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Fuzzy logic application in process modeling of biodiesel reactor

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ABSTRACT

The transesterification reaction is actually replacement of alcohol group from an ester by another alcohol. The reaction was carried out by varying different parameters, like amount of catalyst in reaction, ratio of methyl alcohol to oil, temperature and stirring on the reaction; to find the best conversion of oil to biodiesel. In this paper fuzzy logic is applied to the transesterification reaction studies and the result is compared with the experimental results.

Introduction

The most common way to produce biodiesel is by transesterification, which refers to a catalyzed chemical reaction involving vegetable oil and an alcohol to yield fatty acid alkyl esters (i.e., biodiesel) and glycerol. Triglycerides, as the main component of vegetable oil, consist of three long chain fatty acids esterified to a glycerol backbone. When triglycerides react with an alcohol (e.g., methanol), the three fatty acid chains are released from the glycerol skeleton and combine with the alcohol to yield fatty acid alkyl esters (e.g., fatty acid methyl esters or biodiesel). Glycerol is produced as a by-product. Methanol is the most commonly used alcohol because of its low cost and is the alcohol of choice in the processes developed in this study. In general, a large excess of methanol is used to shift the equilibrium far to the right.

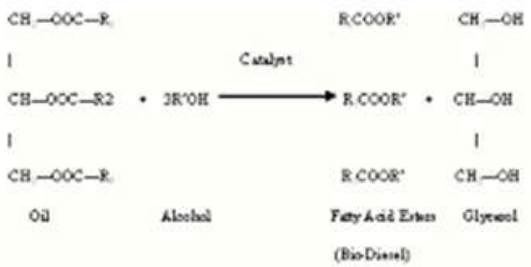

Fig. 1 Transesterification reaction

Methodology

Transesterification Experiment

Overall reaction involved in whole process:

Oil + 3 MeOH ⇌ 3 Biodiesel + Glycerol

Experimental Procedure

A known quantity of Jatropha oil is taken inside the reactor and heated at about 70 ºC. This temperature is maintained throughout the reaction by the thermostat inside the heat jacket. Preheating is used to remove unwanted moisture present in the oil. The trans-esterification is carried out in basic medium and to achieve it, KOH is used as a catalyst. Catalyst is dissolved in alcohol. Once the oil temperature reaches 70 ºC, alcohol solution (containing dissolved catalyst) is added to the reactor and an equilibrium temperature is maintained. During the reaction, alcohol gets vaporized.

To prevent any reactant loss condenser is used to condense the alcohol vapor and reflux it back into the reactor. Once the reaction is over the products are taken out through the outlet in the lower side of the reactor and put in the separating funnel.

Two phases (having different density) are formed as a result of trans-esterification. Separation is done using a separating funnel. Upper layer consists of bio-diesel, alcohol, and some soap (formed as a result of side reaction saponification - free fatty acids get converted to soap).

Lower layer consists of glycerin, excess alcohol, catalyst, impurities, and traces of unreacted oil. Purification of upper layer (to obtain bio-diesel) is done in two steps.

(i) Removal of alcohol - by keeping mixture at elevated temperature ~80 ºC.

(ii) Removal of saponified products - by washing with warm water. Water is immiscible with bio-diesel, hence can be easily separated from bio-diesel.

Experimental Set-Up

Reaction or trans-esterification is carried out in a reactor. Reactor consists of spherical flask, which is put inside the heat jacket. Oil is used is a medium of heat transfer from heat jacket to the reactor.

Thermostat is a part of heat jacket, which maintains the temperature of oil and in turn the temperature of the reactants at a desired value. The reaction is carried out at around 65-70 ºC. Spherical flask consists of three openings. The center one is used for putting stirrer in the reactor.

The motor propels the stirrer. Thermometer is put inside the second opening to continuously monitor the temperature of the reaction.

Condenser is put in the third opening to reflux the alcohol vapors back to the reactor to prevent any reactant loss.

