Modification of Biodiesel Batch Reactor

Chilakpu, K.O; Nwandikom, G.I; Asoegwu, S.N and Egwuonwu, C.C

Agricultural Engineering Department,
Federal University of Technology, Owerri

Corresponding Author: Chilakpu, K.O

Abstract
The reaction of vegetable oil/fat for the production of biodiesel usually takes place in an enclosed device known as a “reactor”. Three major types of reactors available for biodiesel production are: batch, semi-continuous flow and continuous-flow reactors. Batch reactors are plagued with the problem of low productivity and high energy requirement. However, their flexibility in the choice of feedstock and less initial capital and infrastructure investment has encouraged the use for laboratory and commercial purposes. The major aim of this work is to modify the existing batch reactor for increased biodiesel yield. To accomplish this task, two different stirring-arm stages with a horizontal baffle were used. These arms arrangement were meant to increase turbulence during the fluid mixing and create more liquid surface to surface interactions for greater molecular separation and interface reaction. The result of performance evaluation carried out on the modified reactor show that, multiple stages of agitators increased the interface mobility of the alkoxide solution, yielding 98% of biodiesel in a record time of 60 minutes at a mixing speed of 300 rpm. The result of this research shows that, the conversion of alkoxide in the reactor was enhanced by the use of multiple levels of agitators, thus leading to increased biodiesel yield at a lower mixing speed and power requirement. The results of this work will encourage the full utilization of the device for biodiesel production for both laboratory and commercial needs.

Keywords: alkoxide, batch-reactor, baffle, stirring-arms, biodiesel, esterification.

INTRODUCTION
Biodiesel, is a renewable, clean burning biodegradable fuel. (Palligarnia, et al, 2008). In recent years, vegetable oils and animal fats processed into biodiesel have been used as a direct substitute for diesel fuel. Farm tractors and some other automobiles have been powered using biodiesel derived from vegetable oil. As world petroleum supplies become constrained, research attention has been directed to crop-based sources of biodiesel for internal combustion engines.

Bio-fuels (diesel for diesel engines and bio-ethanol for petrol engine) are used as fuel oxygenates to improve combustion and reduce emissions. Biodiesel production is achieved through the process of transesterification. This is usually preceded in some cases by the esterification process for feed-stocks with high free fatty acid (FFA) content (above 4%). The reaction of vegetable oil/fat for the production of biodiesel takes place in an enclosed device known as a “reactor”.

The reactor is a unit where the heating and mixing of the reagents for biodiesel production takes place. It consists of a cylindrical container sealed at the lower end with a discharge tap. The sealed end could be flat or conical shaped to allow for easy discharge of materials. The top of the cylinder which serves as material inlet is usually covered. This is to reduce atmospheric interaction with the alkoxide solution (combination of vegetable oil, alcohol and catalyst). A stirring shaft carrying the stirring arms is located at the center of the cylinder suspended from two ball bearings fixed on the cylinder cover. An electric heating filament/rod is fixed outside the wall of the reactor or sometimes inside the reaction tank to raise the heat level of the solution to the required temperature. The stirring of the alkoxide is usually motorized to achieve and maintain the needed stirring speed.

Three major types of reactors available for biodiesel production are: batch, semi-continuous flow and continuous-flow reactors (http://www.extension.org/biodiesel reactors). In this work, the focus is on the modification of a batch reactor to alleviate the problems associated with it as contained in the problem statement.

SIGNIFICANCE OF THE WORK
Batch reactors are flexible in the choice of feedstock and have less initial capital and infrastructural investment. Its low biodiesel yielding potentials has militated against its use beyond laboratory purposes. Modifying the batch reactor to increase its fuel yield will ensure the full utilization of the device for biodiesel production for both laboratory and commercial needs.
STATEMENT OF THE PROBLEM
The batch reactor is faced with the problem of low productivity and high energy requirement (http://www.extension.org/biodiesel Reactor). This has discouraged it use for the production of biodiesel in commercial quantities.

AREAS FOR IMPROVEMENT
Low productivity and high energy requirement are the key challenges of the batch reactors. This work will aim at enhancing the interface liquid-liquid separation taking place during the alkoxide mixing. This will be achieved by creating more turbulent fluid movement within the reactor to increase biodiesel production at a lower mixing speed.

MATERIALS AND METHODS
A choice of galvanized steel materials for reactor construction was made. This choice is for cost effectiveness and to reduce chemical reactions between the reagents and the wall of the reactor. The cylindrical nature of the reactor wall will facilitate easy mixing of the reagents. The operational volume and height of the reactor was selected to be 114 liters (0.114m³), and 0.63m for the purpose of this work. The diameter of the reactor was determined by;

\[
\text{volume} = \frac{\pi d^2 h}{4} \quad \ldots \quad 1
\]

Thus, \( d^2 = 0.230 \)
\( d = 0.48m \)

Required Mixing Force
The difference in tip velocities between layers of fluid leads to shearing action within the layers, thus, causing molecular separation. The impact of the high velocity streams on the walls of the reactor results in molecule separation also. More agitation enhances the rate of separation (Farral, 1976).

