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*By Universitas Muhammadiyah Sidoarjo*

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# Academia Open

Vol. 11 No. 1 (2026): June  
DOI: 10.21070/acopen.11.2026.14011

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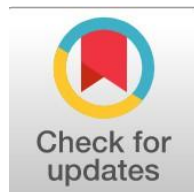
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## Recovery and Purification of Used Lubricating Oil Through Solvent Extraction: Empirical Validation and Process Optimization

Maha A Dawood, author01@gmail.com (\*)

Fuel and Energy Department, College of Oil and Gas Technology Engineering, Northern Technical University Kirkuk, Iraq

(\*) Corresponding author

### Abstract

**General Background:** Mismanagement of used lubricating oil represents a significant environmental and economic challenge due to the loss of valuable hydrocarbon resources and contamination risks to land and water systems. **Specific Background:** Solvent extraction technology has emerged as a promising recycling approach capable of removing contaminants and restoring physicochemical characteristics of degraded lubricating oil while supporting resource conservation strategies. **Knowledge Gap:** However, limited empirical validation combining solvent selection with operational parameter optimization and predictive modeling for oil recovery rate remains insufficiently addressed. **Aims:** This study evaluates solvent extraction performance using several solvent systems and optimizes key process parameters, including solvent-to-oil ratio, temperature, and pressure, while developing regression-based predictive models for oil recovery rate and impurity removal. **Results:** Findings indicate that a propane-based solvent mixture increased recovery rate and reduced secondary waste generation, with optimal operating conditions identified at a solvent-to-oil ratio of 4:1, temperature range of 180–220 °C, and pressure of 4–10 mbar; regression modeling demonstrated strong agreement between experimental and calculated values with accuracy of 94.98 and variance of 0.016. **Novelty:** The integration of comparative solvent evaluation with empirical least-squares regression modeling provides validated relationships linking solvent composition and operational variables to recovery performance. **Implications:** These outcomes support solvent extraction as a sustainable pathway for recycling used lubricating oil, enabling improved resource utilization while reducing environmental burdens associated with conventional disposal practices.

#### Highlights:

- Parameter Window 200 °C and 4–8 Mbar Produced Highest Distilled Volume
- Regression Prediction Reached 94.98 Accuracy With 0.016 Variance
- 4:1 Ratio Minimized Reagent Consumption While Maintaining Yield

**Keywords:** Used Lubricating Oil Recovery, Solvent Extraction Process, Propane Solvent Mixture, Process Parameter Optimization, Oil Recovery Rate Modeling

Published date: 2026-04-02

## Introduction

Environmental pollution is one of the most urgent international problems that endanger human health and the ecological system [1]. Among other pollutants, used lubricating oils are a huge problem because of their large production and the possible damage to the land and water sources [2]. Lubricating oils are very important in internal combustion engines, as they allow the reduction of friction, dissipation of heat, as well as wear [3]. Nevertheless, in the course of operations, the lubricating oil is degraded, and the viscosity of the lubricating oil is altered, it becomes acidic and collects mineral [4], [5], like metals, water and by-products of combustion [6].

The conventional ways of disposal, i.e. landfill or burning, are not environmental and economical [7]. As a result, recycling and relying on the used lubricating oils have become an option as a possible pollution [8][9][10][11][12][13]. There are various procedures of recycling oil and one of them is acid-clay treatment [14], acid-activated clay treatment [15], vacuum distillation [16], and solvent extraction [17]. Solvents extraction has become a potential method among them owing to its high efficiency, low amounts of energy used, and minimum environmental impact [18].

This paper dwells on the optimization of solvent extraction process to recover used lubricating oils. The experimental study of the influence of the primary parameters like the type of solvent, solvent to oil ratio, temperature and pressure is conducted. Moreover, the empirical models are constructed to forecast the rate of oil recovery and impurity removal that can be useful in industrial purposes.

## Methodology

### A. Materials

Vehicle repair facilities were chosen as the source of samples of waste lubricating oil that was first dehydrated to remove moisture and volatile hydrocarbon compounds.