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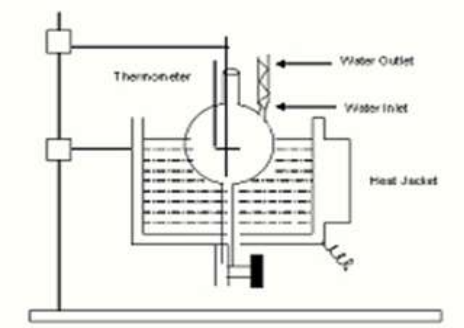


Fig. 2 Biodiesel Production Reactor

Result analysis

Following parameters have been studied:

* Variation of the amount of catalyst in reaction
* Effect of the ratio of the methyl alcohol to Jatropha oil.
* Effect of temperature on reaction
* Effect of stirring on reaction

Representative values of experimental observation:

Jatropha oil: 181 gm; Methanol: 78 gm; KOH: 1.0 gm; o
Time taken: 3.0 hrs; Temperature of Reaction: about 65 C ; Time for separation: 24 hrs

Effect of the Potassium hydroxide (KOH) concentration on transesterification

The variation of KOH was done with the range from 0.25 gm to 1.5 gm.

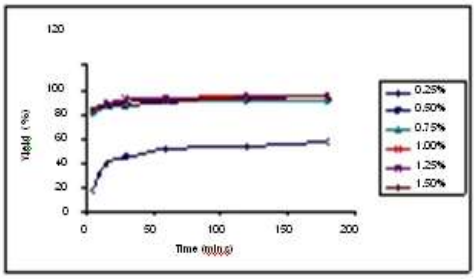


Fig. 4 Variation of Catalyst concentration

Effect of the amount of methanol on transesterification

The range of variation of alcohol was from 39 gm per 181 gm of oil to 156 gm.

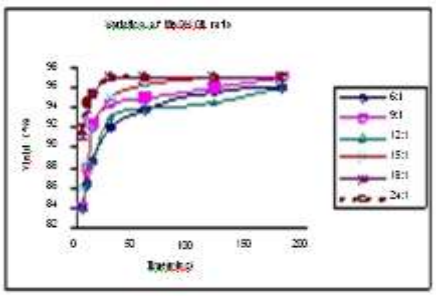


Fig. 5 Variation of MeOH : Oil ratio

Effect of Temperature on Trans-esterification

Temperature variation is considered from 37 deg'C to 65 deg'C. All other parameters were kept constant

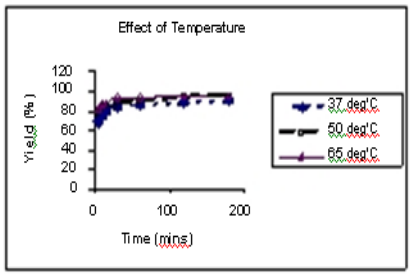


Fig. 6 Effect of Temperature

Effect of Stirring on Trans-esterification

Stirring variation is done from 180 rpm to 600 rpm. All other parameters are kept constant.

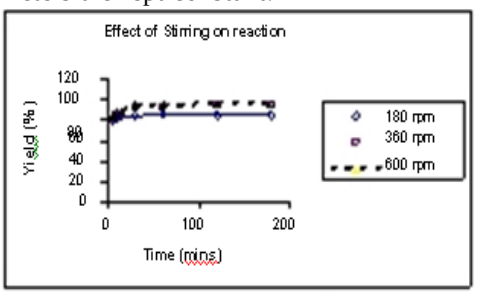


Fig. 7 Effect of Stirring

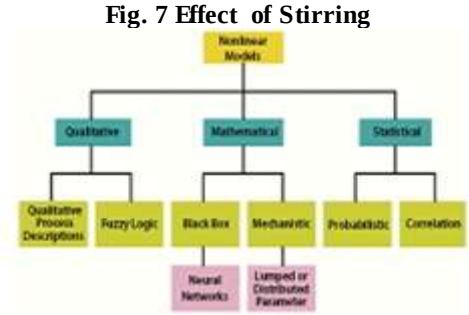


Fig. 8 Classification of nonlinear model forms used in bioreactor modelling

ODEs refer to lumped parameters and are used to describe behavior in one dimension (normally time), whereas PDEs refer to distributed parameters and account for spatial differences (e.g., substrate gradients in large bioreactors). A distributed parameter model can be considered as unstructured and segregated because, although it accounts for spatial differences within a bioreactor, it is still governed by the same unstructured model equations that describe what an entire subpopulation does in that particular area. Although distributed parameter models are more complex and more difficult to develop and solve, their significance is amplified in large bioreactors where, e.g., mixing kinetics and times may become critical to successful bioreactor operation.