Theoretically, the force (F) required to mix 114 liters of jatropha oil with density of 0.92g/ml and at a rotational speed of 300rpm is given by:

\[
F = mr \omega^2 = mr(2\pi n)^2 \quad \ldots \quad 2
\]

\[
= 685.567N
\]

Designing for Cylinder Wall Thickness
The reactor wall is a thin vessels, but are subjected to circumferential stress when powered for mixing (Khurmi, 2005). The walls are further subjected to partial steam pressure when heated. The circumferential force due to mixing sets up internal pressure on the walls of the reactor. There is tendency for the cylinder to split into two troughs when the permissible stress is exceeded, (Khurmi 2005). At this point, the total pressure (P) along the diameter of the wall is given by;

\[
P = \text{Intensity of stress/Area} \quad \ldots \quad 3a
\]

At the critical situation, the circumferential stress (σ) is given by;

\[
\sigma = \frac{Total Pressure}{Resisting Surface} \quad \ldots \quad 3b
\]

The internal pressure acting along the diameter and perpendicular to the wall of the cylinder is given by:

\[
P = \frac{F}{A} = \frac{F}{\pi d h} = 2267.067 N/mm^2 \quad \ldots \quad 3c
\]

But;

Total internal pressure \( P_i \) = (internal pressure due to mixing) + (internal pressure due to saturated pressure), \ldots \ldots \ldots 4

Thus, saturated steam pressure due to heating at maximum temperature is \( P_i = 0.3116bar = 0.3116 \times 10^8 N/m^2 \)

\[
P_i = 2267.067 N/mm^2 + 3116 \times 10^4 N/mm^2 = 3116.228 \times 10^4 N/mm^2
\]

Assuming allowable tensile stress (\( \sigma_c \)) hollow steel shaft to be 40N/mm² (Hall, et al, 1982).

\[
\text{Cylinder Wall Thickness} = \frac{d}{2} = \frac{0.48}{2} \quad \ldots \quad 5
\]

\[= 0.952mm \]

The internal pressure in the reactor is \( 3116 \times 10^4 N/mm^2 \) as against the higher atmospheric pressure of about 1.0135bar, a choice of wall thickness of 0.925mm is ideal. However, a wall thickness of 1mm galvanized sheet was used in order to accommodate any unforeseen situation.

Mixing Power Design
The power requirement for mixing in the reactor was also considered. Since various quantities of the liquids maybe considered, the power requirement was designed for the highest volume of liquid allowable in the reactor. To avoid spilling the solutions through the inspection hole, maximum liquid volume should be 75% volume of the reactor design capacity.

\[
\text{Power} = \frac{100}{100} \times 6 = 961Watts \approx 1.0Kw
\]
Reactor Modification
Existing biodiesel batch reactors consist mainly of single arm level with two agitators. They are usually fixed at the lower end of the stirring shaft. Some batch reactors are equipped with vertical baffles. In this work, two different arm levels with a horizontal baffle tilted at 25° were used. The first arm level consists of two metal bars positioned at the lower end of the stirring shaft at 180° to each other. The rectangular shaped metal bars were tilted at an angle of 25° to the direction of rotation to enhance proper blending of the liquids. The second arms level was placed at a distance of 200mm (28.6% of the shaft length) above the first arms tilted at 25° to the direction of rotation also. The two agitators at the second level were attached to the shaft 180°, while both arms levels are perpendicular to each other for even stirring of fluid. The baffle was placed equidistance between the two stirring arms stages (100mm above the first arms level) as a chord within the cylinder.

These arms arrangements were meant to increase turbulence in the fluid motion and create more liquid surface to surface interactions for greater molecular separation and interface reaction (Farral, 1976). This on the other hand will lead to higher reaction activities of the alkoxide in the reactor leading to higher biodiesel yield. (Chilakpu, 2014).

CONCLUSION
The result of performance evaluation carried out on the modified reactor show that multiple stirring arms, increases the interface mobility of the alkoxide solution. Biodiesel yield of 98% was recorded after 60 minutes at a mixing speed of 300rpm. (Chilakpu, 2014).

The evaluation results (Details not available in this work) have shown that, the conversion of alkoxide in the reactor was enhanced by the use of multiple stages of agitators, thus leading to increased biodiesel yield at a lower mixing speed (300rpm) and energy requirement (1.0kw). This is against the reported yield of 95.55% (Ojolo, et al, 2011) at a speed of 500rpm

REFERENCES


