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RESEARCH ARTICLE

# LIFE CYCLE USED LUBRICATING OIL MANAGEMENT OPTIONS

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ABSTRACT

Used lubricating oil (ULO) is one of the anthropogenic pollutants, contains toxic substances, therefore its handling is very difficult. This hazardous oil needs proper abatement technologies extensively depend not only on the suitability of the technology but from the environment point of view. In this work, base on the life cycle, six management options were evaluated for ULO for their environmental impact point of view. Two of them based on the recycling treatment of ULO, i.e. acid clay and solvent extraction processes for the recovery of main product, the recycled used oil. The other four options based on the energy to generate from ULO are smaller boiler, vaporizing boiler, atomizing burner boiler and cement kiln, where as the emissions were characterized into four environmental impact categories: acidification potential, global warming potential, eutrophication potential and heavy metals. The high environmental load believe to be produced by acid clay treatment in terms of acidification where as the lowest environmental impact created in terms of global warming potential and heavy metals is the cement kiln because of the high temperature in cement kiln, that could has been rightly allowed for the complete combustion of organic compounds in ULO, and other heavy metal contaminants during the cement reaction captured in mortar.



## INTRODUCTION

Used oils are hazardous waste as they display some hazardous properties and therefore classified as "F list designates". In hazardous waste classification used oil has been declared nonspecific source by certain common industrial and manufacturing processes. Used lubricant oil when disposed of improperly has worst environmental and public health impact because during use, new oil picks up toxic chemicals, carcinogenic hydrocarbons and heavy metals. Used oil creates environmental pollution enter natural cycles through the food chain via water, soil and air. In this way used oil pose risk to human health and impedes the growth of plants and their ability to take up water as sometimes used oil contained hydrocarbons, heavy metals, polychlorinated bipnyls (PCBs) and other halogenated compounds (EL- Fadel and Khouy-2001), when released to the environment, particularly to water courses which consequently poses harmful effects to aquatic lives and can't remove easily from the contaminated water by conventional treatment methods. Thus the proper solution for the management of used oil is to make use of lubricating oil more efficiently and to decrease ULO waste by recovery. The recycling treatment of such contaminated materials by acid clay filtration, solvent extraction distillation processes restore to its original quality for re-use as lubricant and membrane technology, (Muller Associates, 1989; Wilson, 1997; Gourgouillon *et al*., 2000). In addition, it will have a significant positive impact on the environment (Kajdas 2000, Boughton, 2004, IARC2–4, 1984). These techniques are categorized as a re-refined technique and presently applied for ULO recovery. (Hamad *et al*., 2005), recently proposed the use of liquefied petroleum gas (LPG) condensate and stabilized petroleum condensate as new solvent materials for ULO in the solvent extraction process. When performance of LPG and stabilized petroleum condensates solvents process compared in terms of ash, asphaltene, carbon residue and metal contaminant removals, was reported that both the solvents to be better than other available commercial processes, i.e. acid clay and acid free clay treatments.

Today, in many countries and states, re-refining of ULO with acid clay is a most popular conventional process and recycle of ULO is being performed mostly in some developing countries like Pakistan. (Durrani *et al.*, 2008). However this method creates another environmental problem as the process is quite toxic process and containing of heavy metals in acid sludge. Now considering the other four options apart from re-refined techniques based on the energy generation from ULO i.e. combustion in boiler, direct burning in cement kiln. (Durrani 2013) investigated on the analysis of energy and environmental benefits for vehicle waste lubricant oil pertaining to its reuse by means of regain the heating value of ULO. The samples were tested by inductively coupled plasma-atomic emission spectrometry (ICP-AES) method and the test results were compared with standard requirements. It was found that minor levels of hazardous element indicated when regained the heating value from the used lubricating oil.

