Used lubricating oil management options based on life cycle thinking

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ABSTRACT

Used lubricating oil (ULO) is among those difficult-to-handle anthropogenic pollutants due to its toxicity and handling difficulty. The selection of proper abatement technologies for ULO depends significantly on the appropriateness of the technology not only in technical terms, but also in environmental points of view. In the present work, six management scenarios for the management of ULO were evaluated for their environmental impacts based on life cycle approach. Two of them, i.e. acid clay and solvent extraction are the treatment processes for the recovery of ULO and the main product from these processes is recycled used oil. The other four scenarios, i.e. small boiler, vaporizing burner boiler, atomizing burner boiler, and cement kiln, are to generate energy from ULO. Emissions were characterized into four environmental impact categories: global warming potential, acidification potential, eutrophication potential, and heavy metals. The acid clay process, which has generally been believed to generate high environmental load, actually produced high environmental impact only in terms of acidification. Cement kiln created the lowest impact in terms of global warming potential and heavy metals. This was due to high temperature in cement kiln which could rightly allow the complete combustion of organic compounds in ULO whereas other contaminants such as heavy metals were captured in mortar during the cement reaction.

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1. Introduction

Used lubricating oil (ULO) is classified as “F list designates”, in the hazardous waste classification from certain common industrial or manufacturing processes (also called wastes from nonspecific sources). Yet, more than 35 million tons of used lubricating oil (LO) from industrial sector has been globally generated annually (Norrby, 2003). It should be noted that heavy metals, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) are main contaminants in ULO; these components are highly toxic when released to the environment, particularly to water courses as this causes the obstruction of sunlight and oxygen from the atmosphere to water, which consequently poses harmful effects to aquatic lives. Difficulties also arise during the treatment as ULO is not easily removed from the contaminated water by conventional treatment methods. Hence, the best solution for the management of ULO is to employ the lubricating oil more efficiently and to minimize ULO waste by recovery.

Until now, there are several approaches in recycling ULO, e.g. acid clay process, solvent extraction, distillation—clay filtration, chemical and clay treatment, membrane technology (Muller Associates, 1989; Wilson, 1997; Gourgouillon et al., 2000) these processes are categorized as a re-refined technique, which is currently most applied for ULO recovery. Recently, Hamad et al. (2005) proposed the use of liquefied petroleum gas (LPG) condensate and stabilized petroleum condensate as new solvent materials for ULO in the solvent extraction process. The performance of both solvents (i.e. LPG and stabilized petroleum condensates) in the extraction process in terms of asphaltene, ash, carbon residue and metal contaminant removals, was reported to be better than other available commercial processes, i.e. acid clay and acid free clay treatments.

Among all the various techniques, refining with acid clay is a traditional method to treat and recycle ULO. However, this technique is, at present, only allowed in some developing countries such as Thailand, and not in developed countries (Hamad et al., 2005). This could be because this particular acid clay process is quite toxic to the environment due to the containing of heavy metals in acid sludge.
Apart from re-refined techniques, another ULO waste management approach is to convert ULOs to energy, e.g. combustion in boiler, direct burning in cement kiln. Shaaban and Salavani (1996) investigated the heat recoveries of used petroleum, oil, and lubricants (POL) and indicated that used POL could be efficiently burned in various types of boilers and burners. This local heating plant boiler fueled by used POL provided great benefit in terms of the cost saving for transportation and disposal of such used POL and the required fuel for boiler. Nevertheless, some combustion problems from the combustion of POL, e.g. burner fouling, higher particulate emission and ash residue, must be well aware of.

Life cycle assessment (LCA) has evolved as an efficient technique for the evaluation of environmental problems (Niederl-Schmidinger and Narodoslawsky, 2008) as it provides complete information on the stages in life cycle of products that contribute most to environmental problems (Morselli et al., 2005; den Boer et al., 2007). Nakaniwa et al. (2001) performed life cycle inventory analysis of waste oil management options. They reported that the re-refined process significantly reduced the consumption of natural energy resources when compared with the non-refined option. Nevertheless, the use of non-refined ULO in producing heat and electricity was still more favorable in terms of environmental impacts than the use of petroleum based thermal power plant.

