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Re-Refining of Automotive Lubricating Oil Using Wiped Film Evaporator

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Abstract
Re-refining of used oil has emerged as a valuable technique to recycle the used oil and make it fit enough to be used again for various purposes like use in automobiles, CNC machines, gear oils etc. Re-refining of used oil provides for a way to substitute the ever decreasing natural crude oil. Also, lubricating oil is considered as a hazardous waste, which, if disposed without proper treatment, causes land or water pollution. The objective of re-refining is to remove the contaminants and degraded additives from the used oil and to make it fit enough to meet the standards set by the governing authorities. This paper focusses on the Wiped Film Evaporation (WFE) method of used oil recycling and comparative analysis of recycled oil with conventional oil through condition monitoring and Spectrophotometric Oil Analysis Program (SOAP) to see the effectiveness of the former. To obtain the results, the used oil was recycled and tests of used oil and virgin oil were done on Kittiwake oil test center and four ball tester. Test of flash point and pour point was also done. SOAP analysis was done to determine the amount of wear metals in each sample. The results obtained were quite satisfactory as most of the properties apart from viscosity were at par with the conventional oil.

Keywords
Re-refining, Wiped Film Evaporation(WFE), Oil analysis, Condition Monitoring

I. Introduction

During its application, lubricating oil is contaminated by dirt, wear metal particles etc. This deteriorates and degrades the lubricating oil and reduces its efficiency making it unfit for further use. For instance, if the lubricating oil gets oxidized, its colour will become darker and the TAN value increase. This in turn produces sludge and precipitates which deposits on the surface of the equipment reducing its efficiency. This is the time to change the oil; otherwise it may lead to more severe consequences. The oil taken out from the system is called the used oil or waste oil [1].

Re-fining is the use of distillation process on used lubricating oils. This process produces a base stock of high quality which can be used to manufacture various varieties of lubricants. The use of re-refining technology is being adapted rapidly in many countries. In this method, the waste oil is converted to a oil which has characteristics similar to that of a virgin base oil. This process includes filtration of used oil followed by vacuum distillation and solvent extraction [2].

Used oil is a very useful source of energy. Used oil can be recycled to produce fresh stock of base oil. It can also be used as a burning fuel for cement and boiler industries and various other industries. Also, disposal of used oil is a major problem as discussed in earlier sections. Another fact which supports used oil recycling is that it takes only one third of the energy to produce base oil stock as compared to that required to produce virgin base oil. Also, a small amount of used oil can contaminate large quantities of water. Thus, used oil recycling and reuse is very important.

Large quantities of used oil are produced globally on a daily basis. This oil has very high potential for reuse. It will help to reduce the adverse environmental effects caused by disposal of used oil and also yield economic benefits. The use of limited natural resource; petroleum will also be reduced. Recycling of used oil thus provides multiple benefits [3].

The nomenclature of oil samples is as follows-

1. Unused Virgin Oil – VO (used 0 Km)
2. Used Virgin Oil – UO (used 1014 Km)
3. Unused Recycled Oil – RO (used 0 Km after refining)
4. Used Recycled Oil – URO (used 948 Km after refining)

II. Experimental Procedure

The re-refining or recycling of used lubricating oil is a 4 step process to obtain the base stock from used lube oil. These steps are as follows-

A. Dehydration

In this step the collected oil is heated at high temperature of about 1200C to remove the water content from the oil. This step is carried out only after filtration of the used oil to remove the sludge or slurries from the oil.

B. Vacuum Distillation or Wiped Film Evaporation

In this step the oil is distilled in vacuum conditions to recover the base oil stock from the mixture or to separate the volatile components from the non-volatile components. Wiped-Film Evaporation is also a vacuum distillation technique. It has been discussed in the later sections.

C. Clay Treatment

In this step, the stock recovered from step 2 is treated with bentonite clay or earth clay to remove the remaining impurities in the oil and to impart proper characteristics to the base stock.

D. Filtration

This is the final step in which the oil stock is filtered through a filter bed to remove any solid impurities remaining in the oil stock.

