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Pilot Plant Design of 1kg Biodiesel Production using Waste Soybean Oil

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Abstract: As part of the efforts in attaining the commercialisation of biodiesel production in Nigeria, this research work considers a pilot plant design for the production of 1kg biodiesel, using waste soybean oil (WSO). CHEMCAD 7.1.2 software was utilised for the plant design and the process flow diagram revealed that four (4) pumps, four (4) heaters, two (2) separators, one (1) drying equipment and two (2) reactors were involved. Also, the simplified and simulated 1kg biodiesel production design plant showed that 0.0513kg/hr of methanol and 0.1800kg/hr of 0.1M H₂SO₄ would be required during the esterification process. And 0.6921kg/hr of methanol, 0.9870kg/hr of WSO as well as 0.1880kg/hr of KOH catalyst would be required for the transesterification process. That is the results obtained serve as template for the simulation of process design plants of varied production capacities. This is a good attempt in the ease of attainment of the commercialisation of biodiesel production in Nigeria.

Keywords: Biodiesel, KOH, Plant design, Transesterification, Waste soybean oil,

1. Introduction

The demand for energy at global level is rising exponentially as a result of the continuous increase in world population and technological advancement. Currently, the main sources of global energy are coal, petroleum and natural gas which are collectively referred to as fossil or non-renewable energy[1–3]. Fossil resources, when extracted and processed, generate certain chemicals and energy when utilised. The production and utilisation of this fossil energy has its associated environmental problems, such as the release of green-house gases (the agents of climate change), sulphur oxides (SOX), nitrogen oxides (NOX) and methane [4–5].

Hence, there is need for alternative sources of energy that are not only renewable but also sustainable. Research has proved that biodiesel fuel is a good and reliable source of renewable and sustainable energy [6]. Biodiesel fuel is simply defined as mono-alkyl ester of vegetable oils or animal fats. This fuel can be generated from the reversible reaction of the transesterification process involving a lipid and an alcohol, using a carefully selected catalyst [7–10]. Considering the huge volume of waste vegetable oils (WVO) generated, WVO can be treated and utilised as the raw materials required for the production of biodiesel. Stoichiometric reaction for biodiesel production through transesterification process is shown in Figure 1.

![Figure 1: Biodiesel production](image-url)
Many advanced countries (such as Germany, USA, France) have made significant impacts in the development and commercialisation of biodiesel technology and this has positively affected both the economic growth and energy security of these countries[11]. Nigeria, with a population of over 180 million people, should not be left out in this development, considering the enormous waste vegetable oils that are being dumped into our streams, land and sewage on daily basis [9, 11].

The establishment of accurate and well simplified designs of the production process for the conversion of the less-valued waste vegetable oils to biodiesel is one of the ways to promote the commercialisation of biodiesel production in Nigeria. This plausible attempt will ultimately boost the growth of the nation’s economy and reduce the environmental problems associated with the wrong disposal of waste vegetable oil. In this research work CHEMCAD 7.1.2 software will be employed in the plant design of 1kg/hr of pure biodiesel considering the two phase esterification-transesterification of waste soybean oil, using KOH catalyst.

2. Assumptions, materials and methods

2.1 Assumptions
The principles of both the esterification and transesterification processes were observed. For the process design to be made possible, the following assumptions were made:

1. 1kg of biodiesel production, with purity level of 99%
2. 1 hour operation at steady state conditions of perfect mixing, constant flowrate and uniform temperature.
3. Waste soybean oil (WSO) has free fatty acid (FFA) of 5wt%.
4. 0.1M H2SO4 was used during esterification for FFA removal.
5. 0.5M KOH catalyzed was used during transesterification process.
6. Transesterification reaction occurred at 60°C.
7. Methanol/oil mole ratio of 13.5 was considered for the transesterification process.

2.2 Materials
The material used was waste soybean oil (WSO) with 5% free fatty acid level. Also CHEMCAD 7.1.2 software was used for the pilot plant design.

2.3 Methods
As reported in Ayoola et al., [4], biodiesel fuel can be produced from WSO and methanol using esterification-transesterification process. Figures 2 and 3 show the block flow and process flow diagrams of the process design of biodiesel production respective. Through esterification process, impurities in WSO were removed through the outlet stream 12 (Figure 3). The esterification process occurred in the reactor R1 and this was achieved by contacting 0.1M H2SO4 and methanol with the WSO.

The treated WSO obtained was heated to a desired temperature and then mixed with a mixture of methanol and KOH catalyst for transesterification reaction in reactor R2. The impure biodiesel obtained was purified through the introduction of washing water. The outlet stream 15 from R2 contained the by-products (glycerol, unreacted methanol and water), while the wet biodiesel obtained (stream 11) was free of the traces of water present (through heating) to obtain pure biodiesel at the outlet stream 20.
3. Results and discussion
Figure 3 showed the process flow pilot plant design while Tables 1 and 2 revealed the compositions (both the quantities and the chemical substances) of the main inlet and outlet streams respectively for 1 kg biodiesel production.
Figure 3: Process flow diagram of the plant design for 1 kg biodiesel production

P = pump, H = heater, M1 & M2 = mixers, R1 = esterification reactor, R2 = transesterification reactor, S = separator