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(Shaaban and Salavani 1996) investigated the heat recoveries of used petroleum, oil and lubricant (POL) and indicated that used POL could be efficiently burned in various types of boiler and burners, used the local heating plant boiler fueled by used POL provided greater benefit in terms of the cost saving for transportation and disposal of such POL and the required fuel for the 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. (Niederl-Schmidinger and Nar)

## MATERIALS AND METHODS

The different ULO management options were evaluated in this studies and boundary was extended to environmental impacts related to the above processes. The evaluation process details can be sum up as follows.

### Objective and Scope of the evaluation

Fig: 1 shows the six ULO management options. The first two options, i.e. acid clay and solvent extraction are the treatment processes for recovery of ULO and the main product obtained is the recycled used oil. Now considering the other four options apart from re-refined techniques based on the energy generation from ULO i.e. combustion in boiler, direct burning in cement kiln. All these six options were investigated depend on their contribution to environmental liabilities. All these options were studied in this work referred as "Oil Management Options" or OMO.

### Estimation

In this study all above used oil management options i.e. six options were evaluated and compared on the basis of equal utilization of 1 kg of ULO, where the each used oil management option generally produce different amounts of recycling lubricating oil (option 1 and 2) or energy (options 3-6). To get the requirement of oil and energy recoveries, additional energy and lubricating oil were applied produce from conventional processes i.e. lignite or virgin lubricating oil. These additional processes are known as "Conventionally Extra Processes" or CEPs. Remember that the comparison was made on the same basis of (i) 0.65 kg of recycled lubricating oil being produced, and (ii) 9084 kcal of energy that is being generated as shown in Table 1.

### Process boundary

The process boundary of the major management options for evaluation of this work is shown in Fig.2, where the emissions linked with the plant construction such as energy recovery, recycled, virgin oil generation and transportation were considered to be unimportant when assume to be distributed throughout the lifetime of such plant, thus were not reported in this study. Fig. 2 shows that the dash line joining between OMO for lubricating oil production and ULD recovery options shows the additional lubricating oil (LO) for some ULO recovery options as given in Table 1.