1. Wiped Film Evaporation

The WFE technique is an alternative to vacuum distillation process. The wiped film evaporator (WFE) is also known as an agitated thin-film evaporator (ATFE). It is a device used to purify liquids with viscosities up to 105 poise. In WFE, temperature sensitive mixtures are allowed only a short residence in the heated zones. WFEs are generally vertical cylinders (Figure 1).The feed material is distributed on the inner surface of the cylinder. The inner surface also has blades or roller wipers arranged axially. These blades distribute the liquid as a thin film when the liquid flows downwards. The evaporator jacket is double walled and is constantly heated using a suitable medium. The pressure in the distillation chamber is controlled using a vacuum system. The vapours leave the chamber through a discharge nozzle and go to an external condenser. Sludge and other non-volatile substances are discharged at the lower end of the evaporator. The temperature is kept high, generally around 150-200^{0}C so that when the oil stock is sprayed on the thin film, it will evaporate as vapour and

the residue left on the screen is wiped off. The oil stock free of impurities is finally obtained by condensing these vapours either in the system itself or by using an external condenser [4].

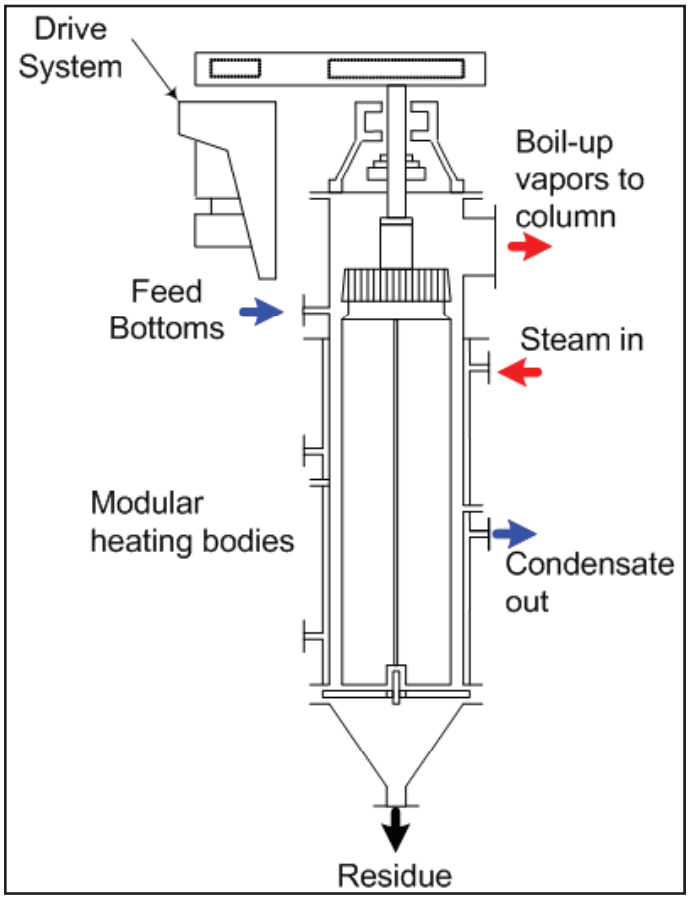

Fig. 1: Vertical Thin Film Evaporator

2. Oil Test Center (Kittiwake)

The kttiwake oil test center provides an effective on site condition monitoring tool which proves to be very helpful in taking quick operational and maintenance decisions. The equipment is a console provided with different modes which can be used for test of a particular parameter using different test cells. The tests which can be performed are:

(i). Water in Oil Test

This is done by selecting mode 4 and following set of instructions. This test determines the amount of water present in the oil.

(ii). TAN Test

This test is done by selecting mode 5 on the console. This test gives idea about the acidity of the oil.

(iii). TBN Test

This test is done by mode 3 on the console. It provides information on alkalinity of the oil sample.

(iv). Insoluble Test

This test is performed on mode 2. This test is done to determine the total amount of insoluble present in the oil sample.

(v). Viscosity Test

This test is done in mode 2 on the kittiwake viscometer. This test gives the viscosity of oil sample at 40^{o}C and 100^{o}C [5]

3. Four-Ball Test

Tests were carried out using the standard test methods ASTM D4172 and ASTM D2783 to measure the wearpreventive properties and extreme pressure properties of the lubricating oils. To perform the test, three steel balls were placed in the oil cup assembly. The oil cup was tightened using a torque wrench. The fourth ball was clamped into a vertical ball holder in the machine. The oil cup assembly was then placed into the machine in suitable alignment with the fourth clamped ball. Then the desired load is applied on the system. The lubricant is heated to a temperature of 75^{o}C before starting the drive motor. The drive motor drives the top ball at the desired set speed. After the 1 hour test period, the heater is turned off and the ball cup assembly is taken out of the machine. The balls were then removed from the assembly and were cleaned using a tissue paper. These balls were then placed under the microscope to measure the scar diameters. The scar diameter is recorded horizontally and vertically and then the average diameter is evaluated [6].