### B. Solvent Extraction

Several solvents were tested for their extraction efficiency, including:

1. Propane
2. Propane with Butane
3. Ternary mixture of 25% 2-propanol, 50% 1-butanol, and 25% butanone
4. Ternary mixture of 25% 2-propanol, 35% 1-butanol, and 40% butanone

The solvent-to-oil ratio was varied from 2:1 to 6:1 to determine the optimal condition.

### C. Process Description

Solvents extraction process was divided into four major steps. First, dehydration: The removal of water and volatile impurities by vacuum distillation at 200 °C to remove water and volatile impurities. The solvent extraction follows where dehydrated oil is mixed with the solvent of choice at optimal proportion of between 2:1 to 6:1 to derive optimal impurities removal. Solvents separation and recycling through vacuum distillation in the solvent recovery step. Lastly, the last purification process is Filtration and additive blending to improve the oil characteristics.

## Results and Discussion

### A. Analysis of Oil Recovery Efficiency

Table 1 presents the experimental findings of the process of oil recovery under different pressure and temperature conditions. The figures denote the correlation between pressure, temperature, and oil recovery efficiency.

**Table1:** Oil Recovery Data from Distillation Runs

Run	Pressure (mBar)	Final Temperature (°C)	Distilled Oil Volume (ml)	Charge (Liter)	First drop Temperature (°C)	Cooling Temperature (°C)
1	4	200	25	1.5	131	20
2	4	158	15	1.5	119	20
3	4	166	22	1.5	115	8
4	8	186	10	1.5	167	20
5	8	195	15	1.5	187	6
6	12	215	5	1.5	190	20
7	12	215	10	1.5	186	4

To calculate oil recovery and efficiency, you can use the following equations:

$$\text{Oil Recovery}(\%) = \frac{\text{Distilled Oil Volume (ml)}}{\text{Charge Volume (L)}} * 100$$

Where, distilled oil Volume is the amount of oil recovered in milliliters (ml), and charge Volume is the initial volume of oil (liter).

$$\text{Efficiency}(\%) = \frac{\text{Distilled Oil Volume (ml)}}{\text{Initial Oil Volume (ml)}} * 100$$

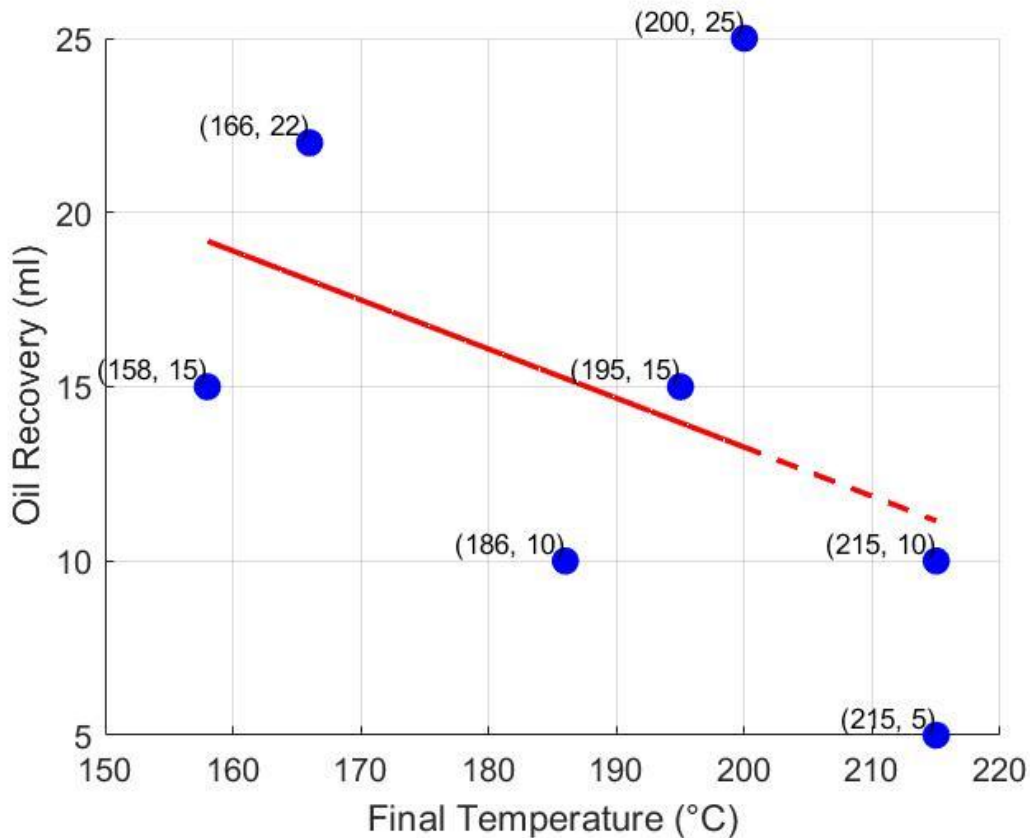
**Table 2:** Oil recovery and Efficiency Results for each run

