REJUVENATIVE TECHNOLOGIES FOR SPENT OIL: A REVIEW

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Abstract The indiscriminate disposal of spent lubricating oil (SLO) has been found to be among the chief sources of pollution to the environment and this has resulted in the disruption of food chains, shortened lifespan and ultimately loss of biodiversity. As observed from the literatures, the treatment and recycling of spent oil is one of the best practices aimed at reducing pollution rate. The cost benefits too when compared to the purchase of virgin lube also serves as an advantage. This study therefore reviews the various methods for treating spent lubricating oil. The challenges and merits of such methods were enumerated for knowledge contribution.

Keywords: Spent lubricating oil, pollution, recycling, methods

Introduction

The dearth of crude oil supplies experienced during the Second World War necessitated the reuse of nearly all types of materials as possible options for fuels, especially spent lubricants. However, with recent inventions in technology and the continuous depletion of fossil fuel reserves, many nations now revert to recycling of spent lubricants in order to fulfil their energy demands (Udonne, 2011). This demand for lubricating oil is constantly on the increase largely due to the establishment of new industries, continuous mechanization of many agricultural practices and the production of more vehicles to aid the mobility of ever increasing human population (Chaffain *et al*., 2001). Zhang *et al*., (2003) posited that in the coming years, the price of lubricating oil will skyrocket owing to the fact that the production of lubricating oil would no longer be able to equate the demand as a result of oil shortages at global levels.

Again, there is also high consumption rate by the developed economies and the dense population experienced in the developing countries. These altogether lend credence to why the consumption and production of lubricating oil will be on the increase in the nearest future. Considering the quantum of spent oil generated globally today, which at many instances have been sources of pollution either on land, to water bodies or as a fuel resources depend on the safety management practices and utilization. It has been estimated that about 3.8 liters of spent oil can foul the taste of about 3,800,000 liters of drinking water. Pramanik, 2003 also pointed out that about 50-100 ppm of spent oil can hamper or defer the treatment process of wastewater. The caloric value of 1 liter of spent lubricating oil is about 8000kj when serving as fuel which can power 100W bulb for almost 24 hours or even provide energy for 1000 W electric heater for 2 hours. Pawlak *et al*., 2010 posited that 3.8 liters of spent lubricating oil can be recycled to generate about 2.3 kg of lubricating oil. Again, where about 67 litres of crude oil is used to produce a Iitre of lubricating oil, only 1.6 litres of spent lubricating oil is required to produce the same quantity (1 liter) of lubricating oil.

Various studies have shown that about 150 kg barrel of crude oil contains only about 1.9kg of lubricating oil (Siddiqi and Anadon, 2011; Sinag *et al*; 2010). Available results proved that most regenerated oils have similar physicochemical parameters to those of crude oils (Hamed *et al*; 2002). Eman and Abeer, 2013 however suggested that the quality of regenerated oil is of high standard when compared to that of crude oil. Aside the known fact that recycled lube requires little energy when compared to fresh lube obtained from crude oil, their efficiency is about 75% and they have almost equivalent prices to those of crude oils. Therefore, it is pertinent that governments, industries and individuals learn and understand how to manage and harness the full potentials of spent lubricating oil (Eterigho and Olutoye, 2008) rather than letting it adds to environmental menace. Hamed *et al;* 2002 states that in the Emirate of Sharjah, recycling of spent oil can generate about $168,000 per annum in fuel or 950,000 liter of base oil among other benefits. Hassanpour and mohammadi (2012a) therefore showed that the best management practice in order to augment the energy from motor oil consumption is the recovery of spent oil.