3: Process flow diagram of the plant design for 1 kg biodiesel production
### Table 1: Compositions of the inlet streams

| Stream Number | Stream Name | Stream 1 | Stream 2 | Stream 5 | Stream 21 | Stream 22 | Stream 35 |
|---------------|-------------|----------|----------|----------|-----------|-----------|-----------|
|               | Methanol    | H₂SO₄    | WSO      | Methanol | KOH       | H₂O       |           |
| Molar flow, kmol/h | 0.0016 | 0.0018 | 0.0016 | 0.0216 | 0.0034 | 0.2775 |
| Mass flow, kg/h    | 0.0513 | 0.1800 | 0.9870 | 0.6921 | 0.1888 | 5.0000 |
| Temperature, °C   | 25.0000 | 25.0000 | 25.0000 | 25.0000 | 25.0000 | 25.0000 |
| Pressure, bar      | 1.0132 | 1.0132 | 1.0132 | 1.0132 | 1.0132 | 1.0132 |
| Average mol. wt.   | 32.0420 | 98.0790 | 612.6745 | 32.0420 | 56.1060 | 18.0150 |
| Volume, m³/h       | 0.0001 | 0.0001 | 0.0011 | 0.0009 | 0.0001 | 0.0050 |

**Flow rates in kg/h**

- Methanol: 0.0513 kg/hr (stream 1) and 0.1800 kg/hr (stream 2).
- KOH: 0.0000 kg/hr (stream 1) and 0.1888 kg/hr (stream 2).

### Table 2: Compositions of the outlet streams

| Stream Number | Stream Name | Stream 12 | Stream 14 | Stream 15 | Stream 20 |
|---------------|-------------|-----------|-----------|-----------|-----------|
| Molar flow, kmol/h | 0.1420 | 0.0002 | 0.1620 | 0.0033 |
| Mass flow, kg/h    | 2.5382 | 0.0037 | 3.1885 | 1.0000 |
| Temperature, °C   | 26.7585 | 105.0000 | 36.0554 | 105.0000 |
| Average mol. wt.   | 1024.2418 | 954.1378 | 975.2727 | 805.1310 |
| Volume, m³/h       | 0.0027 | 0.0000 | 0.0035 | 0.0012 |

**Flow rates in kg/h**

- Methanol: 0.0294 kg/hr (stream 12) and 0.0000 kg/hr (stream 14).
- Water: 2.5088 kg/hr (stream 12) and 0.0000 kg/hr (stream 14).
- H₂SO₄: 0.1800 kg/hr (stream 12) and 0.0000 kg/hr (stream 14).
- Glycerol: 0.0000 kg/hr (stream 12) and 0.0000 kg/hr (stream 14).
- KOH: 0.0000 kg/hr (stream 12) and 0.0000 kg/hr (stream 14).

The result of the pilot plant design revealed that for the production of 1 kg biodiesel, the mass flow rate of biodiesel required for esterification process was 0.0513 kg/hr of methanol (stream 1) and 0.1800 kg/hr of 0.1M H₂SO₄ (stream 2). During transesterification process, the inlet streams contained...
0.6921kg/hr of methanol (stream 21), 0.9870kg/hr of WSO (stream 5) and 0.1880kg/hr of KOH catalyst (stream 22). 5.0000kg/hr of water was introduced (stream 35 for both the esterification and transesterification processes).

The outlet streams of the design had a mixture of water and methanol of 2.5382kg/hr (2.5088kg/hr of water and 0.0294kg/hr of methanol, stream 12) from the esterification stage, 0.0037kg/hr of steam at 105°C from the drying of wet biodiesel, 3.1885kg/hr of a mixture of glycerol, water and methanol (0.6791kg/hr of glycerol, 2.4998kg/hr of water and 0.0096kg/hr of methanol) from the purification of biodiesel during transesterification process. Also, 1kg/hr of pure biodiesel (with purity level of 99%) was produced. These results agreed with the experimental study carried out in the laboratory [8].

Careful evaluation of the flow streams showed that the principle of conservation of mass was observed in the design operation. That is, the results of the design showed the simple step by step procedures to follow in the production of biodiesel in a continuously stirred tank reactor (CSTR) system and good material balance because all the materials and reagents were accurately accounted for. The efficiency of the design process was also justified by the high purity level of biodiesel (99%), high level of converted methanol (98.7%) and total removal of free fatty acid from the WSO.

Also, the process flow diagram revealed that four (4) pumps, four (4) heaters, two (2) separators, one (1) drying equipment and two (2) reactors were involved. It is good to mention that the simulation of the results obtained (using CHEMCAD software) will allow the process to be scaled up to any desired production capacity rate.

4. Conclusion
The simplified 1kg biodiesel production design plant shows that 0.0513kg/hr of methanol and 0.1800kg/hr of 0.1M H₂SO₄ would be required during the esterification process. And 0.6921kg/hr of methanol, 0.9870kg/hr of WSO as well as 0.1880kg/hr of KOH catalyst would be required for the transesterification process. This is a good attempt in the ease of attainment of the commercialisation of biodiesel production in Nigeria.

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