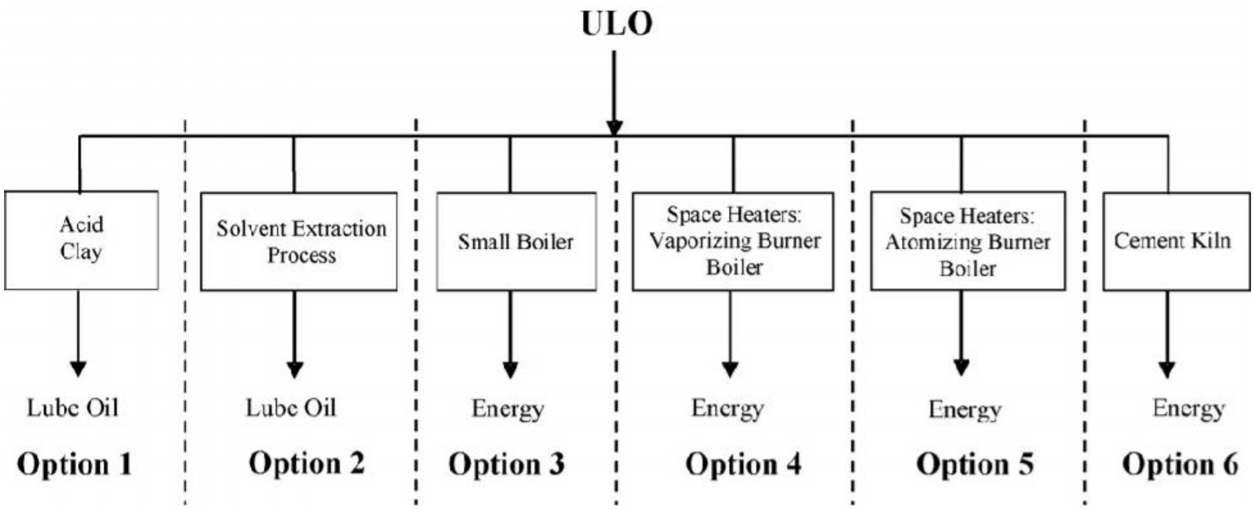


**Fig. 1. ULO management options**

**Table 1. Origin for calculation of the six ULO management options**

| option | Waste management options | Recovery lube oil from OMS(kg) | Recovery lube oil from OMS(kcal) | Lube oil from CSS(kg) | Energy from CSS(kcal) |
|---|---|---|---|---|---|
| 1. | Acid Clay | 0.5 | - | 0.1 | 9543 |
| 2. | Solvent extraction | 0.6 | - | - | 9543 |
| 3. | Small boiler | - | 9543 | 0.6 | - |
| 4. | Boiler vaporizing burner | - | 9543 | 0.6 | - |
| 5. | Boiler atomizing burner | - | 9543 | 0.6 | - |
| 6. | Cement kiln | - | 9543 | 0.6 | - |

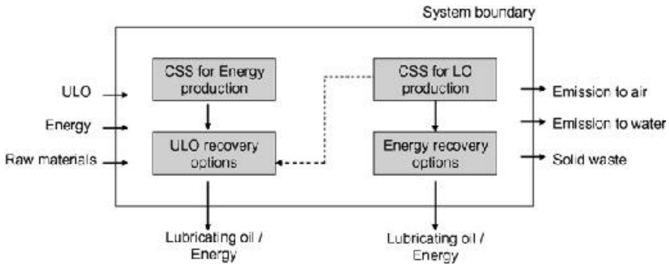


**Fig. 2. Boundaries arrangement of six ULO management options**

## Inventory evaluation

Used lubricant oil management process were evaluated from the energy consumption and emission to air, soil and water, so from the input-output of ULO management point of view acid clay and cement kiln processes data were collected from the local plants in Pakistan. The other data of acid clay obtained from the previous research work and also from the literature, where as the environment evaluation of CSSs, the inventory data were obtained from the local oil recycling plant producing virgin oil for the remaining data were obtained by using the software commercially available (simaPro-Version-7.1)

## Acid clay treatment

As explained, acid clay treatment is one of the successful methods in removing the used lubricant oil for the last three decades ago, called conventional re-refining method, yield around 45 to 75% depending upon the operating condition and feed composition. This method is no longer allowed in developed countries as the process end up with large volume of acidic sludge as the by-product which is highly polluted and undesirable (Muller Associates,1989), but still being commonly employed in some developing countries. It consists of five stages i.e. dewatering, acid treatment, clay treatment, distillation and filtration as shown in Figure 3. (Durrani *et al.*, 2009) ULO first settled naturally and filtered to remove sediments, heavy particles, debris and other solid particles and then heated at elevated temperature for dewatering and striping. 98% sulphuric acid-oil is mixed together with dewatered ULO to remove salt, additive, varnish, gum, metals and also impurities generated due to oxidation and thermal degradation that contain unsaturates, aldehydles, acidic compounds, phenoilc compounds, alcohols non-stable products of hydrocarbons. This acidic oil is now mixed with clay to remove mercaptans and other contaminants to improve color and left large amount of acidic sludge as the by-product.

## Solvent extraction process

Solvent extraction is the modern technology for separating a substance from one or more others by using a solvent and being used widely now a day. The process contains of three main steps:

1. The removal of water and light hydrocarbon compounds.
2. The removal of contaminants and additives
3. The finishing of products (see Figure 4) (Durrani *et al.*, 2011)

First the ULO dehydrated in a simple vacuum distillation, where water, gasoline and light hydrocarbon fraction is stripped off, then dehydrated- sludge containing oil treated with selective solvents by composite solvents with weight ratio of 25% 2-propanol, 37% 1- butanol and 38% butanone at oil ratio 6:1 used for this application, after that sludge is drained off at the bottom of the column and then oil and solvent is recovered by using centrifuge. The solvent is transferred to solvent recovery unit for further use and the extracted oil is distilled in vacuum distillation column and was further neutralized by activated fullers' earth absorbent to remove colour and ordor (Durrani *et al.*, 2011-12) and the average efficiency of oil recovery from the ULO feed by solvent extraction process is approximately 0.68 kg/kg of ULO feed

