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Research Article

Recycling of waste or crude lubricating oil by vacuum distillation to produce reusable lubricants and its economic viability evaluation

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ABSTRACT

Recycling waste or crude lubricant oil is the best alternative to incineration. This article used the vacuum distillation method to recycle of waste lubricant oil. About 90% of lubricating oil was recovered from waste oil within the temperature range of 60-360 ^{0}C. Every measured property like density, viscosity, flash point, pour point, sulfur content, carbon residue, ash content, and water content were investigated and compared with fresh oil. Pour point was found not to improve through vacuum distillation but rather decreased. Similarly, vacuum distillation could not improve the viscosity and density of recycled material but rather decreased. Adding 2% EPDM, SPO ESPRENE V0141, and pellet form of rubber as additives increased those two properties significantly. Finally, 0.1% $NaNO_3$ was also added as an antioxidant. So, lastly, it can be concluded that the vacuum distillation process can effectively recycle waste lubricant oil in an economical and environmentally friendly manner.

Introduction

Global industrialization, urbanization, and mechanization of agriculture increase the volume of used lubricating oil produced each year. The used lubricant oil contains water, salt, broken down additive components, varnish, gum, and other materials (Durrani et al., 2011). Waste lubricating oil refers to the engine oil, transmission oil, hydraulic, and cutting oil after use. It is also referred to as the degradation of the fresh lubricating components that are contaminated by metals, ash, carbon residue, water, varnish, gums, and other contaminating materials, in addition to asphaltic compounds which result from the bearing surface of the engines (Riyanto et al., 2018). This waste engine oil may harm the environment when dumped into the ground or water streams, including sewers, resulting in soil and groundwater contamination (Udonne and Onwuma, 2014). Recycling such contaminated waste oil and reuse of recycled lubricant is highly beneficial not only in reducing engine oil costs and has a significant positive impact on the environment (Lolos et al., 2010; Boughton and Horvath, 2004).

A large amount of waste engine oils have a significant impact on the economy and the environment. They cost millions of dollars to manufacture and represent a high pollutant material when disposed of. If discharged into the land, water, or even burnt as a low-grade fuel, this may cause serious pollution problems because they release harmful metals and other pollutants into the environment (Martins, 2019). Also, due to oxidation or thermal degradation, many impurities are generated in lubricating oil during its application in internal combustion engines. These impurities contain unsaturates, aldehydes, phenolic compounds, alcohols, acidic compounds, and unsafe hydrocarbons products. In addition, used oil absorbs nitrogen oxides and exhaust gases from acidic fuel combustion. Besides, dust, fuel, lubricating oil additives degradation products, and fuel additives regularly decrease the

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lubricating oil performance. Moreover, the viscosity increases by producing of an asphalt-like sludge, in which metallic scrapings act as catalysts at the high operating temperature and oxygen vicinity (Bridjanian and Sattarin, 2006). This used oil needs proper management to make it a valuable product by minimizing the quality of oil being improperly disposed of and reducing the waste oils environmental burden. Therefore, many studies have been done on the recycling of used oil, its management, and its economic viability worldwide, and still going on (Sánchez-Alvarracín et al., 2021; Jafiri and Hasanpour, 2015; Pinheiro et al., 2021).

The used oil was burned initially to produce energy, and later this oil was re-blended to engine oil after treatment.

Recycling of used oil has been carried out by several methods. Oil re-refining is one of the most important recycling technologies used so far. During oil re-refining, the mechanical, physical, and chemical contaminations are removed with the following processes: distillation, clay treatment, and hydrogenation (Kamal and Khan, 2009; Josiah and Ikiensikimama, 2010), acidic refining (Kamal and Khan, 2009; Abdel-Jabbar et al., 2010), solvent refining (Durrani et al., 2012; Ogbeide, 2010) or combinations of the formers. These processes have different yield and product properties, construction, and operational cost. In Bangladesh, yearly lube oil consumption increases by 12% against a 3.42% global rate (Islam et al., 2021). About 23.62 thousand barrels of crude oil are imported per day (Source: The United States Energy Information Administration). Proper recycling can minimize the cost of importing. A recommended solution for this issue is recovering the lubricating oil from the waste oil. Recycling processes using nontoxic and cost-effective materials can be an optimum solution. Acid clay has been used as a recycling method for used engine oil for a long time. This method has many disadvantages, it also produces many pollutants, is unable to treat modern multi-grade oils, and is difficult to remove asphaltic impurities (Fox, 2007). Solvent extraction has replaced acid treatment as the method of choice for improving the oxidative stability and viscosity/ temperature characteristics of base oils. The solvent selectively dissolves the undesired aromatic components (the extract), leaving the desirable saturated components, especially alkanes, as a separate phase (the raffinate) (Rincon et al., 2005a). In another study, a mixture of methyl ethyl ketone (MEK) and 2-propanol was used as an extracting material for recycling used engine oils (Rincon et al., 2005b).