Different ULO management schemes result in various types of products or outputs, i.e. recycled lubricating oil, energy in the form of fuel oil; and consequently provide different types or levels of impact to the environment. In the present work, the environmental impacts from the use of several ULO management options, i.e. to recover ULO (including acid clay and solvent extraction processes) and to generate energy (including incineration in different types of boilers and in cement kiln furnaces) were investigated based on the concept of life cycle thinking and compared based on their environmental burdens.

2. Materials and methods

To apply life cycle approach in the evaluation of different ULO management scenarios, the boundary of the system was extended to include environmental impacts associated with related upstream processes. Details of the evaluation process can be summarized as follows.

2.1. Goal and scope of the evaluation

Fig. 1 illustrates the six ULO management options. The first two scenarios, i.e. acid clay and solvent extraction are the treatment processes for the recovery of ULO and the main product from these processes is recycled used oil. The other four scenarios, i.e. small boiler, vaporizing burner boiler, atomizing burner boiler, and cement kiln are to generate energy from ULO. These six scenarios were investigated based on their contributions to environmental burdens. It should be noted that these options are referred to in this study as “Oil Management System” or OMS.

2.1.1. Basis for calculation

In the present work, six ULO management options were compared based on the same utilization of 1 kg of ULO. As the different of ULO management schemes typically produce different amounts of recycled lubricating oil (options 1 and 2) or energy (options 3–6), in order to achieve the requirement of oil and energy recoveries, additional energy and lubricating oil production from conventional processes, e.g. lignite and/or virgin lubricating oil, respectively, must be applied. These supplementary processes are referred to as “Conventionally Supplementary Systems” or CSSs. Noted that the comparison was based on the same basis of (i) 0.7 kg of recycled lubricating oil being produced, and (ii) 9783 kcal of energy being generated as illustrated in Table 1.

2.1.2. System boundary

Fig. 2 illustrates the system boundary of the main management options for this evaluation. It should be noted that emissions associated with plant construction (energy recovery, recycled and virgin lubricating oil production) and transportation were assumed to be insignificant when being distributed throughout the life-span of such plant, and therefore were not accounted for in this study. In this figure, the dash line connecting between CSS for lubricating oil production and ULO recovery options represents the supplementary LO for some ULO recovery options as mentioned in Table 1.

2.2. Inventory analysis

Energy consumption and emissions to soil, water, and air from the ULO management processes were evaluated. Input–output data of ULO management by acid clay and cement kiln processes were obtained from the plant in Thailand, while those of other processes were achieved from literature. For the environmental impact evalu-
Table 1
Basis for calculation of the six ULO management scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Waste management options</th>
<th>Recovery lube oil from OMS (kg)</th>
<th>Recovery energy from OMS (kcal)</th>
<th>Lube oil from CSS (kg)</th>
<th>Energy from CSS (kcal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acid clay</td>
<td>0.6</td>
<td>–</td>
<td>0.1</td>
<td>9783</td>
</tr>
<tr>
<td>2</td>
<td>Solvent extraction</td>
<td>0.7</td>
<td>–</td>
<td>–</td>
<td>9783</td>
</tr>
<tr>
<td>3</td>
<td>Small boiler</td>
<td>–</td>
<td>9783</td>
<td>0.7</td>
<td>–</td>
</tr>
<tr>
<td>4</td>
<td>Boiler vaporizing burner</td>
<td>–</td>
<td>9783</td>
<td>0.7</td>
<td>–</td>
</tr>
<tr>
<td>5</td>
<td>Boiler atomizing burner</td>
<td>–</td>
<td>9783</td>
<td>0.7</td>
<td>–</td>
</tr>
<tr>
<td>6</td>
<td>Cement kiln</td>
<td>–</td>
<td>9783</td>
<td>0.7</td>
<td>–</td>
</tr>
</tbody>
</table>


2.2.1. Acid clay treatment

As described, this is the traditional method which is no longer allowed in developed countries because it generates undesirable and highly polluted acid sludge (Muller Associates, 1989), however, this process is still commonly employed in some developing countries. In this process, ULO is first filtrated to remove debris and other solid particles and then dewatered by heating or stripping. 92–93% sulfuric acid is mixed with the dewatered ULO to extract metal salts, acids, aromatic, and other impurities as illustrated in Fig. 3(a). Acidic oil is mixed with clay to remove mercaptans and other contaminants and to improve oil color. 30–42% of acid sludge can be combusted, whereas the remaining portion is called combustion residual. The average efficiency of oil recovery is about 0.6 kg/kg of the input ULO.