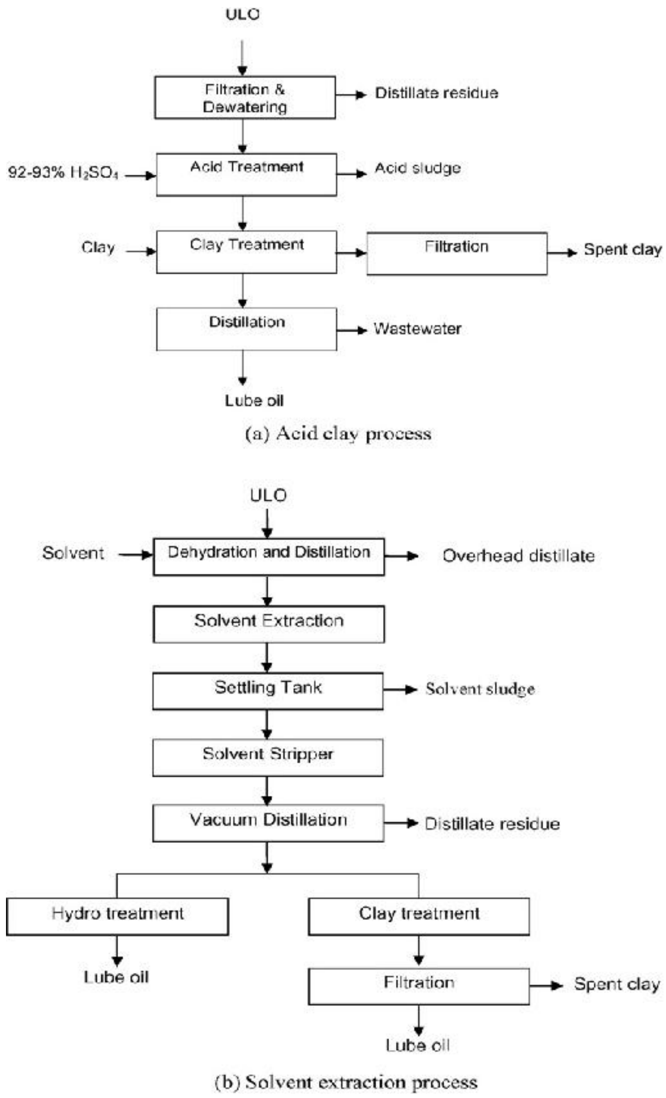


**Fig. 3. Detail of the processes for ULO management (a) acid clay process☹( b) solvent extraction process**

## Co-firing of ULO in boiler

Co-firing approach is widely used where crude oil is mixed with 10-25% of ULO as a supplementary fuel in boiler. The process before mixing the crude oil, firstly remove the water and suspended solids from the ULO. Generally there are several types of boiler that can be used for the burning of the

ULO. Graziano and Daniels (1996) has worked on three different types of boiler for co-firing purpose, i.e. small boiler, vaporizing burner boiler and atomizing burner boiler. Every one generates different amounts of environmental air pollution components, e.g. CO, $CO_2$, $SO_x$, $NO_x$, PM-10, heavy metals: the emission factors summarized in Table 2 and 3, obtained from the US, EPA (1995).

