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# SIMULATION AND EXPERIMENTAL STUDY OF WASTE COOKING OIL TO BIODIESEL PRODUCTION AND ENERGY ANALYSIS

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**Abstract**

Bangladesh heavily relies on imported crude oils for refining. With the fossil fuel crisis, it is vulnerable. Biodiesel from waste cooking oil can be a potential alternative to save foreign currency reserves. This study includes laboratory experiments and process simulation using Aspen HYSYS to produce biodiesel from WCO through transesterification. Biodiesel produced from waste cooking oil (WCO) in the laboratory has similar properties to standard ASTM D6751 and commercial diesel, making it a viable alternative fuel source. The energy analysis showed that WCO-to-biodiesel production is an energy-efficient option for the sustainable management of WCO waste.

*Keywords: Waste cooking oil, Biodiesel, HYSYS, Simulation*

## 1. Introduction

An adequate energy supply is crucial for any country to develop economically and socially. Bangladesh met petroleum product demand mainly by importing crude oil from overseas. However, the current crisis makes low-income developing countries like Bangladesh vulnerable to meeting energy demand for economic growth. One solution to bridge the gap between petroleum demand and supply is using alternate fuels such as biodiesel. It is important to note that the current diesel engine can operate with biodiesel without requiring modifications; this is a significant advantage over other alternative energy sources [1]. In addition, engine performance emission aspects of using biodiesel are also advantageous [2].

Biodiesel is an eco-friendly fuel from renewable resources consisting of short-chain alkyl (methyl or ethyl) esters and fatty acids, according to ASTM D6751. ASTM D6751 provides the quality criteria and analysis procedures for biodiesel (B100), including methyl esters (FAME) and ethyl esters (FAEE), when blended with diesel oil. Studies have explored using different edible sources, such as microalgae [3] and Nepalese Jatropha Curcas [4]. However, nonedible sources like waste cooking oil could be more promising for food security in Bangladesh; demand for biofuels from edible crops may increase food prices and threaten food security. Waste cooking oil (WCO) is a biodiesel feedstock that does not compete with food stock [5]. Despite its high free fatty acid (FFA) and water contents [6], biodiesel from WCO produces non-polluting fuel [7] and does not contain carcinogenic content. It also reduces pollution by converting WCO [8, 9].

Developing sustainable petroleum energy sources and pollution reduction from waste oils motivate this study. In the laboratory study, waste cooking oil was first pretreated (esterification) with methanol and sulfuric acid. Many reviews of biodiesel production processes by transesterification are available [10]. Then, biodiesel was produced by the trans-esterification reaction using different methanol oil ratios. In the transesterification process, methanol and NaOH were used. Next, a continuous transesterification and biodiesel production process model was developed within Aspen HYSYS. The prediction from the Aspen HYSYS model is validated against our experimental results. The simulation findings will be used for scaling up and creating a WCO to biodiesel pilot plant in the future.

## 2. Experimental Methods

WCO is collected from different sources of frying oil, like restaurants and households. For the experiment, 250 ml of WCO was pretreated with acidic (H2SO4) methanol to remove free fatty acid. The methanol-to-oil molar ratio was 2:1 for all experiments (Fig.1 and Fig.2) in the pretreatment process. Pretreatment proceeded for 2hr at 55°C.

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Then, pretreated waste cooking oil was washed with water to remove unreacted methanol and acid. After that, transesterification was observed for different molar ratios of 3:1 (theoretical), 4:1, and 6:1 of methanol to oil. Transesterification proceeded for 1.5hr at 55℃. Maximum yield conversion was observed for the 6:1 molar ratio. For transesterification, we used NaOH (1.3wt% of sample oil) as a catalyst premixed with methanol. After transesterification, a separating funnel separated glycerol, and raw biodiesel was collected for further treatment. First, raw biodiesel was washed to remove unreacted methanol and NaOH. Then, heat for removing the water content, and the final biodiesel was collected. Three biodiesel samples were mixed for different property tests like Specific Gravity, Kinematic Viscosity, Calorific Value, Molecular Weight, and Water content.


