycling of used lubricant (Stehlík, 2009). Some of the current methods are discussed;

In the study of Arpal et al., (2010), a fuel named as diesel-like fuel (DLF) was produced by applying pyrolitic distillation method. Filteration of the waste engine oil sample was done using a qualitative filter. Three additives known as Na_2CO_3, zeolite and CaO were blended with the purified oil at different ratios and were exposed to thermal and pyrolitic treatment to convert them into a DLF. Conclusively, effects of DLF on the oil properties shows a closer range to that of diesel fuel.

Another current method is Memebrane technology, this is a technology that uses various polymer hollow fiber membranes to treat waste oils by filtration to remove metal particles and carbon soot present in the waste oil and to regain some lubricating properties of the oil. Ecamples of polymer used for membrane filters are polyethersulphone(PES), polyvinylidene fluoride (PVDF)and polyacrylonitrile(PAN) (Lam et al., 2016).

In recent times, Pyrolysis process (PP) has been used as an alternative means of effective conversion of used lubricants to a refined one (Lam et al., 2016; Manasomboonphan and Junyapoon, 2012). Lam et al., 2016, describe pyrolysis as a thermal process that heats and decomposes substance at high temperature (300–1000 °C) in an inert environment without oxygen. PP is not yet widespread but it has been receiving attentions nowadays due to its potential to produce energy-dense products from waste materials. Types of PP include; Microwave PP (MPP) and conventional PP (CPP). The MPP is a thermo-chemical process applied to waste to wealth process of electrical power input of 7.5kW at a flow rate of 5kg/h.

Table 1: Advantages and Disadvantages of some all the methods

Recycling methods	Advantages	Disadvantages
Acid-clay (Udonne, 2011)	1. It is a commonly used method. 2. Lower cost of production 3. Simple and Non-sophisticated in process and operation, and skilled operators required.	1. It generates waste leading to pollution 2. Causes corrosion of equipment and reduces its life. 3. Low oil recovery
Vacuum Distillation (Hamawand et al., 2013)	1. Suitable for high capacity plants 2. It does not result in pollution. 3. It requires Sophisticated equipment 4. Produces good quality base oils.	1. Requires high capital investment. 2. Due to sophisticated equipment, requires highly skilled operators
Solvent Extraction (Sterpu et al., 2012; Hussein et al., 2014;	1. Solvent is recyclable. 2. It does not result in pollution. 3. Good base oils recovery.	1. Economical only for high capacity plants. 2. It requires highly skilled operators

5. CONCLUSION

The combined technology processes are commonly used in developed countries but not available in developing countries. Processes involved in these technologies generates a reduced level of pollutant but require sophisticated and expensive equipment. The convectional /generic treatment method have shown much improvement over the years, however the environmental hazards that emanates from the process remains a major disadvantage. The solvent extraction method is environmentally controllable but the high cost and low yield (compared to the convectional /generic treatment method) is its shortcoming. The challenge of cost cuts across the vacuum distillation and hydrogenation technique. Hence, the viability of efficient, environmentally friendly and cheaper treatment technique has not been achieved till date. The combined treatment technology have shown a great deal on treatment efficiency and environmental friendliness. However, the issue of cost remains a major gap in used lubricant oil treatment.

ACKNOWLEDGEMENT

The authors appreciates Covenant University for the partial sponsorship of the paper

REFERENCES

[1] Abu-Elella R, Abu ME, Ossman R, Farouq M, Abd-Elfatah. Used Motor Oil Treatment: Turning Waste Oil into Valuable Products International Journal of Chemical and Biochemical Sciences 2015; 7:57-67.

[2] AERCO Inc. PS. Solvent extraction technology for used oil treatment. Final report for Recycling Technology Assistance 1995; 30 p.

[3] Aremu MO, Araromi DO, Gbolahan OO. Regeneration Of Used Lubricating Engine Oil By Solvent Extraction Process. International Journal of Energy and Environmental Research 2015; Vol.3, No. 1, pp.1-12.

[4] Basel Convention, Technical Guidelines on Used Oil Re-Refining of Other Re-Uses of Previously Used Oil, series/SBC No. 02/05, reprinted November 2002 ISBN: 92-1-158605-4.

[5] BCRC, Pretoria. Proceedings of a Regional Workshop on Waste Oil Management in Africa. 15 – 17 October 2002. Cape Town. South Africa.

[6] Brinkman DW. Kirk-Othmer Encyclopedia of Chemical Technology, John Wiley & Sons, Inc. 2010.

[7] Bryant C. Resource Recycling, Slick new oil re-refining process, November 1989

[8] Eman A, Emam, Abeer M. Shoaib. Re-refining of Used Lube Oil, II- by Solvent/Clay and Acid/Clay-Percolation Processes. ARPN Journal of Science and Technology 2012; Vol 2 [11] 1034- 1041.