Run	Oil Recovery (%)	Efficiency (%)
1	1.67	1.67
2	1.00	1.00
3	1.47	1.47
4	0.67	0.67
5	1.00	1.00
6	0.33	0.33
7	0.67	0.67

### Effect of Temperature on Oil Recovery:

It is clear, based on the analysis, that increased temperatures improve oil recovery, as Figure 1 demonstrates that the maximum recovery is at 200° C (Run 1). This is evidenced in the data by Run 1 which has a final temperature of 200°C resulting in maximum recovery of 25 ml. Conversely, run 2 with a final temperature of 158° C has a lower recovery of 15 ml which points to the pattern that low temperatures lead to low recovery. On the same note, Run 3 with temperature of 166° C recovers 22 ml, which once again confirms that temperature is positively correlated with the oil recovery

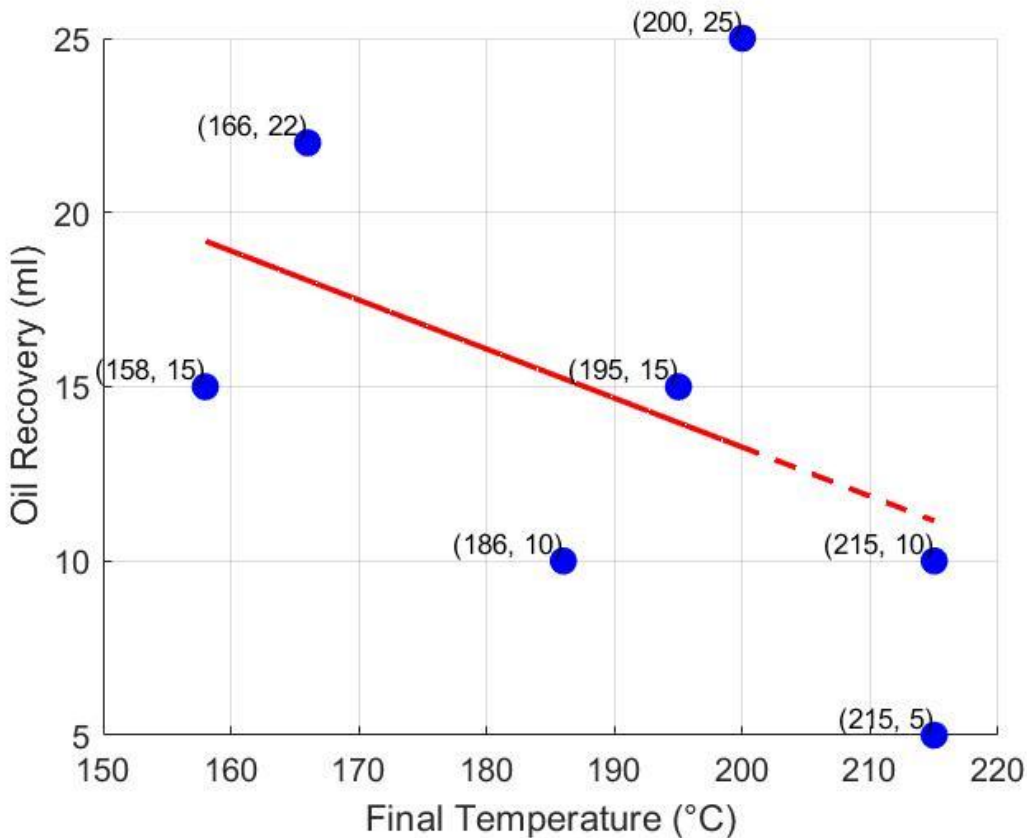
**Figure 1:** Effect of Temperature on Oil Recovery