Modern Software Tools: Although process modeling and simulation tools have been available for many years, the first such software products dedicated for bioprocessing showed up in the mid-1990s. Today, several commercially available programs, often using enhanced graphic features and ranging from dedicated packages to fully integrated suites, even include advanced NN and FL technologies (e.g.MATLAB). Many process simulation software packages also incorporate data mining and analysis features either to find underlying relevant relationships within culture data matrices (featuring both on- and off-line data from process variables) or to handle data sets that may be corrupted by noise or missing data points lt together.

Key process variables need to be identified, e.g., mixing, temperature, pH, dissolved oxygen (DO) and dissolved carbon dioxide (DCO 2). Their relationships with bioreactor performance (such as cell density and viability, product quality and yield, substrate feeding, and waste product accumulation) must be understood through comparisons with profiles from the large-scale process. Those relationships are then characterized as fully as possible and the operating ranges for their respective variables determined.

Since the number of process variables and data are often limited, neuro-fuzzy networks combine fuzzy logic and neural network technology allowing "expert rules" to be

added to data sets for improving overall model robustness. That can be very useful in bioreactor processes where controlled variables are often restricted to a limited range for design reasons (e.g., minimum or maximum achievable feed rates) or safety reasons (e.g., maximum allowable liquid volume height, vessel pressure, and so on). Capturing real-life experiences from skilled operators (expert knowledge) for a problem domain augmented with a fair dose of common sense can compensate for sparse and noisy data, often resulting in a faster learning phase.

The values obtained in the experiment were used for developing a model of biodiesel reactor using the advanced concept of Fuzzy logic. For this we have taken the experimental values of fraction of yield at different samples of time upto one hour.

Using these values we have obtained the fuzzy set time as input variable using triangular membership function. We have derived the rule base from the experimental values obtained in the production of biofuel.

The resultant FLC (Fuzzy Logic Controller) predicted the yield of biofuel with considerable accuracy.

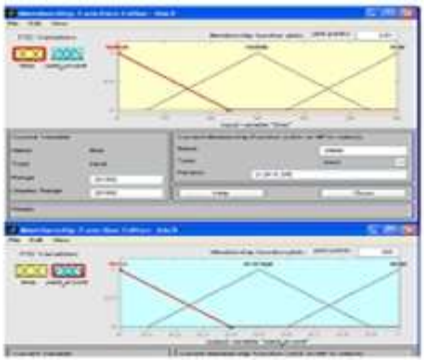
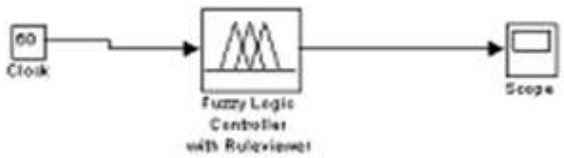


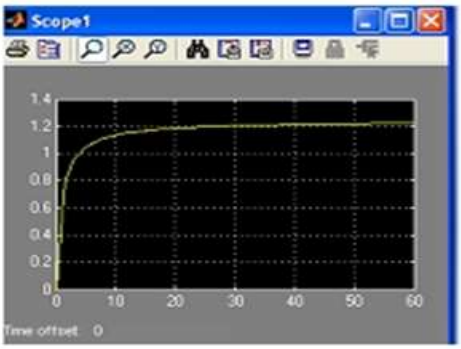
Fig. 9 Fuzzy input and output variable modeling

Table 1 Fuzzy Rule Base

Time	Yield percent
Initial	Average
middle	Large
final	Large

Fig. 10 FLC for Bio Reactor





Conclusions

Results in this study can be summarized as follows:

* The best time of reaction is 1 hr
* Optimum catalyst is 1.0 gm per 181 gm of oil.
* Optimum amount of methanol is 39 gm per 181 gm of oil.
* The prediction obtained using this FLC is accurate with reference to the experimental results.
* Optimum amount of methanol is 39 gm per 181 gm of oil.

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