



# Sustainable Pumping System Powered by Biodiesel: Conversion of Used Cooking Oil via Transesterification

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## Introduction

This project focuses on developing a process to convert used cooking oil into biodiesel through transesterification. The biodiesel serves as a sustainable and clean energy alternative to conventional diesel, addressing waste recycling and reducing emissions in high-energy consumption applications like pumping systems. This aligns with Saudi Arabia's Vision 2030 for sustainability and renewable energy.

## Problem Statement

High-energy consumption systems, such as pumps, rely heavily on conventional diesel, contributing to significant carbon emissions. Additionally, improper disposal of used cooking oil leads to waste management challenges. A sustainable process to produce biodiesel from waste oil is needed to replace traditional diesel and reduce environmental impacts.

## Proposed Solution

The solution involves designing and simulating the transesterification process to convert used cooking oil into biodiesel. This biodiesel will replace conventional diesel, providing a clean and efficient energy source for high-energy-demand systems, while promoting waste recycling and environmental sustainability.

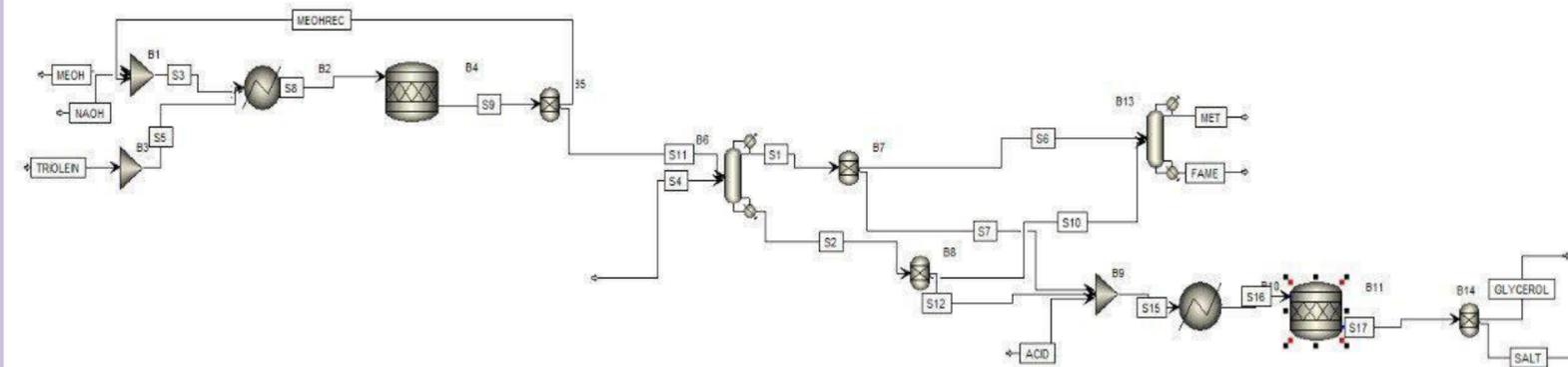
## Constraints

- FFA content <2%.
- Project Budget < 3000 SAR.
- Viscosity <6.0 mm<sup>2</sup>/s.

## Target Specification

- Methanol to UCO ratio 3:1.
- CO<sub>2</sub> emission reduction > 60%.
- Conversion of UCO > 95%.
- Catalyst amount 1% of UCO.
- OR Model allows multi tours.
- Optimization model does not have to visit all restaurants if it is not possible.

## Prototype Design



Trial	FFA Content (%)	Conversion (%)
1	1.62	94.04
2	1.56	95.9
3	1.4	95.82
4	1.57	95.49
Avg	1.5375	95.3125

The prototype design, created using Aspen Plus with the UNIQUAC thermodynamic package, simulates the transesterification process for converting used cooking oil into biodiesel. The process begins with pre-treatment to reduce FFA content, followed by the transesterification reaction where methanol and NaOH react with triglycerides to produce biodiesel and glycerol. Downstream steps include separation and purification of biodiesel, with a water-washing stage to eliminate soap formation and ensure product quality. Experimental validation demonstrated an average FFA content of 1.54% and a biodiesel conversion efficiency of 95.31%. Key features include optimized FFA reduction, high conversion rates, and effective separation of by-products, making the design both efficient and environmentally sustainable.

