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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 H_2SO_4 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 energyhas its associated environmental problems, such as the release of green-house gases (the agents of climate change), sulphur oxides (SO_X), nitrogen oxides (NO_X) 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, WVOcan 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.

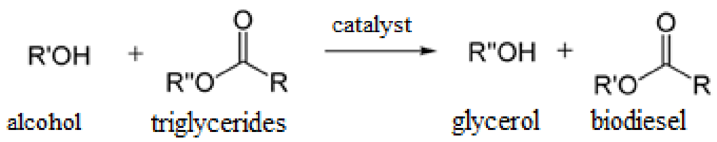

Figure 1: Biodiesel production

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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. Ant this plausible attempt will ultimately boost the growth of the nation'seconomy 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. 1hour 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 H_2SO_4 was used during esterification for FFA removal.
5. 0.5M KOH catalyst was used during transesterification process.
6. Transesterification reaction occurred at 60^0C.
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 H_2SO_4 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.

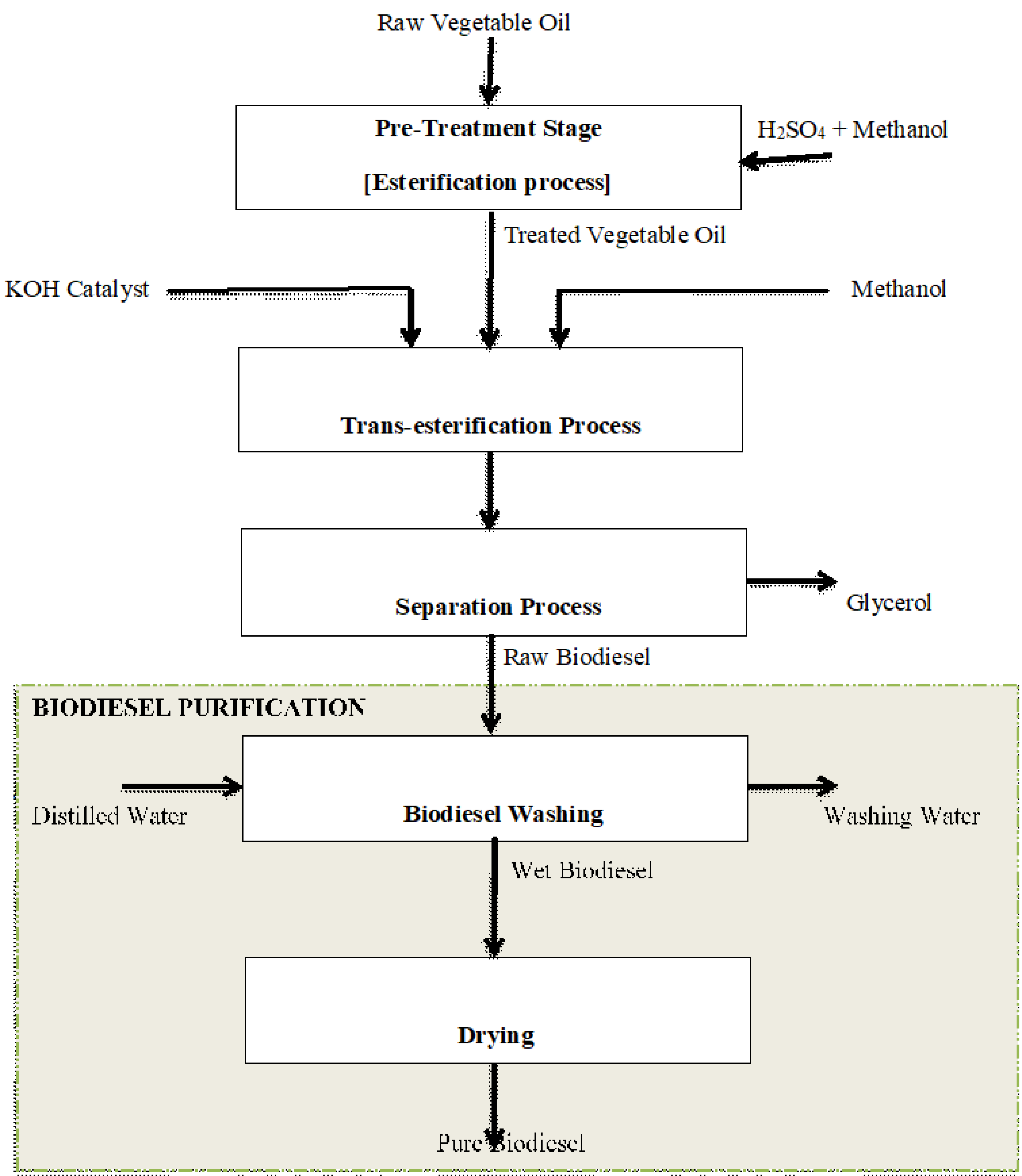
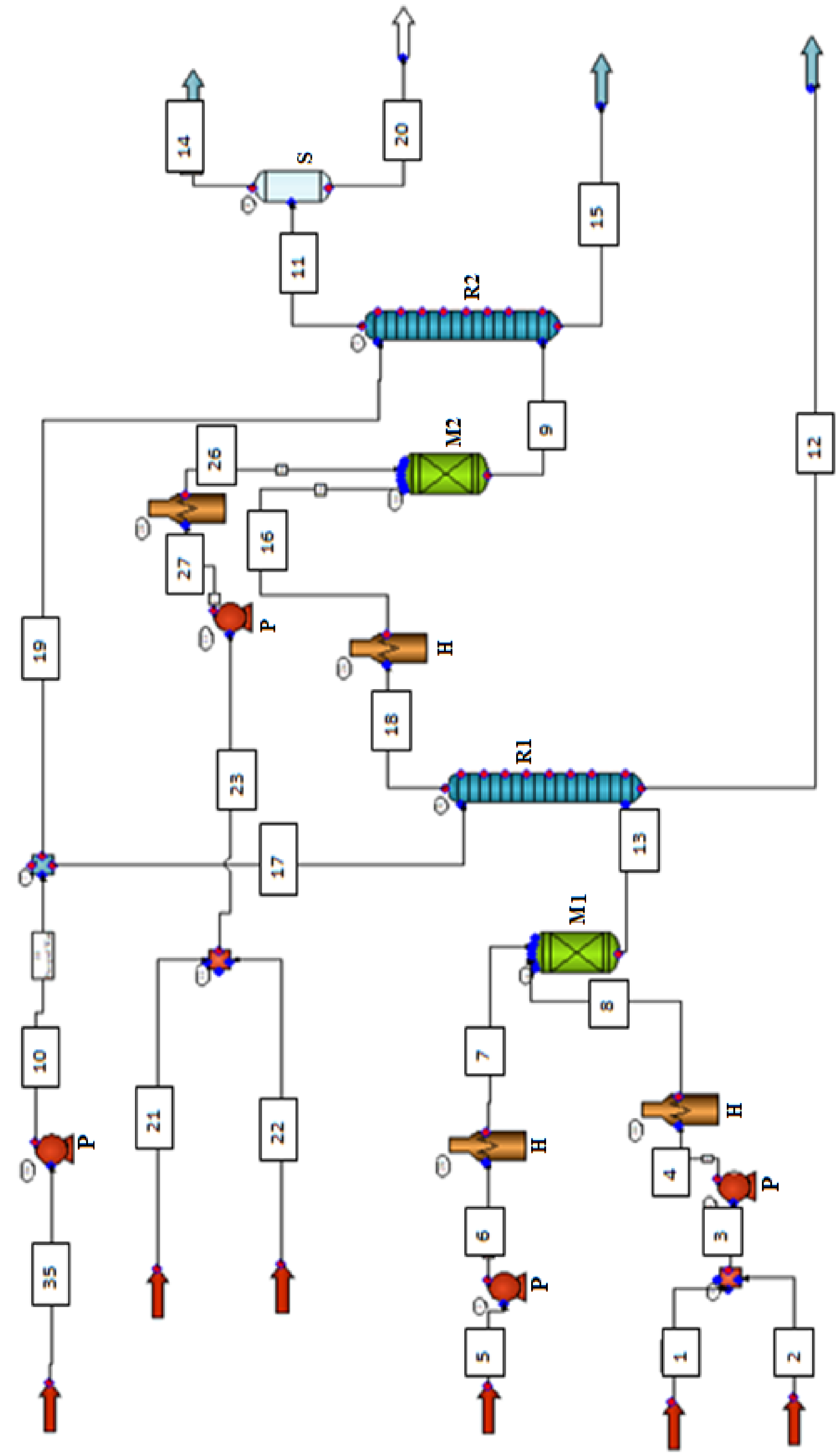


