Design of a Batch process for Re-refining of used Lube oil using Composite Solvent Technique

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Abstract: This work presents a design of a batch process for re-refining of used lubricating oils using a composite solvent technique. The composite solvent includes 1-Butanol, 2-propanol and Methyl Ethyl ketone in the ratio of 2:1:1. This composite solvent is observed to have more advantages over the traditional singular acidic, basic and alcoholic solvents. The solvent to oil ratio taken is 3:1 which is the optimum ratio considering cost and other factors. The work includes a comparative study of solvents from a few sources, plant P&ID, and pump design for a batch of 75 kg of used oil and rough cost estimation. The process was found to be cost effective and efficient with a recovery of 75.6% with 95% solvent recovery.

Introduction

Over the years, the demand and consumption of petroleum based products has increased due to depletion of easily accessible sources of petroleum and ever increasing demand from emerging economies[1]. Increasing automotive and industrial lube consumption has lead to problems of disposal of large amounts of used contaminated lube oil. Currently, adopted waste oil management options are reprocessing, reclamation, regeneration, destruction, exporting to facilitate abroad and other reuse practices.

Having a huge recycling potential with a greater yield from automotive and manufacturing industries, India faces major constraint in recycling waste / used oil in cost of the collection, storage and subsequent transportation of the waste to the recycling unit[2].

Various methods for recycling used lubricating oils were discovered including vacuum distillation of the used lubricating oil .However this process lead to problems of coking and column fouling during distillation and therefore some form of pre-treatment to remove contaminants and additives was required before vacuum distillation[1]. In the solvent extraction process, solvent selectively dissolves the base oil and rejects the contaminant matter i.e. carbon black, oxidation products,additives,lacquer etc. The solvent then is separated from the solvent lube solution through distillation or flashing.

Comparison of various solvents

Various solvents were used for re-refining of used lube oils, however each solvent had its own set of advantages and limitations. Generally, a good solvent should have the properties of good solubility for oil as well as it should be a good flocculating agent. The property of good solubility facilitates extraction of oil whereas flocculation is a property required for efficient sludge removal.

The comparison of process parameters of a few solvents are given below[1,3,4]:

Solvent	Boiling point (K)	Solvent to oil ratio	% Recovery of oil
Supercritical Ethane	184.15	12:1	16
Tetrahydrofurfuryl alcohol	451.15	1:1/1.5:1	83
Hexane	341.15	6:1	74
Methyl Ethyl Ketone (MEK)	352.79	4:1	31
Butanol	390.55	4:1	93.4

Propanol	370.15	9:1	90.7

Other treatments included acid clay treatment involving treatment with sulphuric acid for extraction. Supercritical propane, acetic acid etc were also used for treatment of waste lubes.
For extraction, single solvent as well as composite solvents can be used.
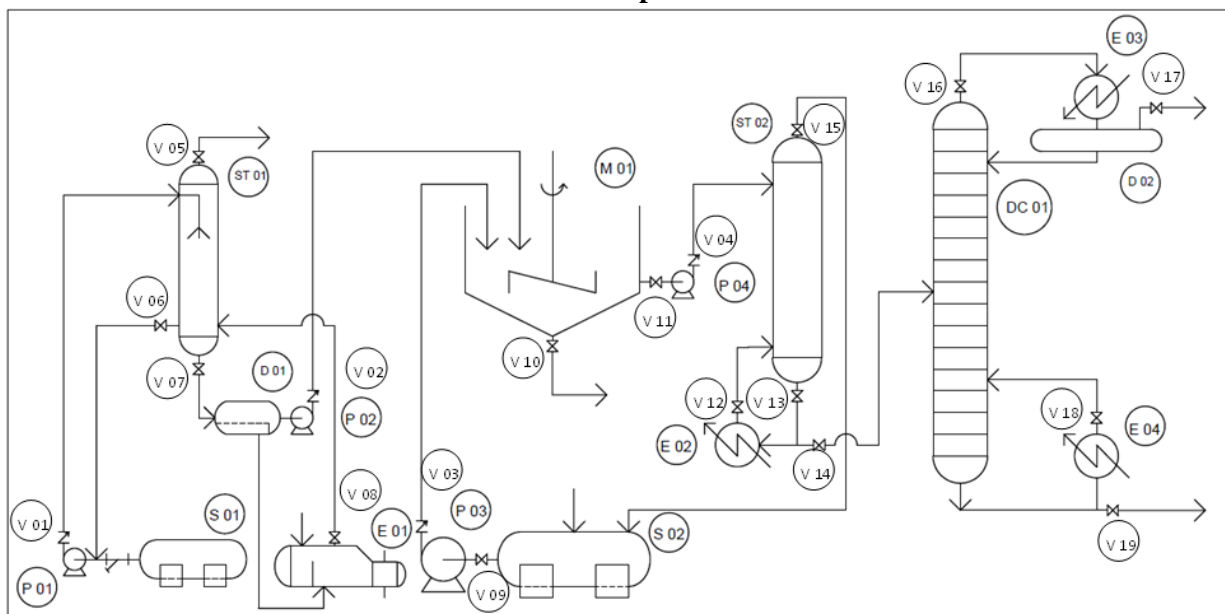
Use of Composite solvent

The composite solvent has two single components: basic compound miscible with base oil (n-hexane) and a flocculating compound that improves the segregation and flocculation of waste oil impurities (2-propanol). Solvent extraction process reduces the contaminants to levels such that no further operational problems were encountered on vacuum distillation.[5]