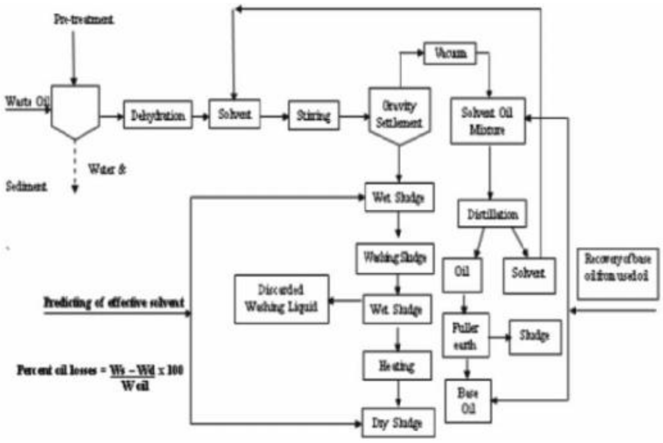


**Fig. 4. Detail of the processes for ULO management by solvent extraction process.**

Systems (SOSs). These were further characterized into the following environmental impact categories: Global warming potential (GWP), eutrophication potential (EP), acidification potential (AP) and Heavy metals (HM). SimaPro (Version 7.1) was used and all these characterization were computed. The study was limited to the environmental impact, so no further efforts were made for the normalization and weighing factors.

## RESULT AND DISCUSSION

In the forthcoming discussion, ULO treatment processes were categorize 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 each options were characterized from the environment impact point of view and described as under

### Global warming potential (WWP)

The worldwide warming potential from the use of various ULO management processes are shown in Figure 4. It has been observed that the incineration of ULO when used in boilers contributes the maximum GWP compared to the others, either from Oil Management System valuation (white bars) or from life cycle consideration (full bars). When considering the oil recovery system, the highest pollution to the environment was generally believed acid clay process but amazingly this process produces to some extent lower GWP than that of solvent extraction process. The acid clay process obviously found the lowest GWP generator, when compared based only on the performance of OSSs and its impact associated with CSSs never remained relatively high. This further signify by CSS a GWP derived toward the ignite utilization for energy production from the contribution of the acid clay process.

**Table 2. Emission factors for various air pollutants from ULO combustion (US.EPA, 1995)**

| Source category | PM | PM-10 | Pb | NOx | SOx | CO | TOC | HCl | $CO_2$ |
|---|---|---|---|---|---|---|---|---|---|
| Small boilers | 64A | 51A | 5.5L | 19 | 147S | 5 | 1 | 33CL | 22,000 |
| Space heaters: vaporizing burner | 2.8A | ND | 0.41L | 11 | 100S | 1.7 | 1 | ND | 22,000 |
| Space heaters: vaporizing burner | 66A | 57A | 50L | 16 | 107s | 2.1 | 1 | ND | 22,000 |

*Remark*: Unit = lb of pollutant/103 gallons of blended waste oil burned (1 gallon = 3.785 L, 1 kg = 2.205 lb); A= wt% of ash in fuel; S = wt% of sulfur in fuel; L = % wt of lead in fuel;
Cl = % wt of chlorine in fuel; ND= no data.
a Space heater = small combustion unit generally less than 70kw or 250,000–280,000 Btu/h.

**Table 3. Emission factors for toxic metals from ULO combustion (US.EPA, 1995)**

| Pollutant | Small boiler Space heaters: | Space heaters: vaporizing burner | Space heaters: atomizing burner |
|---|---|---|---|
| Arsenic | 0.11 | 0.0025 | 0.006 |
| Cadmium | 0.0093 | 0.00015 | .0012 |
| Chromium | 0.02 | 0.1900 | 0.18 |
| Manganese | 0.068 | 0.0022 | 0.05 |
| Nickel | 0.011 | 0.005 | 0.16 |

### Direct burning of ULO in cement kiln

In this last option, ULO is used as a fuel, extremely at high temperature (1500-2000 $^0$C) along with reaction time 10-15s in cement kiln. The energy and emission data are obtained from the local cement factory in Pakistan.

### Impact assessment

The impact assessment was carried out including emissions from the Oil Management Systems and Supplementary OIL

In the assessment of energy recovery option, different types of boilers, i.e. small boilers, vaporizing burner boilers, and atomizing burner boilers, do not performed differently in terms of GWP. Though GWPs considerably higher from other options, and when compared particularly with the similar option of combustion in cement kiln. In this energy recovery option, a few quantities of carbons are captured in the clinker, and eventually results in the lower CO2 emission.