4. SOAP Analysis

SOAP Analysis was done using method 3050A and the apparatus used was GBC Avanta HG 3000 apparatus.

III. Results

A. Results of oil Test Center and Flash Point, Pour Point

The results obtained by test of viscosity, TAN, TBN, Flash point and Pour point have been depicted below graphically-

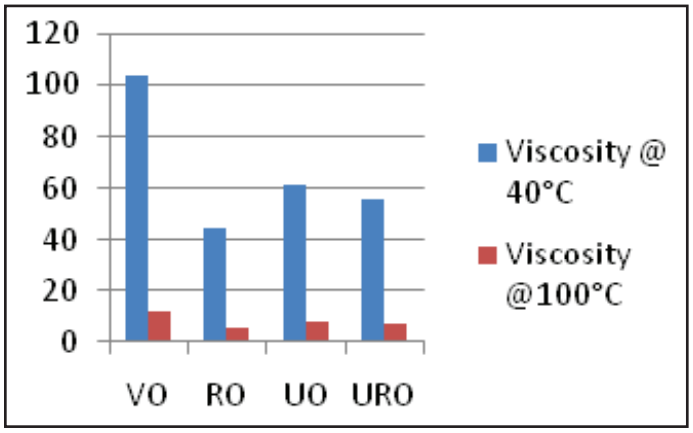

Fig. 2: Viscosity

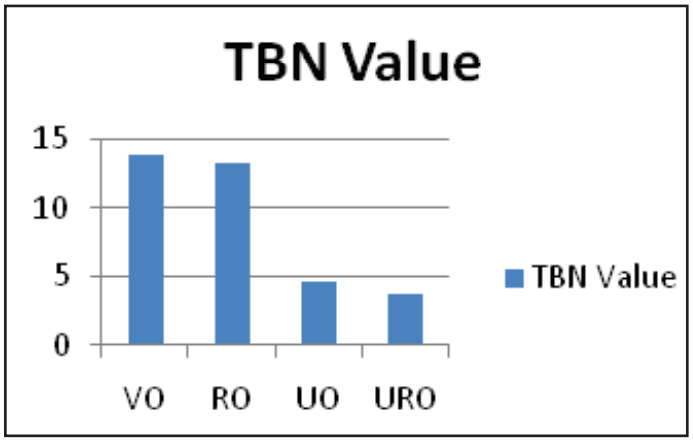

Fig. 3: TBN Value

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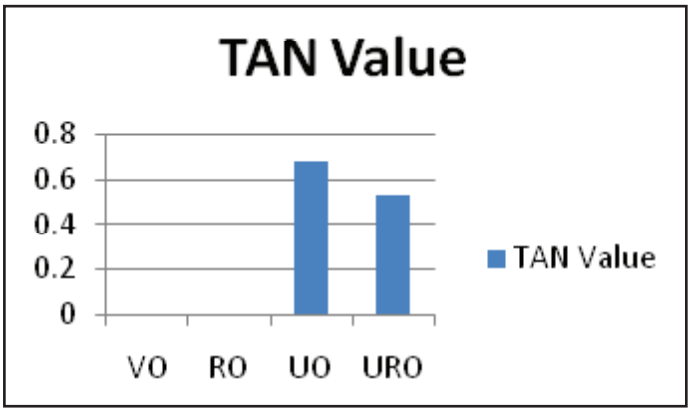