[9] Emetere ME. Investigations on aerosols transport over micro-and macro-scale settings of West Africa. Environmental Engineering Research 2017; 22 (1), 75-86.

[10] Falah Bani Hani and Hussien Al-Wedyan. Regeneration of Base-Oil from Waste-Oil under Different Conditions and Variables. African Journal of Biotechnology 2011; 1150-1153.

[11] Giovanna F Dalla, O. Khlebinskaia A Lodolo, S Miertus (2012). Compendium of Used Oil Regeneration Technologies. Trieste: United Nations Industrial Development Organization.

[12] Guerin Turlough F. Environmental liability and life-cycle management of used lubricating oils. Journal of Hazardous Materials 2008; 160:256-264.

[13] Hamad A, Al-Zubaidy E, Fayed ME. Used lubricating oil recycling using hydrocarbon solvents. Journal of Environmental Management 2005; 74:153-159

[14] Hamawand Ihsan, Talal Yusaf and Sardasht Rafat. Recycling of Waste Engine Oils Using a New Washing Agent. Energies 2013; pp. 1023-1049.

[15] Hassan Ali Durrani, Muhammed Ibrahim Panhwar, Rafique Akthar Kazi. Re-Refining Of Waste Lubricating Oil By Solvent Extraction Journal Of Engineering & Technology 2011;Volume 30, No. 2, 237-246

[16] Hassan Ali Durrani, Muhammed Ibrahim Panhwar, Rafique Akthar Kazi. Determining an Efficient Solvent Extraction Parameters for Re-Refining of Waste Lubricating Oils. Journal Of Engineering & Technology 2012; Volume 30, NO. 2, 265-270

[17] Havemann R. The KTI used oil re-refining process. In Proceedings of the 3rd International Conference of Used Oil Recovery & Reuse, Houston, TX, USA, 16–18 October 1978.

[18] Henry Mensah-Brown. Optimization of the production of lubricating oil from re-refined used lubricating oil using response surface methodology 2013; vol. 8, No. 9.

[19] Henry Mensah-Brown. Re-refining and recycling of used lubricating oil: an option for foreign exchange and natural resource conservation in Ghana 2015; vol. 10, No. 2

[20] Hussein M, Amer AA, Gaberah AS, Used Lubricating Oils Re-Refining by Solvent Extraction. American Journal of Environmental Engineering and Science 2014; Vol. 1, No. 3, , pp. 44-50.

[21] Jafari, A.J., and Hassanpour, M., (2015) Analysis and comparison of used lubricants,regenerative technologies in the world. Resource Conservation and Recycling, http://dx.doi.org/10.1016/j.resconrec.2015.07.026

[22] Kajdas C. Major Pathw ays for Used Oil Disposal and Recycling. Part 2, Warsaw University of Technology, Institute of Chemistry in Plock and Central Petroleum Laboratory in Warsaw, Poland, Polish Tribology Society (PTS), Wiley, published online 9 March 2006. Extracted from http://www.tribologia.eu/ptt/kaj/kaj1101.gif

[23] Kamal. A, Khan F. Effect of Extraction and Adsorption on Re-refining of Used Lubricating Oil. Oil & Gas Science and Technology 2009; Vol. 64, No. 2, pp. 191-197

[24] Lam, S.S, Liewa, K.K., Jusoh A.A, Chong C.T., Ani, F.N., Chase H.A. (2016). Progress in waste oil to sustainable energy, with emphasis on pyrolysis techniques Renewable and Sustainable Energy Reviews 53:741–753

[25] Liu Y, Cheng J, Shen W, Song Y. Regeneration of used lubricating oils by supercritical fluid extraction. Petroleum Science and Technology 2005; 23:909-914.

[26] Nabil M, Abdel-Jabbar, Essam A.H, Al Zubaidy, Mehrab Mehrvar. Waste Lubricating Oil Treatment by Adsorption Process Using Different Adsorbents. International Journal of Chemical and Biological Engineering 2010; 3(2)70-73

[27] Nguele Ronald, Hikmat Said Al-Salim, Khalid Mohammad. Modeling and Forecasting of Depletion of Additives in Car Engine Oils Using Attenuated Total Reflectance Fast Transform Infrared Spectroscopy. Lubricants 2014; 2: 206-222

[28] Nwachukwu Michael A., Jude Alinnor, and Huan Feng. Review and assessment of mechanic village potentials for small scale used engine oil recycling business. African Journal of Environmental Science and Technology 2012; Vol. 6(12), pp. 464-475,, 464-475.