Thus, the term 'spent oil' describes any oil which can be any of petroleum based oil or of the synthetic origin which has through contamination or pollution becomes unfit for its intended purposes owing to the presence of impurities either physical or chemical which has made it lose some of its original properties (Ameh *et al.,* (2012), Balandincz *et al*; (2008). Spent oil is not often classified as hazardous waste except in cases where some of its constituents like chlorinated solvents, PCB exceed the toxicity limits (Qu *et al.*, (2022), USEPA, 2005). Vorapot *et al*; 2009 posited that total used lubricant oils are grouped in the category F of hazardous waste materials. These compounds are often generated from common industrial processes or as by-products during the synthesis of coolants, insulation and during corrosion prevention activity. These groups of compounds were formerly referred to as non-special source wastes. Most of the industrial lubricants are usually grouped based on their viscosity and their ISO grade. The commercial lubricants currently in use comprise a range of ISO grades ranging from 10 to 1000. Vehicular oils are often classified according to the society for automobile engineers (SAE) grading system and over the viscosity range as demanded. Base oil can be obtained from myriad of sources with crude oil being the chief commercial source. To therefore promote and enhance the efficiency of lubricating oil, additives are often added to the base oil (Miller *et al*., 2007). The main difference between fresh and spent lubricating oil is the amount of additives content. In the spent oil, the additives break down as a result of constant usage, wears and tears of engine or metal interiors, interaction with dusts, presence of water and reaction with various oxidative aromatic compounds.

Kheireddine and El-Halwagi (2013) showed that the consumption of additives increase the content of toxic aromatic components in the lubricating oil.

Recycling of spent oil is therefore of strong essence aside requiring lesser energy cost when compared to the refining of crude oil but because it helps provide for a green and safer environment as it mitigates land, water and air pollution. Thus, the recycling of spent oil generated by consumers is the most valuable option by experts (Jafari and Hassanpour, 2015)

This study aims to provide a detailed review on various recovery methods of spent oil ranging from the conventional to the recent advances and their shortcomings.

Conventional Methods of Spent Oil Recovery

Acid-Clay Method

This method, though of age was once known as a popular re-refining process when it was first introduced in the mid-1960s by several industries in the United States. It involves the use of large amount of sulphuric acid and clay in treating spent oils (Udonne and Bakare, 2013; Hamawand *et al.,* 2013) as the clay serves as adsorbent for the removal of the dark colour and the attendant odour. The process produced acceptable base oil but it was considered substandard despite its low cost of operation, simplicity, and low capital investment with no special skills required by operators (Giovanna *et al*., 2012). Aside this, the process also generated acid tar and other hazardous wastes as by-products. As the campaign for safer environment intensifies, this process has been banned in many countries.

Falah & Hussien, 2011 suggested that in order to make benign the hazardous wastes produced by this method, the acid treatment step can better be carried out under atmospheric pressure so as to get rid of the suspended particles, removed the oxidized polar compounds and other acidic products. To achieve good recovery yield from spent oil, Princewill & Sunday (2010) opined that this to a large extent is a function of the spent oil source, concentration of contamination in the oil, type and grade of acid used and the various pretreatment stages employed.

Studies conducted by Ellela *et al.,* (2015) where various acids including phosphoric, sulphuric, methanoic and acetic acid were used to treat used motor oil. The studies maintained that methanoic, sulphuric and acetic acid have great changes on the kinematic viscosity while phosphoric acid remained unaffected by the used lubricating oil. The studies therefore observed that treatment with acetic acid showed better results when compared to formic acid-clay.