Whisman et al. (1978) introduced a composite solvents treating, used oil using 2-propanol, 1-butanol and butanone. Their investigation showed that the two alcohols make a binary system that was reasonably effective. However, best results were obtained at a solvent to oil ratio of 8 to 1, which was considered unfeasible. They evaluated various ratios of the ternary systems and noticed that the 2-propanol rich systems produced poorly separated sludge. While butanone rich systems produced good sludge separation but it seemed to re-dissolve segregated ash-forming materials. Therefore they chose a solvent system of (1:2:1) of (2-propanol, 1-butanol, butanone) with a solvent to oil ratio of 3 volumes to 1. [5]

Process description

The solvent extraction process we have discussed consists of preliminary filtration and stripping at temperatures below 330°C and atmospheric pressure followed by mixing with composite solvent at ambient temperatures and sludge separation. The extracted oil and solvent mixture is further sent to a solvent recovery section operating at 184°C and atmospheric pressure. The recovered lube oil then sent to a vacuum fractionation column at 184°C and 100-200 mmHg pressure. Various fractions of lube can be separated at various temperature cuts depending upon the grade of oil required. Asphaltenes and heavy molecular weight compounds are obtained. The obtained lube oils can be further sent for deodorizing, decolorizing and blending with other lubes[6].

P & ID of the process

Piping & Instrumentation Diagram for Composite solvent treatment process of batch of 75 kg[7]

Legend:

Sr.no	Description	Denotation
1.	Pump	P 01, P 02, P 03, P 04
2.	Heat exchanger	E 01, E 02, E 03, E 04
3.	Storage tank	S 01, S 02
4.	Stripping column	ST 01, ST 02
5.	Mixer & settler	M 01
6.	Vacuum distillation column	DC 01
7.	Decanter	D 01
8.	Check valve	V 01, V 02, V 03, V 04
9.	Gate valve	V 05, V 06, V 07, V 08, V 09, V 10, V 11, V 12, V 13, V 14, V 15, V 16, V 17, V 18, V 19

Results and discussion

Initially propane was used for extraction of lube. However, propane is hazardous and flammable therefore this process is regarded as a hazardous process. Also, the extraction involves solvent losses, and highly skilled operating maintenance[7]. Use of supercritical fluids also required extreme pressures higher than 10 atm and requires high pressure sealing systems which makes solvent extraction plants expensive to construct, operate and the method also produces remarkable amounts of hazardous by-products.Hexane is used for solvent extraction of edible oils.It is however obtained from a non renewable source and is consumed faster than the emergence of a new source[1].

Problems arising from acid treatment include environmental problems associated with the disposal of acid sludge and spent earth, low product yield (45–65%) and incomplete removal of metals, especially lead[4]. A number of solvent extraction systems were examined , but while those processes do not cause a loss of desirable aromatic compounds, neither are most of those processes effective in removal of contaminants from waste oil hence has to be combined with more severe treatment like acid or caustic treatment in order to reprocess the oil completely which again leads to toxic sludge[6].The process given by Whisman et.al has several advantages over the other process. The sludge that results from solvent precipitation is chemically and environmentally neutral and can be used as a road surfacing agent or as a source of heavy metals.The sludge produced is much lower than the prior processes and the generally about 60-75% of oil is recovered. Also, all of the purification steps are mild and the natural lubricity and antioxidation characteristics of lube is not lost.

Based on the composite solvent process a batch plant was designed for a feed of 75 kg. The re-refined oil obtained comes up to 56.7 kg with a recovery of 75.6% and 83.16% on dry oil basis. The solvent to oil ratio taken was 3:1 whereas the solvent composition taken is 2:1:1 for 1-butanol,2-propanol and Methyl Ethyl ketone.The solvent recovery is taken 95% by stripping. If high pressure saturated steam is used for heating purposes,the total amount of steam required was calculated to be 63.5kgs.The properties of each solvent were obtained and the viscosity of mixture was calculated using the Viscosity Base Index formula and then applying additive property.

Viscosity Base Index given by Refutasequation[9]

$VBI_i = 14.534 \times \ln(\ln(v_i + 0.8)) + 10.975$

$VBI_{mixture} = \sum_{i=0}^{n} (x_i \times VBI_i)$

Pump design

The batch process consisted of 4 pumps. Laminar flow through the pipes was assumed and 2 inch pipe diameter was taken. Elevations and distances from the equipments were assumed. Pressure drop across valves

were calculated using k-method or the resistance coefficient method[10]. Considering atmospheric pressure in the storage tanks, the stripper, mixer settler and solvent recovery section, the differential pressure was calculated .A safety margin of 20% was taken for variable pressure.

The NPSHA was calculated by obtaining the vapour pressures of the solvent and lube[11,12].The motor and pump efficiency were taken as 0.85 and 0.6 respectively and the shaft and motor power was calculated from hydraulic power[13]. The details of the 4 pumps designed are given below:

Pump	Differential pressure (kPa)	NPSHA (m water)	Motor power required (W)
P 01	12.149	10.609	20.526
P 02	2.210	11.262	4.234
P 03	5.628	9.726	1.171
P 04	9.631	9.32	3.319

The cost of this small scale batch process was estimated and the payback period and rate of return was calculated using Simple Payback Period Method[14].The Payback period obtained was 1.52 years and a rate of return of 65.5%.

Conclusion

Comparison of various solvents was done with composite solvent and recovery of oil was obtained. Batch process for the composite solvent extraction was designed and cost estimation was carried out. The batch process was found to be economically feasible.

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