Fig.1: Experimental Setup

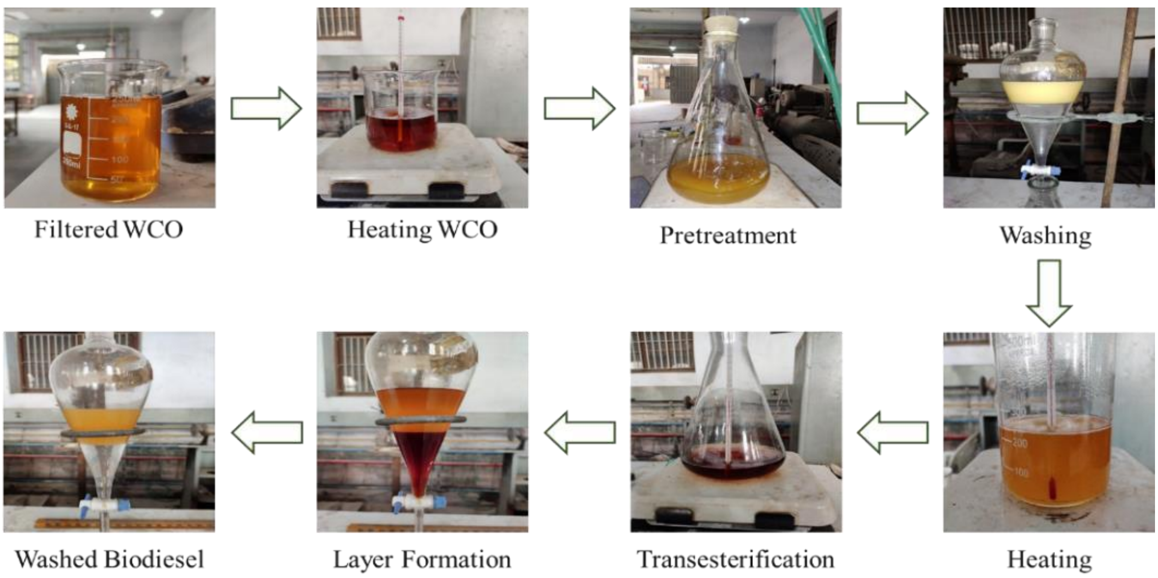


Fig.2: Different Experimental Steps

## 3. Process Simulation

In steady-state mode, process simulation for biodiesel production from WCO was carried out in Aspen HYSYS v10 (Fig.3). Due to the extreme polarity of glycerol and methanol, the Non-Random Two Liquid (NRTL) thermodynamic package model was utilized. The chemical components methanol, glycerol, sulphuric acid, and sodium hydroxide are available in the HYSYS component library. Since Oleic acid is the primary fatty acid in vegetable oil, biodiesel was represented by methyl oleate($C_{19}H_{36}O_2$), and WCO was represented by triolein ($C_{57}H_{104}O_6$)). The compounds' molecular weight, boiling point, density, critical temperature and pressure, the heat of formation, and combustion were estimated by Aspen HYSYS. The molar ratio of methanol to oil utilized in the transesterification reaction was 6:1, as this ratio produced the highest yield in the experiment. A continuous transesterification and biodiesel production process flow sheet was developed.