Fig. 4: TAN Value

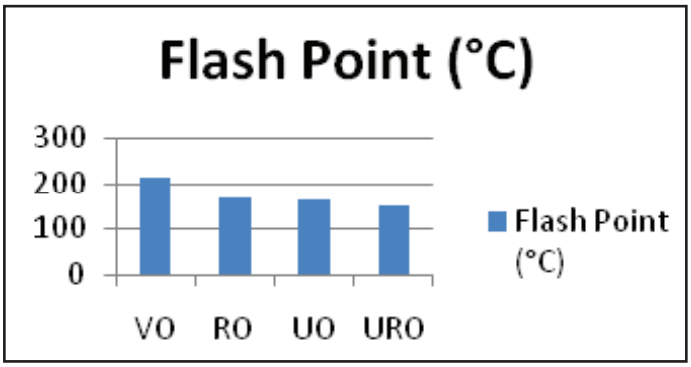

Fig. 5: Flash Point

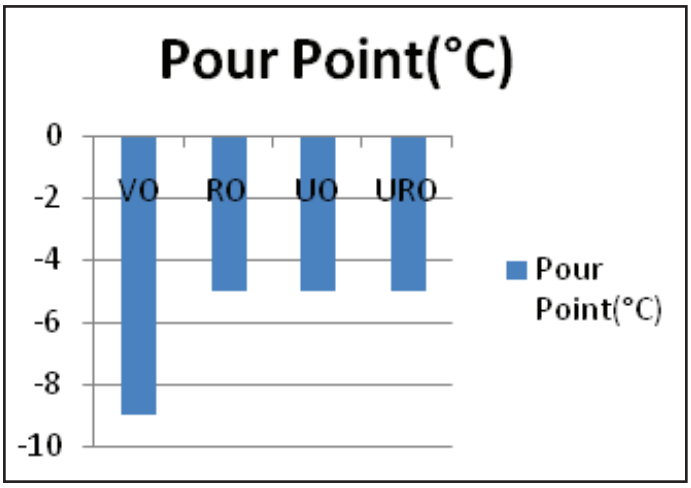

Fig. 6: Pour Point

B. Results of Four Ball Test

Table 2 shows the wear scar diameters on the balls after application through four ball tester with each lubricant urn by turn. By this data, comparative analysis of anti-wear properties of virgin oil and recycled oil can be done easily. It seems to be obvious that lubricant with lower viscosities tend to have poor anti wear properties. The formula used for calculating the average scar diameters is as follows-

$$Min.\,Scar\,Diameter = \frac{\{Horizontal\,Diameter + Vertical\,Diameter\}}{2}$$

$$Avg.\,Scar\,Diameter = \frac{\{min.\,scar\,dia\,of\,ball\,1 + min.\,scar\,dia\,of\,ball\,2 + min.\,scar\,dia\,of\,ball\,3\}}{3}$$

Table 2: Wear Scar Diameter

S.No.	Engine Oil Sample	Scar Diameter (mm)			Avg. Scar Diameter (mm)
		Ball 1	Ball 2	Ball 3	
1.	Used Oil Sample UO	2.1	1.95	1.65	1.9
2.	Used Recycled Oil Sample URO	2.575	2.55	2.6	2.575

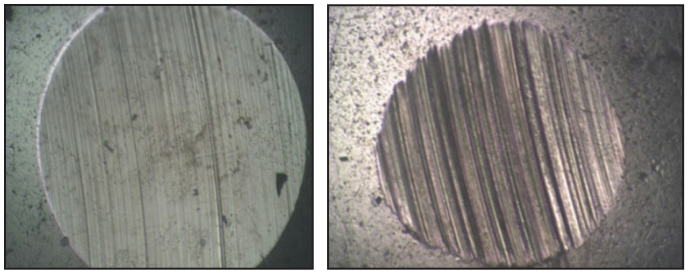

Fig. 7: Microscopic Wear Scar Image of Sample UO (Left) and Sample URO (Right)

C. Results of SOAP Analysis

Table 3 shows the results of SOAP Analysis of both virgin and recycled petrol engine oils. This table also gives information about the comparative wear rate of each element in the engine due to the use of lubricating oil.

Table 3: Result of SOAP Analysis

S. No.	Wear Metal Element	Concentration in oil sample	
		UO	URO
1.	Iron (Fe)	6.46	7.24
2.	Aluminium (Al)	5.27	6.18
3.	Copper (Cu)	0.827	0.536
4.	Lead (Pb)	0.06	0.04
5.	Zinc (Zn)	0.98	1.58
6.	Cadmium (Cd)	0.006	0.006
7.	Manganese (Mn)	0.04	0.18
8.	Cobalt (Co)	0.0	0.0

V. Conclusion

It was observed that the viscosity of the recycled oils is very less as compared to virgin oils in unused state, but all other properties are close enough for both recycled as well as virgin oils. After use, the trend of change in all properties other than viscosity appears to be similar. The viscosity of virgin oil decreased whereas the viscosity of recycled oils increased after use. This might be mainly due to two reasons: Excessive wear in the engine; and evaporating away of liquid or fuel content of lube oil due to non capability to bear the operating temperature. The results of four ball analysis showed that wear scar was bigger and deeper for recycled oil which can be understood as a effect of lower viscosity.The results of SOAP analysis were also comparable for both oils.

From this study, it can be concluded that if more stress is laid on improving viscosity during refining stage or by blending more amount of viscosity inhibitors, then the recycled oil can emerege

as a more powerful substitute to conventional oil and can be used on a much larger scale than today.

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