2.2.2. Solvent extraction process

This process is a modern technology, which has been exercised and being used widely nowadays. It consists of three main steps: (i) the removal of water and light hydrocarbon compounds; (ii) the removal of contaminants and additives, and (iii) the final finishing of products (see Fig. 3(b)) (Elbashir et al., 2002). ULO is firstly hydrated and light hydrocarbon is stripped off fractionally in the distillation column. The dehydrated-sludge (containing oil) is then treated with the mixture of oil in solvents, with the weight ratio of 1:2.67. It is noted that the mixture of butyl alcohol, isopropyl alcohol, and methyl ethyl ketone with the ratio of 2:1:1 is also used as the solvent for this application. After the sludge is drained off at the bottom, the centrifuge is used to recover oil and solvent. The solvent is transferred to solvent recovery unit, whereas the extracted oil is distilled in vacuum distillation column followed by clay treatment or hydrotreatment to remove color and odor (Barry, 1979). The average efficiency of oil recovery of the solvent extraction process is approximately 0.7 kg/kg of ULO feed.

2.2.3. Co-firing in boiler

This process is one of the most widely applied approaches where 10–25% of ULO is mixed with crude oil as a fuel supplement in boiler. In this process, water and suspended solids in ULO must be firstly removed before mixing with crude oil. There are several types of boiler that can be applied for the burning of ULO. Graziano and Daniels (1996) examined three types of boiler for this purpose, i.e. small boiler, vaporizing burner boiler, atomizing burner boiler. Each of these boilers generates different amounts of environmental air pollution components, e.g. CO, CO₂, SO₂, NOₓ, PM-10, heavy metals; the emission factors of these air pollutants from ULO combustion are obtained from the US EPA (1995) and summarized in Tables 2 and 3.

2.2.4. Direct burning in cement kiln

In this last approach, ULO is used as a fuel at extremely high temperature (1500–2000 °C) with the reaction time of 10–12 s in cement kiln. The data of emission and energy efficiency for this process are obtained from local anonymous Cement Company in Thailand (Soisungnoen, 2001).

2.3. Impact assessment

Emissions from the Oil Management Systems and those conventional supplementary systems (CSSs) were characterized into the following environmental impact categories: global warming...
potential (GWP), acidification potential (AP), eutrophication potential (EP) and heavy metals. All characterizations were computed by SimaPro (Version 7.0). Note that there were no attempts to use the normalizing and weighing factors for further converting of these environmental impacts.

2.4. Interpretation

The interpretations of all results were based on the comparison between various management options. All results and further discussion of the interpretations are given in the next section.

3. Results and discussion

In the upcoming discussion, the ULO treatment processes were categorized into (i) “oil recovery”, i.e. solvent extraction and acid clay, and (ii) “energy recovery”, i.e. small boilers, vaporizing burner boilers, atomizing burner boilers, and cement kilns. The environmental impacts from each scenario were characterized and are described as follows.

3.1. Global warming potential (GWP)

Fig. 4 shows the global warming potential from the use of different ULO management processes. It can be seen that the incineration of ULO in the boilers contributes the highest GWP compared to the others, either from life cycle consideration (full bars) or from only Oil Management System valuation (white bars).

For the oil recovery scheme, the acid clay process, which has generally been believed to generate high pollution to the environment, surprisingly produces slightly lower GWP than that of solvent extraction process. In fact, the acid clay process obviously is the lowest GWP generator among all treatment processes when compared based only on the performance of OSSs. Nevertheless, the impact associated with the CSSs for this acid clay process is relatively high. The contribution of GWP for acid clay scenario from the CSS represents the GWP derived from lignite utilization for energy production.

In the evaluation of energy recovery options, different types of boilers, i.e. small boilers, vaporizing burner boilers, and atomizing burner boilers, do not performed differently in terms of GWP. However, GWP’s from these options are dramatically higher than those from other options, and particularly when compared with the similar option of combustion in cement kiln. For the burning in cement kiln option, some carbons are captured in the clinker, and eventually results in the lower CO₂ emission.