### Effect of Pressure on Oil Recovery

The findings imply that at lower pressure (4-8 mbar), there are high volumes of oil recovery and on the other hand, there are reduced volumes of oil recovery at a high pressure (12 mbar) as depicted in Figure 2. To demonstrate this point, the oil recovery at 4 mbar (Runs 1, 2, and 3) is also much greater, with 25 ml of oil being recovered at 200 °C in Run 1, 15 ml in Run 2, and 22 ml in Run 3. Conversely, at an 12 mbar (Runs 6 and 7), although the final temperature gets to 215 C, the recovery volumes go down, with 5 ml in Run 6 and 10 ml in Run 7. It means that with low pressure the separation efficiency

increases, as the boiling point of hydrocarbons decreases.



### Cooling Temperature and First Drop Temperature:

The temperature at which the condensation process began and thus the recovery of oil was initiated was noted to vary depending on the pressure of the system and the final temperature which was reached. Experiment 3, as an example, at an initial condensation point of 115 ° C, there was the suggestion of premature volatilization, which would lead to process efficiency. On the other hand, the temperature of the cooling process also had a great impact on the recovery rates, showing low temperatures favoring better condensation and separating solvents. Indicatively, the Experiment 7 operated under a cooling temperature of 4 ° C that enabled good results in condensation.

### B. Optimization of Process Parameters

More important operational parameters such as temperature, pressure and solvent to oil ratio were optimized so as to maximize the efficiency of oil recovery without compromising the quality of oil. The optimization strategy was to balance these factors in order to have the highest yield without destroying the integrity of the oil during the extraction process. It was found that a solvent to oil ratio of 4: 1 was ideal since it was known to give maximum recovery with minimum solvent usage. The temperature was kept between 180 ° C and 220 ° C to avoid thermal degradation and to have good separation. Also, the work under vacuum pressure of 4-10 mbar helped to recover the solvents and reduce the oxidative damage.

Predictive modeling of the oil recovery rate (ORR) was done by way of least-squares regression analysis on the LINEST tool of Microsoft Excel in order to come up with the empirical relationships. The models are associated with the correlation of solvent composition ratios to both oil recovery efficiency and impurity removal, which allows the prediction of the effect of changes in process parameters on the rate of recovery to be accurately predicted. Two empiric equations were developed out of a large body of laboratory experimental evidence.

#### a. For oil recovery:

$$\begin{aligned} \text{Ln } y_1 = & 48.61 + 0.378 X_1 + 1.676 X_2 + 3.215 X_3 - 8.376 * 10^{-3} X_1^2 - 2.109 * 10^{-2} X_2^2 - 3.644 * 10^{-2} X_3^2 - \\ & 2.936 * 10^{-2} X_1 X_2 - 4.455 * 10^{-2} X_1 X_3 - 5.788 * 10^{-2} X_2 X_3 \\ \text{Ln } y_2 = & -75.169 - 0.747 X_1 + 0.641 X_2 + 1.263 * 10^{-2} X_1^2 - 2.362 * 10^{-2} X_3^2 + 1.857 * 10^{-2} X_1 X_2 + 4.089 * 10^{-2} X_1 X_3 \\ & + 2.080 * 10^{-2} X_2 X_3 - 3.061 * 10^{-4} X_1 X_2 X_3 + 4.689 * 10^{-4} X_3^3 \end{aligned}$$

#### b. For ash reduction:

Where,  $\text{Ln } y_1$  oil recovery percent,  $\text{Ln } y_2$  is the oil recovery percentage,  $\text{Ln } y_2$ : ash reduction percent is the ash reduction percent, and  $X_1, X_2, X_3$  are the weight percentages of the solvent components. Figure 3 depicts the relationship between oil

recovery and the solvent components 1 i.e. the experimental and theoretical values are plotted against the weight percentage of the solvent component 1.