Although the acid clay method produces comparable oil to that of fresh one but is highly expensive. Expensive solvents and vacuum distillation are required to carry out this method (Shakirullah et al., 2006; Udonne, 2001). Recently propane was used as a solvent (Ghosh et al., 2011). Propane can dissolve paraffinic or waxy material and immediately dissolves oxygenated material. Asphaltenes, which contain heavy condensed aromatic compounds and particulate matter, are insoluble in liquid propane. These properties make propane ideal for recycling the used engine oil, but many other issues must be considered. 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.

In addition, extraction occurs at higher pressures and requires high pressure sealing systems, making solvent extraction plants expensive to construct and operate. The method also produces remarkable amounts of hazardous by-products (Rincón et al., 2003). Membrane technology is another method for the regeneration of used lubricating oils. The process is a continuous operation as it removes metal particles and dust from used engine oil and improves the liquidity and flashpoint of the recovered oils. Despite the above-mentioned advantages, the expensive membranes may get damaged and fouled by large particles (Dang, 1997). It was found that distillation/clay and activated/charcoal could be recovered from 80% lubricant oil and acid/clay method to about 50%

(Abdulkareem et al., 2014). Vacuum distillation and hydrogenation are two other methods that can be used for recycling used engine oil (Vasiliadou, 2021). The Kinetics Technology International (KTI) process combines vacuum distillation and hydro-finishing. This method removes most of the contaminants from the waste oil. The process starts with atmospheric distillation to eliminate water and light hydrocarbons. This is then followed by vacuum distillation at a temperature of 250 °C. The final stage is the hydrogenation of the products to eliminate the sulfur, nitrogen, and oxygenated compounds. This stage is also used to improve the color and odor of the oil. The product can be of quality standard (Gp.I) with a yield of approximately 82% and minimized polluting by-products (Vasiliadou, 2021, Sinağ et al., 2010). This article investigated the impact of vacuum distillation on recycling waste and crude lubricant oil to find optimum recycling.

Material and Apparatus

Waste lubricant oil from local market of Dholaikhal, old Dhaka, crude oil from the garage of Dholaikhal, old Dhaka, 2% EPDM, SPO ESPRENE V0141 rubber pellet from Sumitomo chemical company of japan, $NaNO_3$ from sigma USA. Fuller's earth powder from Neel Kanth Minechem India, Electric balance from Unilab pharmaceutical and chemical Pvt Ltd India, Cloud And Pour Point Apparatus from Hamco, India, Abels Flash Point Apparatus from alfa engineering solution, Maharastra, India, Bomb calorimeter from Advance research instrument company, Oune India, Vacuum distillation plant (ASTM D1160) from India, Distilled water plant (model: Basic/PH4 Pure-HIT still) was purchased from Glasco Company Ltd., UK, viscometer and pycnometer from Indiamart, Centrifuge machine (model no. PSM-LE018), Uttar Pradesh, India.

Experimental methods

Collection of waste lubricating oil

To recycle, two waste oil samples are collected. One is collected from the Market after being used in small machinery and another (crude) from the garage after being used in vehicles. Then preliminary these two waste oil properties were analysed.

Analysis of properties: The different properties like density (by pycnometer), viscosity (by viscometer), pour point (by Cloud And Pour Point Apparatus), flash point (by Abels Flashpoint Apparatus), sulfur content (by bomb calorimeter), water content, carbon content and ash content of the waste and crude lubricant oil has been evaluated through traditional methodologies.

Vacuum distillation process: In vacuum distillation, the samples (the waste oil and crude oil) were not subjected to temperatures above 370 to 380 °C because the high molecular weight components in the crude oil will undergo thermal cracking and form petroleum coke at temperatures above that. A vacuum pressure of about 6 mm Hg was maintained in each vessel. After the vacuum distillation, 2% EPDM, SPO ESPRENE V0141 rubber pellet was added as additives or viscosity modified, and 1% of Fuller's earth was used as the bleaching agent. Then 0.1% $NaNO_3$ was used as an anti-oxidant and stirred very well. The retention time in each vessel was maintained about 30 to 40 minutes. A filtration centrifuge of 6000 rpm was used to sediment or sludge out. The whole recycling process by vacuum distillation is schematically represented in Fig. 1.

Result and discussion

Properties investigation of lubricant oils: The properties of waste lubricant oils (market waste oil and crude oil) were evaluated and a vacuum distillation process was carried out to refine the oil. After that, the properties were evaluated and compared with the standard. All the measured properties are included in Table-1. The effect of the vacuum distillation on lubricant oil has been visualized from their values before and after vacuum distillation. Moreover, the effect of temperature has also been investigated, and the density and viscosity were found to decrease with temperature (Fig. 2-A,B).