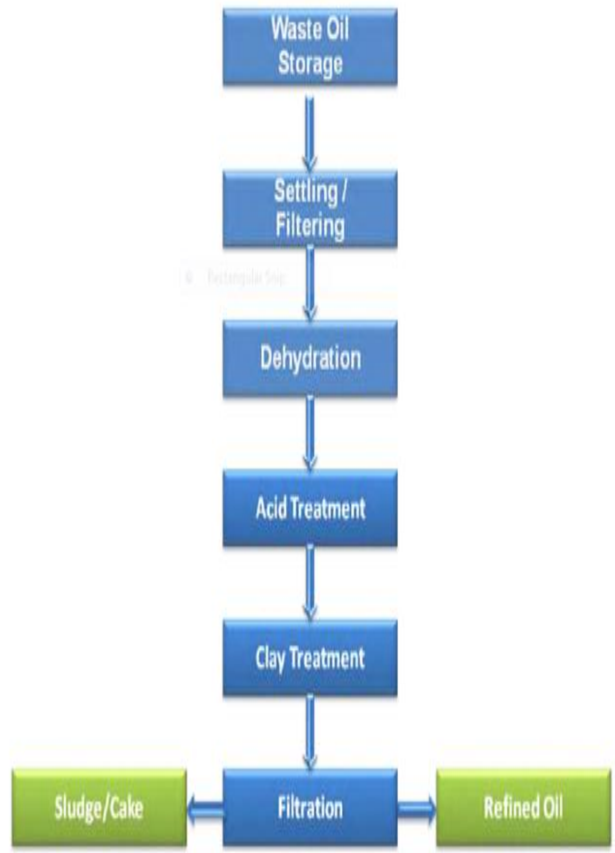

Figure 1. Acid-Clay treatment process chats

Acid Activated Clay Method

This method shows very great similarities with the acid-clay method. The only distinction is that no acid is used in the recovery operation. This process though very simple, its shortcomings which include low oil yields, use of large amount of clay and its disposal challenges serve as its Achilles heels. Thus, under increasing environmental concern, the process has lost its relevance.

Solvent Extraction Method

This process usually operates under high pressures and requires seasoned personnel for its skilled operating systems (AERCO Inc. PS, 1995). The solvents dissolve the unwanted aromatic fractions while leaving the much desired saturated fractions, mostly the alkanes as a separate phase (Rincon *et al*., 2005). Various solvents including but not limited to toluene, acetone, ethanol, methy ethyl ketone (MEK), 2-Propanol amongst others have been used extensively for solvent extraction. Hassan *et al.,* (2012); Katiyar and Husain (2010) showed that among the various solvents used, methyl ethyl ketone displayed high performance because of its minimal oil losses with higher rate of sludge removal.

In another instance, Hussein *et al.,* (2014); Aremu *et al.,* (2015) also posited that the use of butan-1- ol for extraction produced a very high sludge removal. In the findings of Oladimeji *et al.,* (2018), where the use of single solvent and composite blend were examined; the single solvent being propan-2-ol, methyl ethyl ketone respectively and the composite blend were made of 25% propan-2-ol and 75% methyl ethyl ketone. Results obtained showed that methyl ethyl ketone has the best yield. Also of importance is the fact that the solvent to oil ratio was found to have much effect on the oil properties than the temperature.

Although, arrays of solvents abound which can be used for solvent extractions; Kamal and Kahn (2009) reported that the best solvents selection process can be achieved using the Burrel's classification which states that alcohols are solvents showing high capacity, ketones are solvents displaying moderate capacity while hydrocarbons are those with low capacity tendencies. These solvents fulfill this usefulness as a result of their high tendencies to form hydrogen bonds.

Kamal and Khan (2009) and Osman *et al*., (2017) also showed that solvent extraction and adsorption were found to be an effective method for the recycling waste lubricating oils.

Hydrocarbon solvents though with low yielding capacity can also be used and this includes liquefied petroleum gas condensate (Hamad *et al*., 2005).

Generally, it was found that the higher the solvent to oil ratio, the higher the percentage of sludge removal.

Evaporation Technology (ET) Method

This method also known as Vacuum Distillation (VD) has attracted several studies on the recovery of spent oil. Many studies have been conducted using this method to recover spent oil including the works of Bridjanian and Sattarin, 2006; Emam and Shoaib, 2012. The principle involves chemical pretreatment of the waste oils such that the contaminants will not be precipitated as this can results in either corrosion or fouling of the equipment. The pretreated waste oils are then distilled to separate the light hydrocarbon and water (Gorman, 2005).The light hydrocarbons can then be sold out or served as plant fuel. Using a thin film evaporator or conventional vacuum column, the oil then undergoes high vacuum distillation for the separation of diesel fuel. Metals, residues and various products of additive degradation are forwarded to a more complex asphalt flux stream. The distillate obtained is then hydrotreated under high temperature and pressure in the presence of catalyst in order to remove oxygenated organic catalyst, sulphur compounds, chlorine and nitrogen. The spent catalyst from the hydrotreating process can then be disposed off.

The hydrotreated oil is then fractionated under high vacuum into desired fractions which can then be used as motor components, hydraulic or industrial oils. The residues obtained can be used for road surfacing and roof repairs.