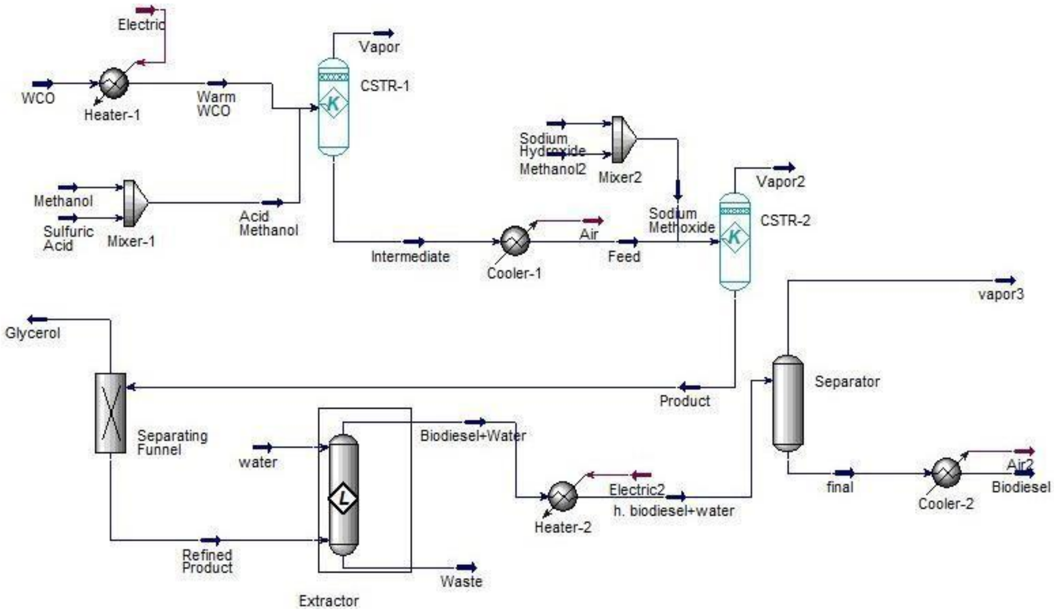


Fig.3: Process Flow Diagram of Biodiesel Production from WCO in ASPEN HYSYS

## 4. Results and Discussion

### *4.1 Yield Comparison for Simulation and Experiment*

Various methanol-to-oil molar ratios were used to observe biodiesel yield (Fig. 4). For simulation, methanol-to-oil ratios were 2,3,4, & 6; for the experiment, methanol-to-oil ratios were 3, 4, & 6. The simulation curve reached a maximum yield of 99.5% at a 3:1 stoichiometric ratio (Fig. 4). The yield remained the same for ratios 4 & 6. However, a decrease in yield was observed when the ratio was 2, as it was below the theoretical value. For the experiment The maximum yield for the experiment was 80.35% for a methanol-to-oil ratio of 6. For molar ratios of 3 and 4, biodiesel yield was 46.22% and 71.41%, respectively.

Where,

$$\text{The yield of biodiesel } (\%) = \frac{\text{Mass of biodiesel}}{\text{Mass of WCO}} \times 100$$

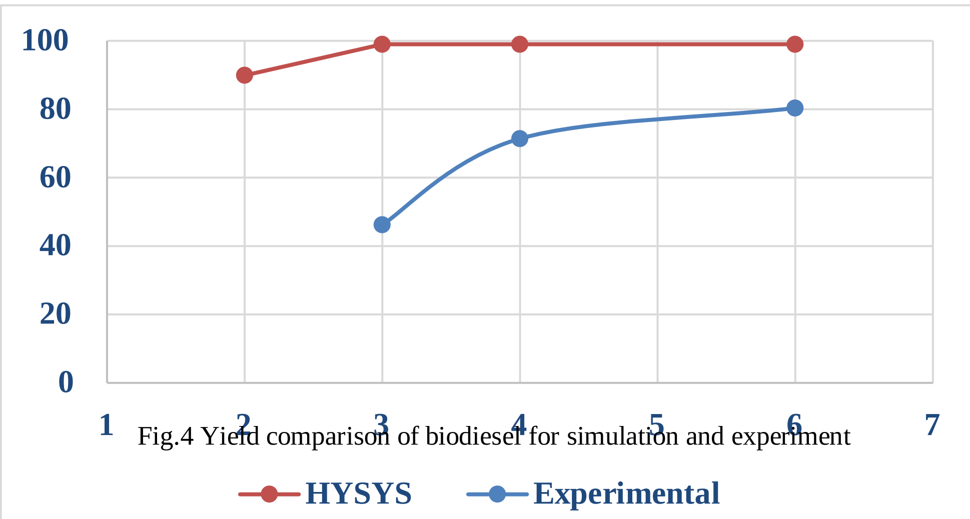


Fig.4 Yield comparison of biodiesel for simulation and experiment

*4.2 Physical Properties Comparison*

Experimental results were compared to HYSYS, the ASTM values, and the commercial diesel (Table 1 and Fig. 5). Experimental specific gravity and calorific value met the standard, but the kinematic viscosity was higher.

Table 1: Comparison of Properties with standard and commercial Diesel

| Property | Experimental Values | HYSYS Values | Standard ASTM D6751 | Diesel [11] |
|---|---|---|---|---|
| Specific Gravity | 0.88 | 0.88 | 0.86.-0.9 [EN 14214] | 0.85 |
| Kinematic Viscosity ($mm^2/s$) @ 40 $^oC$ | 7.58 | 7.03 | 1.9-6 | 1.3-4.1 |
| Calorific Value (MJ/Kg) | 39 | 39.93 | 39-41 | 43-46 |
| Molecular Weight (g/mole) | 296.2 | 296.5 | - | - |
| Water content (%v/v) | 0 | | 0.05% max | 0.05% max |