Table 1. Properties of Market waste oil and crude oil before and after vacuum distillation compared to standard

Properties	Market waste oil		Crude oil		Standard value
	Before vacuum distillation	After vacuum distilled	before vacuum distillation	After vacuum distilled	
Density (g/ml)	0.880 (15°C), 0.876 (20°C), 0.873 (25°C), 0.870 (30°C), 0.865 (40°C), 0.860 (50°C)	0.877 (15°C), 0.867 (20°C), 0.859 (25°C), 0.851 (30°C), 0.839 (40°C), 0.787 (50°C)	0.8496 (15°C), 0.8467 (20°C), 0.8435 (25°C), 0.8407 (30°C), 0.8354 (40°C), 0.8294 (50°C)	0.794 (15°C), 0.792 (20°C), 0.790 (25°C), 0.788 (30°C), 0.787 (40°C), 0.785 (50°C)	0.90 (15.5°C)
Viscosity (cSt)	342.3405 (15°C), 284.9523 (20°C), 211.0863 (25°C), 147.6384 (30°C), 100.0032 (40°C), 57.9564 (50°C), 25.8640 (100°C)	316.29 (15°C), 261.37 (20°C), 230.59 (25°C), 178.98 (30°C), 92.332 (40°C), 43.088 (50°C) 25.095 (100°C)	108.8503 (15°C) 85.5414 (20°C), 70.6056 (25°C), 60.1958 (30°C), 39.8288 (40°C), 29.1927 (50°C), 8.3731 (100°C)	81.694 (15°C), 68.342 (20°C), 60.109 (25°C), 54.085 (30°C), 36.208 (40°C), 27.156 (50°C), 7.920 (100°C)	Up to 210 (40°C)
Pour point	-14°C	-16°C	-15°C	-20°C	-9°C
Flash and Fire point	66°C and 70°C	152°C and 154°C	34°C and 37°C	130°C and 134°C	>188°C
Sulphur content (wt %)	1.02 %	0.46 %	2.25 %	0.67 %	nil
Water Content (v/v)	Trace amount	Nil	2 %	Nil	< 0.20
Carbon residue (wt %)	2 %	1 %	2.99 %	0.2 %	nil
Ash content (wt %)	1 %	0.5 %	1.159 %	0.13 %	0.01 %
Range	IBP (100°C), 5 % (236°C), 10 % (242°C), 15 % (254°C), 20 % (270°C), 30 % (312°C), 40 % (314°C), 50 % (344°C), 60 % (344°C), 70 % (344°C) , 80 % (360°C)	IBP (70°C), 5 % (210°C), 10 % (223°C), 15 % (241°C), 20 % (260°C), 30 % (280°C), 40 % (301°C), 50 % (309°C), 60 % (319°C), 70 % (333°C), 80 % (348°C) 90 % (360°C)	IBP (70°C), 240°C (5 %), 260°C (10 %) 268°C (15 %), 275°C (20 %), 280°C (30 %), 286°C (40 %), 291°C (50 %), 310°C (60 %), 330°C (70 %), 341°C (80 %), 360°C (90 %)	IBP (60°C), 5 % (200°C), 10 % (212°C), 15 % (230°C), 20 % (243°C), 30 % (260°C), 40 % (266°C), 50 % (280°C), 60 % (300°C), 70 % (315°C), 80 % (338°C) 90 % (360°C)	