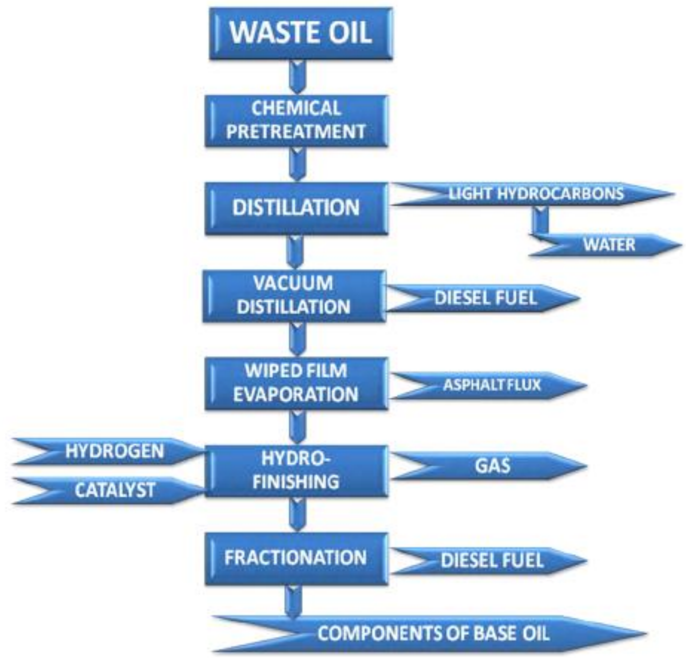

Figure 2. Flow diagram of Evaporation Technology process

Hydrogenation Method

This process is purely a hydrogenation process where spent oil which has been well filtered is mixed with hot hydrogen in a pressurized chamber. The resulting mixture is transferred to a separator fixed to a residue stripper (Basel Convention, 2002). This is then processed through a catalytic reactor to enhance the removal of soluble metals and then through hydro-finishing reactor where oxygenate conversion, light hydro cracking, dechlorination, desuphurisation among other reactions take place. The treated hydrocarbon products obtained showed improved physicochemical properties. The product emanating from this process is a hydrocarbon product with varying boiling point range which can be fractionated to produce neutral oil products having various viscosities and this makes them very useful as they can be used in blending lubricating oil (Basel Convention, 2002).

Membrane Technology

This method incorporates three types of polymer hollow membranes including polyacrylnitrile (PAN), polyethersulphone (PES) and polyvinylidene fluoride (Lam *et al;* 2016) for the recovery of spent lubricating oils. The process operates on a continuous basis usually at a temperature of 40^0C and 0.1 Mpa pressure where dust, metal and other particles are removed and this results in the enhancement of the oil flash point (Hamawand *et al*; 2013). As a result of prolonged operational use, the membranes get fouled and are often destroyed by big particles (Dang, 1997) and this becomes the shortcoming of the process.

Catalytic Processes

An example of this method is the Hylube process. It is a proprietary process designed by the Universal oil products (UOP) based in Germany where spent oils are catalytically processed into refined base stocks for re-blending to marketable base oils (Kalnes *et al*; 2006). A good Hylube process feedstock involves a blend of spent oils with a high concentration of particulate matters like phosphorus, calcium and iron which are by-products of used additives (Chari; 2012).

The Hylube process operates with a temperature of about 300 – 350^{0}C and pressures of 60-80 bar within the reactor section (Kalnes and Schuppel; 2007) and has more than 85% efficiency rate of recovering lube oil from the lube boiling range of hydrocarbon in feedstock (Kupareva *et al*; 2013). This method requires highly skilled personnel that can manage the operation conditions; aside been expensive.

Combined Technologies

These are more advanced technologies where two or more conventional methods are combined in a single operation. As a result of the challenges encountered while removing contaminants from spent oil, the use of single method may not yield optimum results and emission control process may not be thorough. To solve this process, many companies have developed specific process for the removal and treatment of contaminants that are present in spent oils (Brinkman, 2010)

These methods which are often complex in nature are assembly of sophisticated equipment and processes which require skilled personnel. Some of these processes are hereby discussed.