### Heavy metals emission

As discussed the two oil recycling processes i.e. solvent extraction and acid clay processes, the solvent extraction process received considerable attention as releases less heavy metals than the acid clay, mostly copper, nickel, arsenic, mercury, lead and cadmium that is much higher than in the solvent extraction process as shown in Fig 6. Furthermore, it has also been well established fact that these heavy metals under acidic condition could easily be released and resulted in toxic acid sludge. These metals are emitted in cases of the conversion of ULO to energy, depending on the treatment process. The heavy metals released from cement kiln and vaporizing burner boiler found lower with two orders of magnitude than those from atomizing burner and small boilers, mainly highlighted for its positive environmental performance with respect to heavy metals emission. That could be possible due to the burning of contaminants at higher temperature at adequate reaction time and the absorption of heavy metals in mortar during burning. About the different boiler options, the atomizing burners and small boilers generated heavy metals emission than vaporizing burners, respectively reported by Surprenant *et al*. (1983) and Fennelly *et al*. (1984). So, it has been concluded that in terms of heavy metal emission the direct burning in cement kiln and the burning in vaporizing burner are the most promising processes in terms of heavy metal emission.

## Acidification potential

Fig.5 illustrates acid emission from every treatment process, as shown that emission of numerous acid gases, e.g., NO*x*, So*x*, HCl, HF and ammonia from the oil recovery options of ULO, became the cause of acidification potential expressed in terms of kg-SO2.