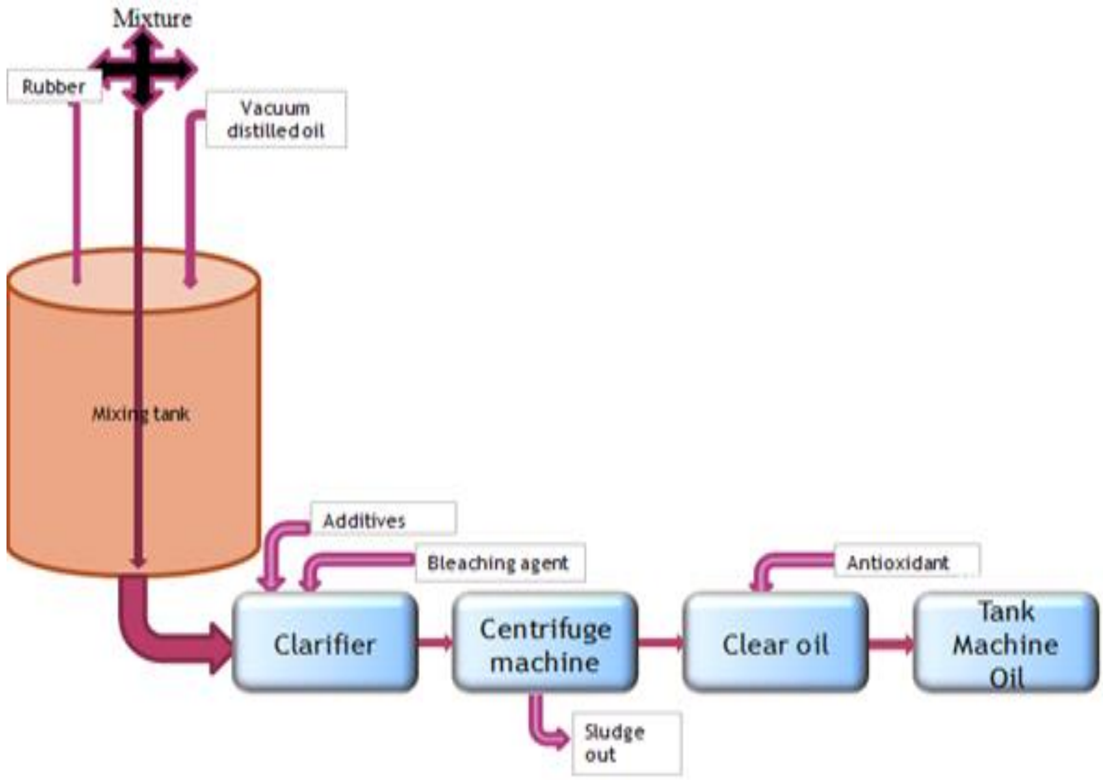

Fig. 1. Pictorial representation of the recycling plant for the preparation of lubricating oil from waste oil by vacuum distillation.

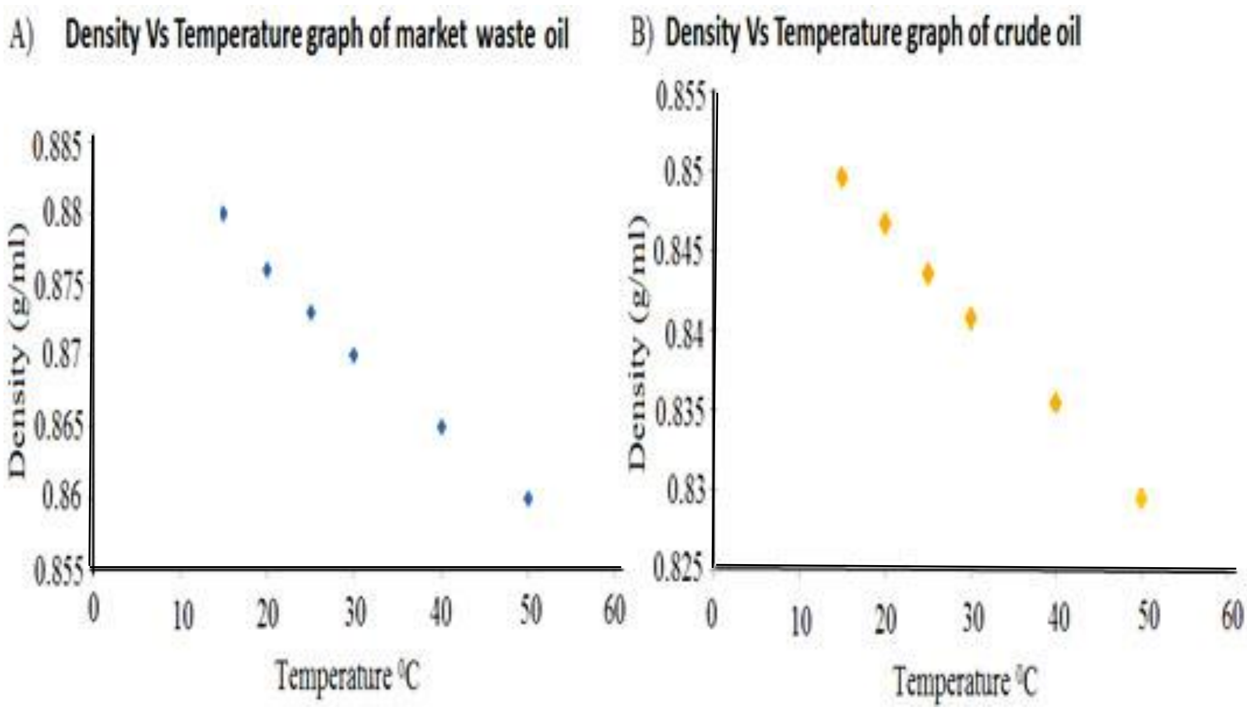

Fig. 2. Effect of temperature on the density of A) Market waste lubricating oil and Crude oil.

Investigation of the effect of rubber on density and viscosity: All properties except density and viscosity are improved after vacuum distillation. Therefore rubber pellets were used as additives or a viscosity modifier. And it has been found to significant improve of the viscosity and density of the lubricant oils after the rubber is added, as shown in Table 2 and Fig. 3 and Fig. 4, respectively.