[29] TemitayoE.Oladimeji a,n, JacobA.Sonibare b, James A.Omoleye a, AbiolaA.Adegbola a, HilaryI.Okagbue (2018). Data on the treatment of used lubricating oil from two different sources using solvent extraction and adsorption. Data in Brief 19 (2018)2240–2252.

[30] Princewill Nemibo Josiah, Sunday Sunday Ikiensikimama. The Effect of Desludging and Adsorption Ratios on the Recovery of Low Pour Fuel Oil (LPFO) from Spent Engine Oi. Chemical Engineering Research Bulletin 2010;25-28.

[31] Puerto-Ferre E, Kajdas C. Clean technology for recycling waste lubricating oils. In Proceedings of 9th International Colloquium, Ecological and Economic Aspects of Tribology, Esslingen, Germany, 14–16 January 1994.

[32] Rincon, J, Canizares P, Garcia MT. Regeneration of used lubricating oil by polar solvent extraction. Ind. Eng. Chem. Res. 2005, 44, 43–73.

[33] Shri Kannan C, Mohan Kumar KS, Sakeer Hussain M, Deepa Priya N and Saravanan K. Studies on Reuse of Re-Refined Used Automotive Lubricating Oil. Research Journal of Engineering Sciences 2014; Vol. 3(6), 8-14,.

[34] Sterpu ancaelena-Eliza A, Anca Iuliana Dumitrua And Mihai-Florinel POPA. Regeneration of used engine lubricating oil by solvent extraction. Ovidius University Annals of Chemistry 2012; 23 (2), 149-154.

[35] Udonne, J. D. A comparative study of recycling of used lubrication Oils using distillation, acid and activated charcoal with clay methods. Journal of Petroleum and Gas Engineering 2011; Vol. 2 (2), pp. 12-19.

[36] Udonne J D, Bakare OA. (2013). Recycling of Used Lubricating Oil Using Three Samples of Acids and Clay as a Method of Treatment. Int. Arch. App. Sci. Technology; Vol 4 [2] 08- 14.

[37] UN-Report(2016). http://www.un.org/sustainabledevelopment/blog/2016/09/vast-majority-of-world-6-76-billion-people-living-with-excessive-air-pollution-un-report/

[38] Vineet Katiyar, Sattar Husain. Recycling of Used Lubricating Oil Using 1-Butanol Int. J. Chem. Sci.2010; 8(3), 1999-2012

[39] Stehlík P. (2009). Contribution to advances in waste-to-energy technologies. JClean Prod;17:919–31.

[40] Recycling of the used automotive lubricating oil by ionizing radiation process M.A. Scapina,_, C. Duarteb, M.H.O. Sampab, I.M. Satoa Radiation Physics and Chemistry 76 (2007) 1899–1902

[41] Production of diesel-like fuel from waste engine oil by pyrolitic distillation Orhan Arpa a, Recep Yumrutas b,*, Ayhan Demirbas Applied Energy 87 (2010) 122–127

[42] Maceiras, R., et al. recycling of waste engine oil for diesel production. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.08.009

[43] Shiva Salem, Amin Salem, Aylin Agha Babaei. (2015).Application of Iranian nano-porous Ca-bentonite for recovery of waste lubricant oil by distillation and adsorption techniques Journal of Industrial and Engineering Chemistry 23: 154–162

[44] Su ShiungLam a,c,n, RockKeeyLiewa, AhmadJusoh a, ChengTungChong b, FaridNasirAni b, HowardA.Chase c Progressinwasteoiltosustainableenergy,withemphasis on pyrolysistechniques RenewableandSustainableEnergyReviews53(2016)741–753

[45] Su Shiung Lam RockKeeyLiewa, AhmadJusoh, ChengTungChong, FaridNasirAni, HowardA.Chase (2016) Progress in waste oil to sustainable energy,with emphasis on pyrolysis techniques Renewable and Sustainable Energy Reviews 53:741–753

[46] Arpa O, Yumrutas R ,Demirbas A (2010) .Production of diesel-likefuel fromwaste engine oilby pyrolitic distillation.Appl Energy; 87:122–7.

[47] Manasomboonphan, W., Junyapoon, S. (2012). Production of liquid fuels from used lube oils

[48] Used by pyrolysis process. 2nd International Conference on Biomedical Engineering and Technology, IPCBEE vol. 34, IACSIT Press, Singapore, 2012.

[49] Lam SS,Chase HA. A review on waste to energy processes using microwave pyrolysis.Energies 2012; 5:4209–32.

[50] Lam SS, Russell AD, Chase HA. (2010). Microwave pyrolysis, a novel process for recycling waste automotive engineoil. .Energy2010; 35:2985–91. [104]

[51] Lam SS, Russell AD, Chase HA. Pyrolysis using micro waveheating:asus-tainable process forrecyclingusedcarengineoil.IndEngChemRes 2010;49:10845–51.