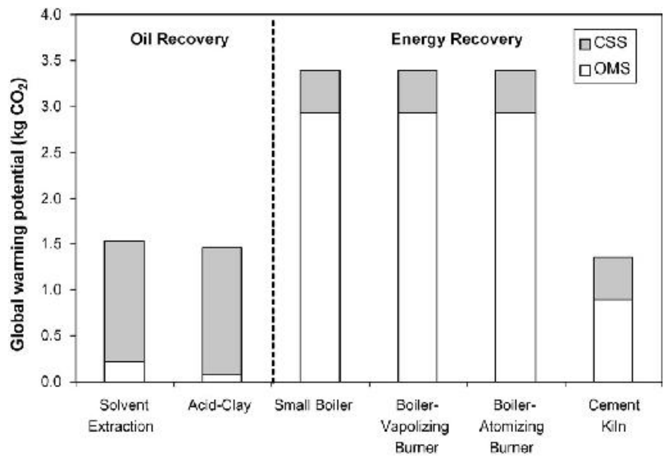


**Fig. 4. Global warming potential for the different scenarios of ULO management**

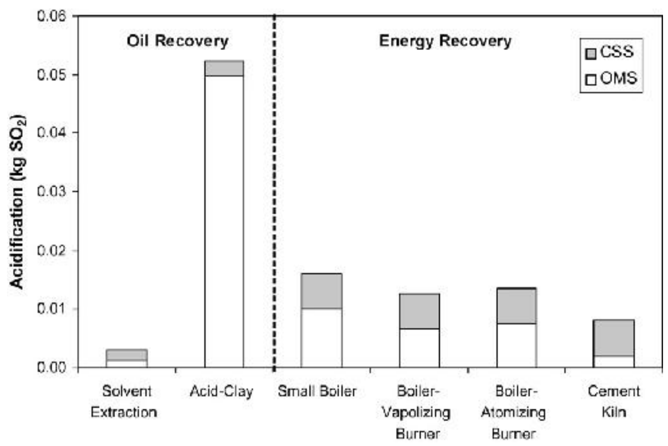


**Fig. 5. Acidification potential for the different scenarios of ULO management**

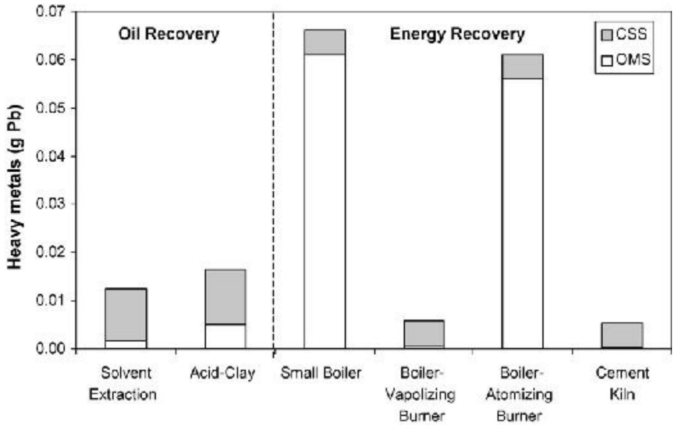


**Fig. 6. Heavy metals emissions for the different scenarios of ULO management**

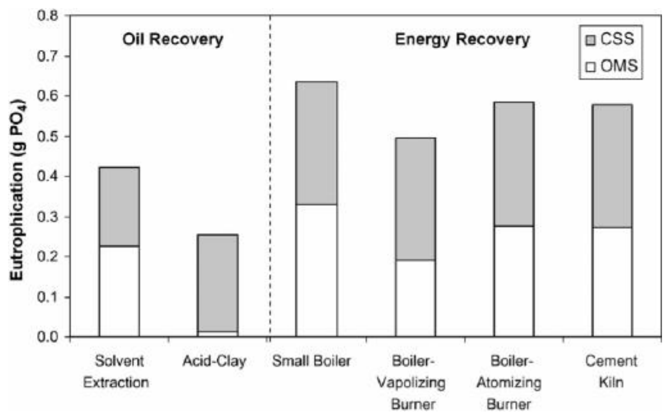


**Fig. 7. Eutrophication potential for the different scenarios of ULO management**

The results show that highest amount of acidification potential produced by acid clay treatment, where as in cement kiln for energy recovery option ULO generates significantly less acidification potential (particularly from OMS) than those in boilers. This is mostly because the variations in sulfur dioxide discharge that is due to the different sulfur content in the fuel supplies. Hence no considerable variations in acidification potential are found among three types of boilers. In all these three treatment processes, the lowest acidification potential indicates the solvent extraction option and makes the possible recycles of used solvents in the solvent extraction process.

## Eutrophication potential

The experimental work shows in Figure 7, that solvent extraction appears to have higher potential for eutrophication than acid clay, this is due to the presence of high level of phosphorus, nitrate, and ammonia, emission to water. This is because of the dissolution of ammonia and phosphate in the solvent and was released during the destruction of the solvent (Seyler *et al*., 2005). In case of cement kiln, the main source of eutrophication comes from the emissions of nitrogen dioxide and for nitrogen oxides in the case of boilers in the energy recovery scenarios. The order of preference could be arranged from high to low as: vaporizing burner boiler, cement kiln, atomizing burner boiler, and small boiler, respectively. So for the eutrophication sign the most desired is the acid clay process considering the both OMS and CSS.

### Conclusion

The main objective of the study was to develop concept in analyzing technology options for the management based on the life cycle use of lubricating oil. The six scenarios for ULO management life cycle options were comparatively evaluated including two oil recovery options i.e. solvent extraction and acid clay processes and four energy recovery options, i.e. burning in small boiler, vaporizing burner boiler, atomizing burner boiler, and cement kiln, demonstrated that every option could pose significantly different environmental impacts. For example, the acid clay option, that was created environmental pollution, but performed poorly in acidification potential aspect, however relatively cleans in terms of worldwide warming and eutrophication potentials. The energy recovery options mostly played significant role in worldwide warming potential and eutrophication. In case of life cycle thinking process, the origin for calculation has to be cautiously established and in this case, this was achieved by having separate oil management options and conventional management options. Fail to integrate this might get error in result in quantify evaluation that could be essential in decision-making process of acute delicacy. This has been evidently established that acid clay produced the lowest WWP among all ULO management options, on the other side, could involve a comparatively higher WWP when the impacts from CSS were included.

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