Overall comparison of the lubricant oils: Finally, the effect of vacuum distillation and rubber addition on the properties in terms of density (Fig. 5A) and viscosity (Fig. 5B) with fresh oil, non distilled market waste oil and crude oil, and vacuum distilled market waste oil and crude oil respectively. It has been found from the study that density values when rubber is added to vacuum distilled oil are comparable to the fresh oil, and viscosity values when rubber is added to vacuum distilled oil are superior to the fresh oil. The impact of vacuum distillation on flash points and pour points, have also been evaluated. From the experimental data, it can be clearly said that vacuum distillation can improve the flash point value of crude oil and is close to fresh oil (Fig. 6A), but the pour point value is significantly decreased (Fig. 6B).

Moreover, it has been found that market waste oil and crude have a significant amount of sulphur content though vacuum distillation can cause a lowering of sulphur content but not that much (Fig. 7A). Interestingly, carbon residue could be significantly decreased and comparable to fresh oil (Fig. 7B). Besides, ash content could also be significantly decreased by vacuum distillation compared to non-distilled market waste oil and crude oil (Fig. 8A). Finally, water content was found significant in crude oil only compared to fresh oil and market waste oil. But vacuum distillation could remove water content almost completely (Fig. 8B).

Table 2. Rubber Added oil density and Viscosity

Properties	Market Waste oil	Crude oil	Standard value
Density (g/ml)	0.890 (15°C),	0.886 (15°C),	0.90 (15.5°C)
	0.881 (20°C),	0.875 (20°C),	
	0.876 (25°C),	0.865 (25°C),	
	0.872 (30°C),	0.854 (30°C),	
	0.866 (40°C),	0.843 (40°C),	
	0.861 (50°C)	0.830 (50°C)	
Viscosity (cSt)	720.8051 (15°C),	360.0021 (15°C),	Up to 210 (40°C)
	588.0870 (20°C),	295.1073 (20°C),	
	452.6661 (25°C),	224.6521 (25°C),	
	355.1250 (30°C),	191.0543 (30°C),	
	223.4923 (40°C),	160.9630 (40°C),	
	157.6782 (50°C),	127.0503 (50°C),	
	89.3412 (100°C)	60.6412 (100°C)	

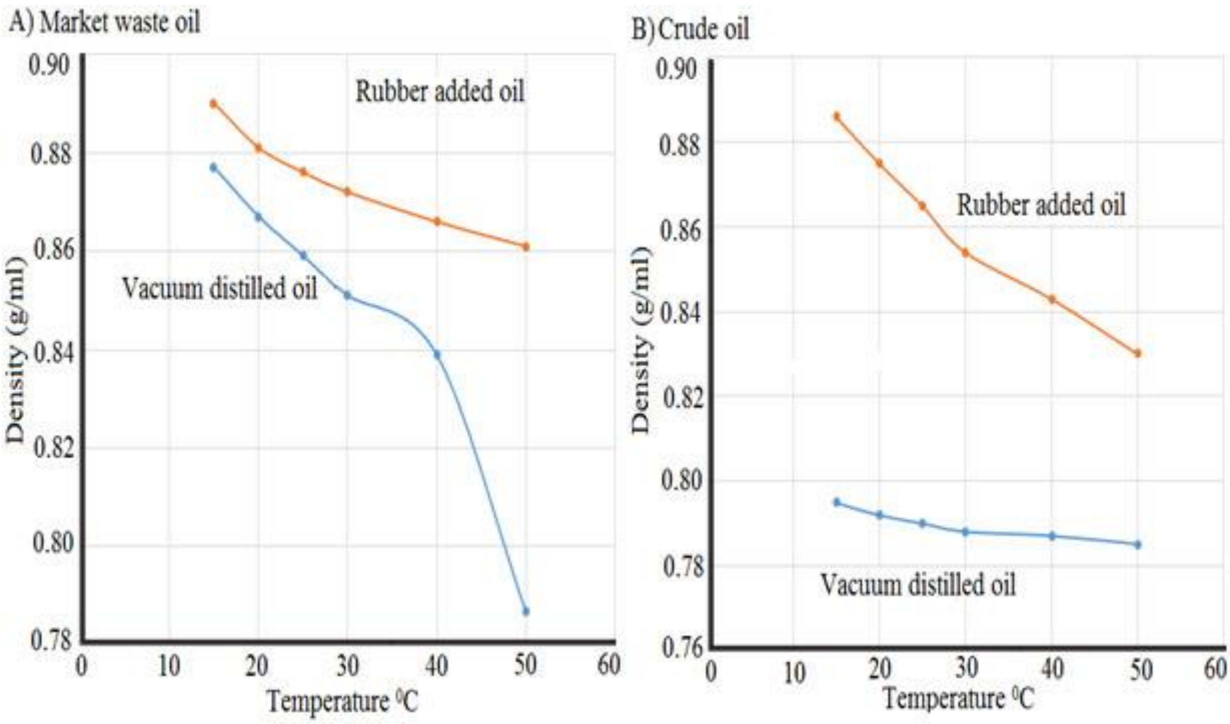

Fig. 3. Effect of temperature on the density of vacuum distilled (A) Market waste lubricating oil and (B) crude oil and after adding rubber, respectively