Studi technologie progetti s.p.a. Method

This method combines both hydrofinishing and vacuum distillation in its operation (Basel Convention, 2002). It involves vacuum distillation, dehydration and subsequent separation of the lubricating portion and hydrofinishing of bas oil from residue. The method is considered environmentally safe as little harmful contaminants re generated (Kupareva et al; 2013)

Propak Thermal Cracking Method

This method involves several operational sections and is thus characterized by products flexibility and large operations where processing conditions like temperature and pressure can be varied to produce products like gas oil, base of desired properties (Kupareva *et al;* 2013). The propak method is an assembly of several sections including screening, dewatering, thermal cracking, separation, purification and stabilization. Depending on the state of products desired, purification and stabilization of product are usually the last stages. In the design of many plants, heavy fractions are recycled back as heat source for the process

Cyclon Process

This process utilizes spent oils from which water has been removed followed by the removal of lighter hydrocarbon fractions through distillation while the heavier fractions are sent to high vacuum distillation where most of the base oils components are driven off by heat from the heavy fractions. The oils are then extracted from the residue with propane in de-asphalting section and then sent to hydroprocessing unit where other oils are then processed.

Based on certain desired properties of base oil, the oils are then treated with hydrogen and then fractionated (Schiessler *et al.,* 2007)

Modern Methods Of Recovering Spent Lubricating Oil (Slu)

These are more sophisticated and highly improved technologies which involve the coupling of two or more methods in order to achieve maximum recovery rate which is often difficult with single process technology. Because of the difficulties encountered while trying to achieve maximum emission control largely due to the complexities involved in the recycling of spent oil, several companies have now designed special processes for optimum recovery of spent oil (Brinkman, 2010). Details of some of these technologies are enumerated as follows:

Meinken Technology

This process involves the incorporation of hydrogenation, acid-clay treatment with contact distillation and thin film techniques which enables it to reduce the amount of sulphuric acid and clay to minimal level (Basel Convention, 2002). The advantages of this process include the ease of handling, ability to treat low quality spent oil and the low investment involved. But for economic reasons that arise from disposal management and internal corrosion, the process is gradually losing importance. However, some refineries still operate this process though with modifications.

The Blowdec Technology

The aim of this process is to separate both solids and liquids from initial waste materials and the subsequent liquefaction of the hydrocarbon based polymers through thermal degradation and mechanical means with concomitant breaking of heavier hydrocarbon fraction while preventing the formation of coke. This method has been found to be very efficient in the recycling of waste materials having high concentration of organic component (Mada'r and Juriga, 2003). The process involves processing of waste organic materials in a hot whirly bed in the Blow Dec reactor which is made using solid particles. This method has the advantage of treating various wastes with organic content and materials which are hydrocarbon stained. Maximum recovery is obtained during the Blow Dec process where chemical and physical operations take place (Basel Convention, 2002).

Pyrolysis Process (Pp)

Lam *et al.,* (2012) defined pyrolysis as a thermal process where heat is used to decompose substances with oxygen usually at high temperature in the range of 300 to 1000^{o}C in an inert environment. Though, pyrolysis process has not been on wider applications but it has been receiving attention recently as a result of its tendency to produce denser energy products from materials. This method has also been shown to be an effective alternative in the conversion of spent lubricants to a refined type (Manasomboonphan and Junyapoon; (2012). Example of this process includes the conventional pyrolysis and the microwave pyrolysis.

Conclusion

Different methods have been proposed for the recovery of spent lubricating oils; the performances of such methods and their environmental impacts have been the primary discussions among various scholars. Acid-clay being one of the oldest methods, was very simple in operation, involves low capital, and requires no sophisticated machinery but it resulted in generation of acidic sludge that calls for serious environmental concern. It also leads to corrosion of equipment which through time shortens its operational lifespan. Vacuum distillation process though it produces good quality base oil; requires sophisticated equipment and this requires skilled personnel to operate. The process is suitable for high capacity plant and this makes it capital intensive. Solvent extraction method has the advantage of solvent recovery with little or no environmental threat, good base oil recovery but it is only economical for high capacity plants considering the ratio of solvent to oil. Where two or more solvents are to be used in maximizing recovery rate, getting the right proportion for optimum efficiency also poses a challenge.

The combined treatment technologies and the modern methods have demonstrated a great deal of efficiencies in the recovery rate of re-refined oils while also reducing greatly the amount of pollutants released to the environment. Therefore, concerted efforts should be made in developing an efficient recovery processes with high yielding capacities that is geared towards greener environment.

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