### Optimization Model Assumptions:

1. The goal is maximizing quantity.
2. We do not have to visit all restaurants.
3. At most a visit to each restaurant.
4. Each tour must be one connected path.
5. The tour is limited to a certain time.
6. The plant operation must be included in each tour.
7. The tour's truck is limited to a certain load.
8. An average travelling speed is estimated for each truck.
9. Available Liters of UCO are known at each restaurant.
10. The distances between restaurants are known.
11. An average time to collect one liter of UCO is estimated.
12. An average oil collecting equipment installation and uninstallation time is estimated.
13. A truck can take several tours.

This formulation has been built in a python code to serve as a daily tool to obtain the optimal routing schedule. It requires a specified excel format to work properly.

Maximize The Collected Used Cooking Oil:

$$\text{maximize } \sum_{o=1}^O \sum_{k=1}^K \sum_{i=1}^n \sum_{j=1}^n l_i x_{i,j,k,o}$$

Subject to:

1. Visit Each Restaurant at Most Once:

$$\sum_{o=1}^O \sum_{k=1}^K \sum_{i=1}^n x_{i,j,k,o} \leq 1 \quad \forall j = 2, \dots, n \text{ \& } i \neq j$$

2. Subtour Elimination Constraint:

$$u_{i,k,o} + 1 \leq u_{j,k,o} + n(1 - x_{i,j,k,o}) \quad \forall k, o \text{ \& } i, j = 2, \dots, n, i \neq j$$

3. Required Time Is Less than Available Time:

$$\frac{[\sum_{o=1}^O \sum_{i=1}^n \sum_{j=1}^n d_{i,j} x_{i,j,k,o}]}{v_k} + \sum_{o=1}^O \sum_{i=1}^n \sum_{j=1}^n [x_{i,j,k,o} * (t_k l_i + a_k)] \leq S_k \quad \forall k$$

4. Visit The Operations Base Exactly Once Assuming It Is Index = 1:

$$\sum_{i=1}^n x_{i,1,k,o} = 1 \quad \forall k, o$$

5. Leaving The Operations Base Exactly Once Assuming It Is Index = 1:

$$\sum_{j=1}^n x_{1,j,k,o} = 1 \quad \forall k, o$$

6. If A Restaurant Is Visited, It Must Be Left:

$$\sum_{j=1}^n x_{i,j,k,o} = \sum_{j=1}^n x_{j,i,k,o} \quad \forall k, o, i \text{ \& } i \neq j$$

7. Maximum Load For The Truck:

$$\sum_{i=1}^n \sum_{j=1}^n l_i x_{i,j,k,o} \leq C_k \quad \forall k, o$$

## Testing / Validation

- Methanol to UCO Ratio 3:1: Verified in the simulation using Aspen Plus, ensuring optimal reaction conditions for biodiesel production.
- CO<sub>2</sub> Emission Reduction > 60%: Confirmed through literature review, demonstrating significant environmental benefits from using biodiesel.
- Conversion of UCO > 95%: Achieved through experimental trials, validating the high efficiency of the transesterification process.
- Catalyst Amount 1% of UCO: Determined experimentally and verified in the simulation model as the optimal concentration for effective biodiesel production.
- After testing the optimization model, it allowed multi tours for each truck when more tours are required to maximize the collected UCO quantity. Also, If no enough time is available, the model only visit restaurants that will maximize the collected UCO quantity

## Conclusions

The biodiesel production process from used cooking oil via transesterification proved efficient, achieving over 95% UCO conversion with optimized parameters. Validated by simulations and experiments, it reduces CO<sub>2</sub> emissions by over 60%, providing a sustainable, clean energy solution for high-energy applications while addressing waste management challenges.