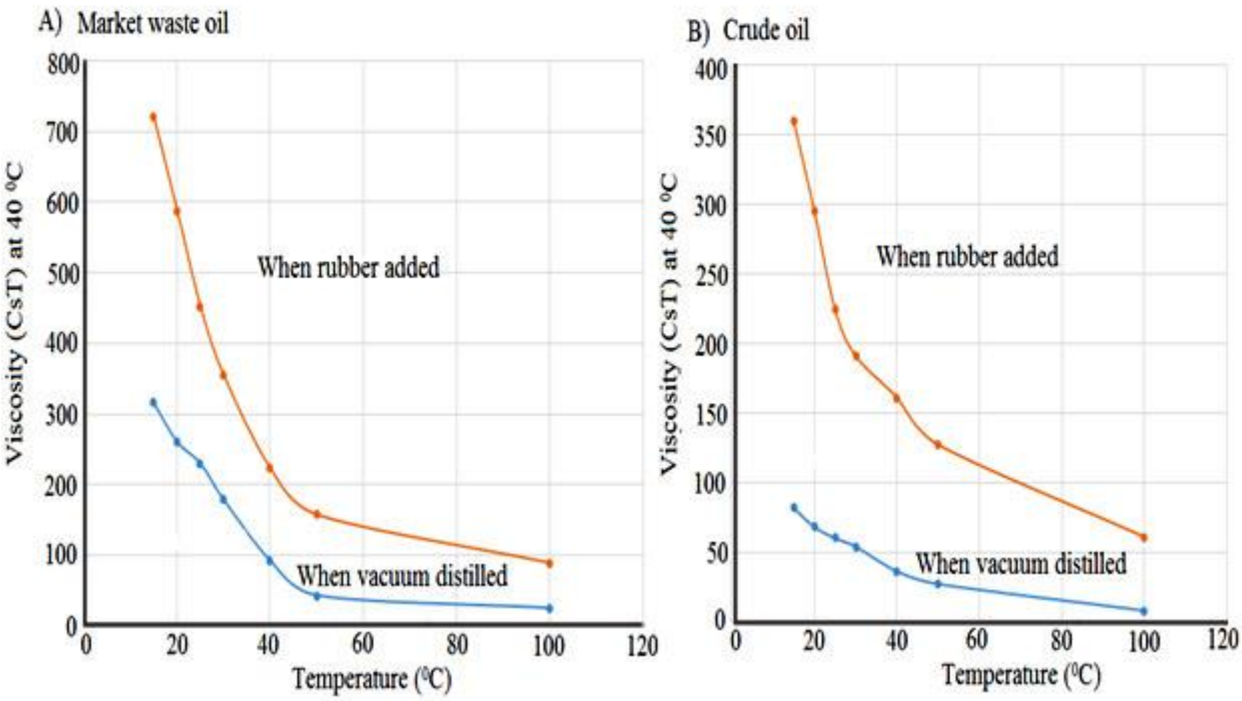

Fig. 4. The effect of temperature on the viscosity of vacuum distilled A) Market waste lubricating oil and crude oil and after adding rubber, respectively.