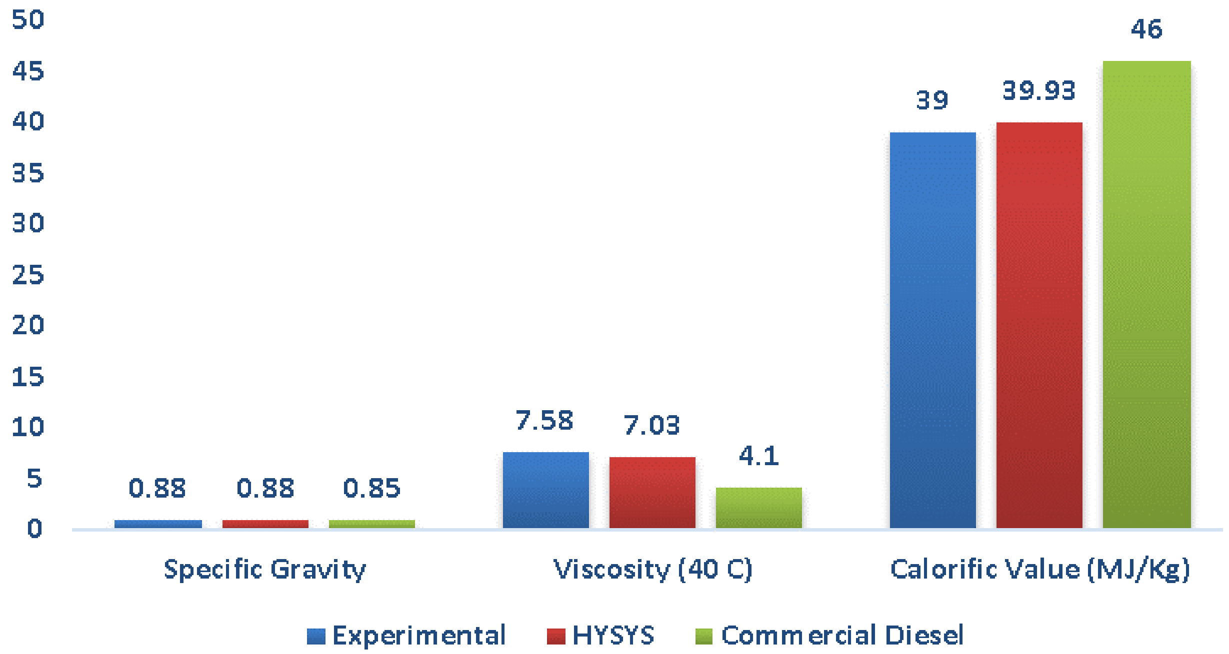

Fig.5 Comparison of biodiesel and commercial diesel properties

*4.3 Energy Estimation of Biodiesel Production*

Biodiesel production uses waste cooking oil, methanol, catalysts, labor, machinery, and electricity as inputs to produce biodiesel, glycerol, alcohol, and water as outputs. Experimental biodiesel energy equivalents (of 6:1 methanol oil molar ratio) were shown in Table 2. Corresponding reference values for energy analysis are taken from different references.

The energy output-input ratio in biodiesel production is 0.837, and Energy Productivity is 0.018. However, if we neglect the energy of WCO, the ratio becomes almost 2, indicating that for every MJ of energy consumed, twice the amount of useful energy is being produced.

where,

Energy Ratio = Output Energy / Input Energy;

Energy Productivity = Yield / Input Energy.

Table 2 Energy for per liter biodiesel production.

| | Parameter | Unit | Equivalent (MJ/unit) | Quantity per unit volume of Biodiesel (L) | Energy per unit biodiesel (MJ) |
|---|---|---|---|---|---|
| Input | WCO | L | 25.00 [12] | 1.25 | 31.25 |
| | Methanol | L | 33.67 [13] | 0.397 | 13.37 |
| | Catalyst (NaOH) | Kg | 23.30 [14] | 0.014 | 0.32 |
| | Catalyst ($H_2SO_4$) | L | 3.00 [14] | 0.0095 | 0.03 |
| | Electricity | KWh | 3.6 [12] | 2.5 | 9 |
| | Human Labor | h | 1.96 [12] | 0.036 | 0.07 |
| | Machinery | Kg | 8 [15] | 0.012 | 0.096 |
| | **Total input energy** | | - | | **54.14** |
| Output | Biodiesel | L | 39.00 [16] | 1.00 | 39.00 |
| | Glycerol | L | 25.30 [17] | 0.105 | 2.65 |
| | Methanol | L | 33.67 [13] | 0.11 | 3.70 |
| | **Total output energy** | | - | | **45.35** |

## 5. Conclusion

A laboratory data-based simulation within Aspen Hysys produces biodiesel with compatible properties to ASTM standards and diesel. However, its viscosity is higher than commercial diesel and must be blended. A 6:1 methanol and oil ratio yields the most biodiesel, and biodiesel production from WCO is energy intensive yet efficient as evidenced by the energy ratio and productivity indices. The simulation findings can be an efficient tool for scaling up and developing a WCO biodiesel manufacturing plant for commercial use.


## Acknowledgment

Properties of produced biodiesel such as kinematic viscosity, calorific value, molecular weight, and water content value tests were carried out in the fuel lab of the Department of Chemical Engineering, Bangladesh University of Engineering and Technology. Their support is highly acknowledged.


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