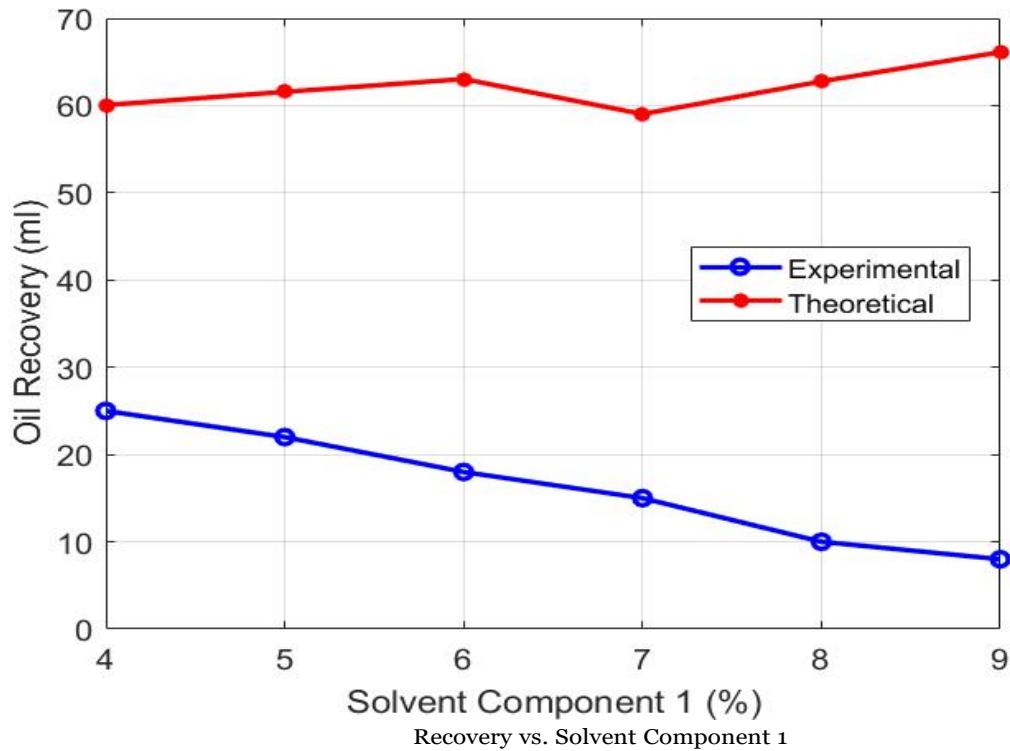


Figure 3 Oil

Figure 4 indicates the ash reduction against the solvent Component 1, where this plot is used to compare experimental and theoretical ash reduction according to the weight percentage of the solvent component 1 (X1).

Figures 4 Ash Reduction vs. Solvent Component 1

## Conclusion

This paper establishes that solvent extraction, especially on the propane-based solvents is an effective and quick method to recover and purify used lubricating oils and this is environmentally friendly process. Key findings include:

**Temperature and pressure** critically influence recovery efficiency, with optimal conditions at 200°C and 4–8 mbar.

**A solvent-to-oil ratio** of 4:1 maximizes recovery while minimizing solvent use.

Empirical models accurately predict oil recovery and ash reduction, facilitating process optimization.

The method offers **economic and environmental** benefits by reducing waste and conserving resources.

Future work should focus on scaling up the process and exploring alternative solvents to further enhance sustainability.

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