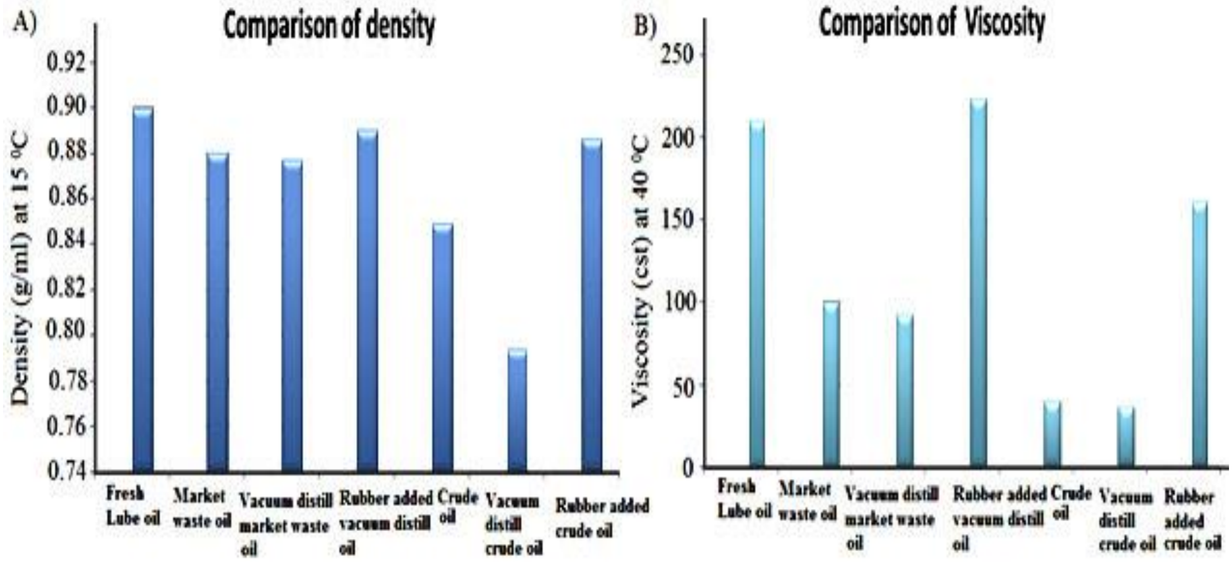

Fig. 5. Comparison of (A) the density and (B) the viscosity of rubber added market waste oil and crude oil with vacuum distilled oil, non-distilled oil and fresh oil, respectively.

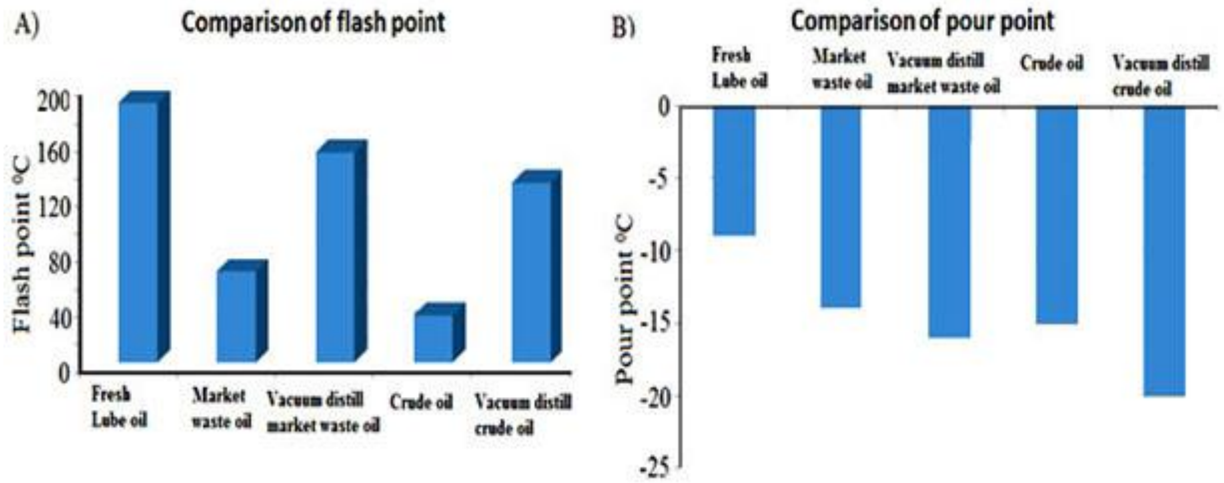

Fig. 6. Comparison of the (A) flash point and (B) pour point of market waste oil and crude oil with vacuum distilled oil and fresh oil, respectively

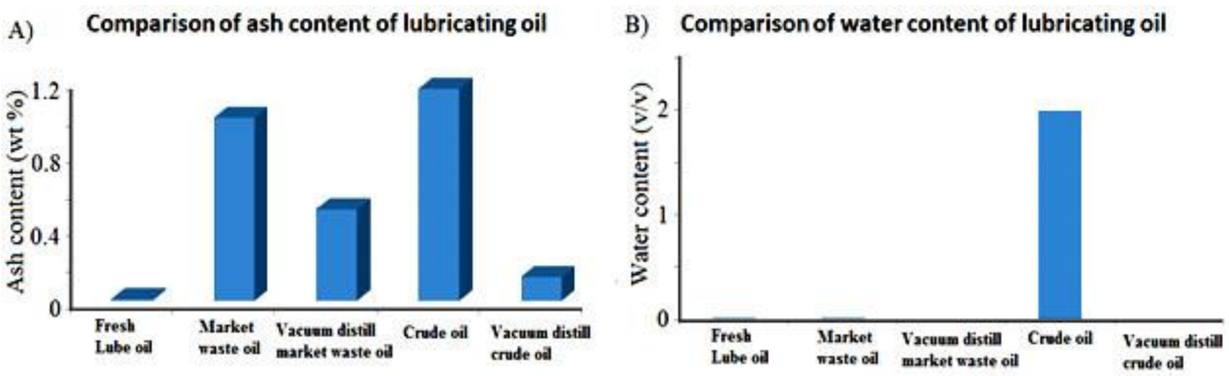

Fig. 7. Comparison of the sulphur content and carbon residue content of market waste oil and crude oil with vacuum distilled oil and fresh oil, respectively.