Figure 2: Block flow diagram of biodiesel production

3. Results and discussion

Figure 3showedthe processflow pilot plant designwhile Tables 1and 2 revealed the compositions (both the quantities and the chemical substances)ofthe main inlet and outlet streams respectively for 1kg biodiesel production.



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

Figure 3:Process flow diagram of the plant design of 1kg biodiesel production

Table 1: Compositions of the inlet streams

Stream Number	**1**	**2**	**5**	**21**	**22**	**35**
Stream Name	**Methanol**	**H_2S0_4**	**WSO**	**Methanol**	**KOH**	**H_2O**
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, ^{0}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, m^3/h	0.0001	0.0001	0.0011	0.0009	0.0001	0.0050
Flow rates in kg/h						
Methanol	0.0513	0.0000	0.0000	0.6921	0.0000	0.0000
KOH	0.0000	0.0000	0.0000	0.0000	0.1888	0.0000
H_2O	0.0000	0.0000	0.0000	0.0000	5.0000	0.0000
palmitic acid	0.0000	0.0000	0.1141	0.0000	0.0000	0.0000
stearic acid	0.0000	0.0000	0.0409	0.0000	0.0000	0.0000
triolein	0.0000	0.0000	0.1552	0.0000	0.0000	0.0000
trilinolenin	0.0000	0.0000	0.0713	0.0000	0.0000	0.0000
linoleic acid	0.0000	0.0000	0.1430	0.0000	0.0000	0.0000
oleic acid	0.0000	0.0000	0.0545	0.0000	0.0000	0.0000
trilinolein	0.0000	0.0000	0.4073	0.0000	0.0000	0.0000

Table 2: Compositions of the outlet streams

Stream Number	**12**	**14**	**15**	**20**
Stream name	**H_2O+Methanol**	**Steam**	**Glycerol+Methanol+H_2O**	**Biodiesel**
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, ^{0}C	26.7585	105.0000	36.0554	105.0000
Average mol. wt.	19.1405	18.0150	20.8460	300.5092
Actual dens kg/m3	1024.2418	954.1378	975.2727	805.1310
Volume, m^3/h	0.0027	0.0000	0.0035	0.0012
Flow rates in kg/h				
Methanol	0.0294	0.0000	0.0096	0.0000
Water	2.5088	0.0037	2.4998	0.0000
H_2SO_4	0.1800	0.0000	0.0000	0.0000
Glycerol	0.0000	0.0000	0.6791	0.0000
KOH	0.0000	0.0000	0.1888	0.0000
methyl myristate	0.0000	0.0000	0.00000.0007	
palmitic triglyc	0.0000	0.0000	0.0000	0.0063
methyl stearate	0.0000	0.0000	0.0000	0.0388
stearic acid tri	0.0000	0.0000	0.0000	0.0022
methyl oleate	0.0000	0.0000	0.0000	0.2028
triolein	0.0000	0.0000	0.0000	0.0085
methyl linolate	0.0000	0.0000	0.0000	0.5323
trilinolenin	0.0000	0.0000	0.0000	0.0039
methyl palmitate	0.0000	0.0000	0.0000	0.1084
linoleic acid	0.0000	0.0000	0.0000	0.0043
oleic acid	0.0000	0.0000	0.0000	0.0016
methyl linolenate	0.0000	0.0000	0.0000	0.0677
trilinolein	0.0000	0.0000	0.0000	0.0224

The result of the pilot plant design revealed that for the production of 1kg biodiesel, the mass flow rate of biodiesel required for esterification process was 0.0513kg/hr of methanol (stream 1) and 0.1800kg/hr of 0.1M H_2SO_4 (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 105^0C 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 wasalso 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 H_2SO_4 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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