3.2. Acidification potential

Acid emission from each treatment scenario is presented in Fig. 5. Emission of several acid gases, e.g. SO₂, NOₓ, HCl, HF and ammonia from the oil recovery options of ULO, which resulted in acidification potential, is expressed in terms of kg-SO₂. The results indicate that acid clay process appears to produce the highest amount of acidification potential. For the energy recovery scenario, the use of ULO in cement kiln generates considerably less acidification potential (particularly from OMS) than those in boilers. This is mainly due to differences in sulfur dioxide discharge which is from the different sulfur content in the fuel supplies. No significant differences in acidification potential are observed among the three types of boilers. More importantly, among all treatment processes, solvent extraction scenario shows the lowest acidification potential due to the possible recycles of used solvents in the solvent extraction process.

3.3. Heavy metals emission

Among the two oil recycling processes, the solvent extraction releases less heavy metals than the acid clay as shown in Fig. 6. This is mainly due to the presence of several heavy metals, e.g. cadmium, lead, mercury, arsenic, nickel, and copper in the acid clay process, which is significantly higher than in the solvent extraction process. In addition, it has also been well established that heavy metals could easily be released under acidic condition which is likely to be the case for the acid clay process, and this resulted in toxic acid sludge. For the cases of the conversion of ULO to energy, different amounts of heavy metals are emitted depending on the treatment process. In particular, the heavy metals released from vaporizing burner boiler and cement kiln are significantly lower with two orders of magnitude than those from small boilers and atomizing burner boilers. In this regard, cement kiln is particularly highlighted for its positive environmental performance with respect to heavy metals emission. This could be due to the burning of contaminants at high temperature at sufficient reaction time as previously described and also the absorption of heavy metals in mortar during burning. Among the different boiler options, Surprenant et al. (1983) and Fennelly et al. (1984) both reported that vaporizing burners generated lower heavy metals emission than that of atomizing burners and small boilers, respectively. Therefore it is concluded here that the direct burning in cement kiln and the burning in vaporizing burner are the most promising processes in terms of heavy metal emission.

3.4. Eutrophication potential

Fig. 7 illustrates that solvent extraction seems to have higher potential for eutrophication than acid clay due to the presence of high level of ammonia, nitrate, and phosphorus emission to water. This could be due to the dissolution of ammonia and phosphate in
Fig. 4. Global warming potential for the different scenarios of ULO management.

Fig. 5. Acidification potential for the different scenarios of ULO management.

Fig. 6. Heavy metals emissions for the different scenarios of ULO management.
the solvent, and these were released during the destruction of the solvent (Seyler et al., 2005). In the energy recovery scenarios, the main source of eutrophication comes from the emissions of nitrogen dioxide in the case of cement kiln and of nitrogen oxides in the case of boilers. The order of preference could be ordered from high to low as: vaporizing burner boiler, cement kiln, atomizing burner boiler, and small boiler, respectively. For the overall consideration (both OMS and CSS), the acid clay process is the most favorite for this eutrophication indicator.

4. Conclusion

This work emphasized the importance in the use of life cycle concept in analyzing the technology options for the management of used lubricating oil. The comparative life cycle evaluation of the six scenarios for ULO management, which comprised two oil recovery options, i.e. acid clay and solvent extraction processes, and four energy recovery options, i.e. burning in small boiler, vaporizing burner boiler, atomizing burner boiler, and cement kiln, illustrated that each option could pose significantly different environmental impacts. For instance, the acid clay option, which was expected to be extremely polluting, however, was only performed poorly in acidification potential aspect but quite clean in terms of global warming and eutrophication potentials. Most energy recovery options played an important role in global warming potential and eutrophication over the oil recovery options. In terms of life cycle thinking process, the basis for calculation must be carefully established, and in this case, this was achieved by having separate oil management options and conventional management options. Fail to incorporate this might result in mistakes in the quantifying evaluation which could be crucial in decision-making process of extreme delicacy. For instance, acid clay which, by itself, evidently introduced the lowest GWP among all ULO management options, on the other hand, could involve a relatively higher GWP when the impacts from CSS were included.

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