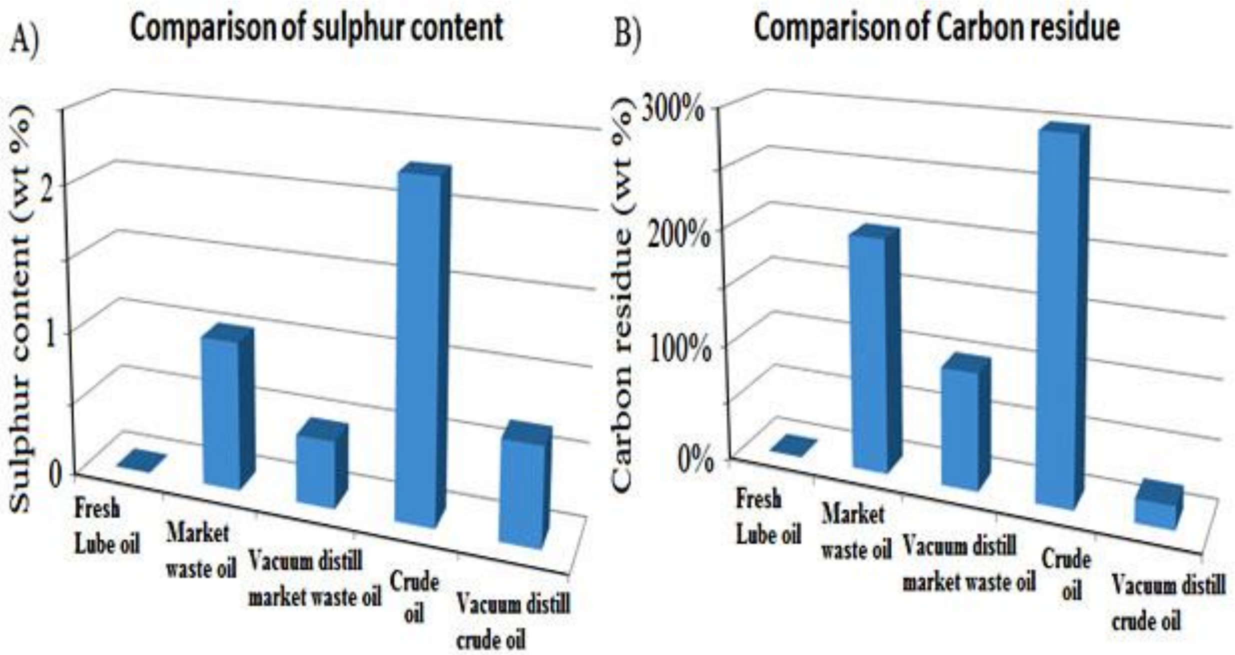

Fig. 8. Comparison of the ash content and water content of market waste oil and crude oil with vac distilled oil, and fresh oil, respectively.

Economic viability investigation

After analyzing all the data, it was noticed that the vacuum distillation process was found to be the best method to improve the properties of waste lubricant oil to lubricant. A large amount of waste oils is generated every day, and a vacuum distillation-based small-scale recycling plant can be an excellent and cost-effective option for oil Recovery. The total production cost of preparing lubricating oil is 100 taka per liter, whereas, in comparison to the market, its cost is above 300 takas. That means it is economical to use and profitable for business purposes. An economic analysis of the recycling of lubricant oil from waste and crude lubricant oil-based small-scale batch plants is described below in Table 3.

Table 3. The total production cost of lubricating oil from waste oil in a small scale-batch plant.

Raw materials	Amount	Cost (Taka)
Waste lube oil	1000 ml	45.00
Rubber	20 gm	10.00
Fuller Earth	10 gm	20.00
Colour	0.125 gm	0.50
Container	1 liter per piece with cap	18.00
Label	1 liter pack	1.50
Outer carton	1 liter pack (24 piece)	1.46
Sealing	1 liter pack	0.30
Other cost		4.24

Total production cost per liter = 100.00

Conclusion

In this research, recycling lubricating oil from waste lubricating oil has successfully done by vacuum distillation method. By this method, 90% of lubricating oil has recovered from waste oil much better than the reported one, about 62 to 66% (Rahman et al., 2008). Every measured property like density, viscosity, flash point, water content, carbon residue, ash content, and sulphur content has developed, which are close to standard value. But the pour point has decreased. However, the vacuum distillation viscosity and density of recycled oil have decreased by the using of 2% EPDM, SPO ESPRENE V0141, pellet form, Mooney viscosity of

OCP as viscosity modifier, viscosity and density has increased before that by the centrifugation sludge have removed. After that, 0.1% $NaNO_3$ was added as an antioxidant. So, finally, it can be said by the vacuum distillation process that waste oil can be effectively recycle, and it is so much economical to use and environmentally friendly.

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Conflict of Interest

The authors declared that they have no conflict of interest.

Author's contribution

M.R. Akanda contributes to conceptualization, supervision, and manuscript drafting, M. Hasan contributes to carrying out the whole experiment, and M.A. Rouf contributes to conceptualization, supervision, and instrumental support from BCSIR.

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