Sustainable Materials and Technologies 12 (2017) 18–22

Contents lists available at ScienceDirect

Sustainable Materials and Technologies

journal homepage: www.elsevier.com/locate/susmat

A simplified model for evaluating best biodiesel production method: Fuzzy analytic hierarchy process approach

K. Anish Kumar [a], P. Senthil Kumar [a,*], Sai Madhusudanan [a], Vignesh Pasupathy [b], Peranamallur Rajan Vignesh [a], Ayyakudi Ravichandran Sankaranarayanan [a]

[a] Department of Chemical Engineering, SSN College of Engineering, Chennai 603110, Tamil Nadu, India
[b] Department of Computer Science, SSN College of Engineering, Chennai 603110, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 24 December 2016
Received in revised form 5 March 2017
Accepted 19 March 2017
Available online 24 March 2017

Keywords:
Biodiesel
Fuzzy AHP
Optimization
Buckley's method
Production methods

ABSTRACT

Biodiesel refers long chain alkyl esters that are derived from vegetable or animal based sources. There are various feasible production methods of biodiesel known to mankind. Selection of the most appropriate method of biodiesel production is important for both economic and environmental reasons. Optimization is achieved using Buckley's method to arrive at the best method for biodiesel production. The proposed method attempts to choose the best method of biodiesel production based on parameters –acid value, viscosity, glycerol separation, conversion, sulphur content, emission characteristics and cost. The production methods considered are-acid, alkali and enzymatic catalyst method, microwave and ultrasound assisted method, micro emulsion and supercritical method. The conventional analytic hierarchy process (AHP) method fails to accommodate vagueness in answers, in order to overcome the problem fuzzy AHP approach was used. The parameters conversion and cost dominated the parameter and based on these parameters, supercritical alcohol method proved to be the best fit.

1. Introduction

Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, animal fat tallow) with an alcohol producing fatty acid esters. Though biodiesel is the need of the hour, there is no denying the fact that biodiesel is still not so popular when compared to petroleum and diesel fuels. This is primarily due to the fact that production of biodiesel requires more energy than they can generate. A study conducted in the year 2005 found that the producing ethanol from corn grain required 29% more energy, from switch grass required 50% and from biomass required 57% more energy than the end product [1]. Currently there is just no energy benefit to using biomass for liquid fuel. There are various methods known for production of biodiesel from feedstock. Each of these methods has their own advantages and shortcomings.

Accordingly selecting a desirable method of biodiesel production is vital for the success of biodiesel projects. In such a decision making process, permutation and combination of various processes using the process parameters is highly inefficient and time consuming. This is where optimization comes in. General methods of optimization takes in custom generated parameters and survey results, compares them with process parameters and runs an algorithm where the final result is most desirable method in most cases.

The analytic hierarchy process (AHP) is an effective method used for multi-criteria decision-making [2]. It uses pair-wise comparison of all the criteria on a scale ranging from 1 to 9. But one of the major drawbacks of the AHP is its incapability to handle the ambiguity associated with the mapping of one's perception to an exact number. To solve this issue, Buckley developed the fuzzy AHP model, which incorporates fuzzy numbers in the place of real numbers. Fuzzy AHP is a systematic method of multi-criteria decision making, which uses concepts of fuzzy set theory. The decision maker ranks a criterion in comparison to another criterion in the form of linguistic terms such as 'Very Unimportant', 'Less Important', 'Equally Important', 'More important' and 'Very important' [3]. Numerous literature reviews were conducted regarding use of Multi Criteria Decision Making (MCDM) in biodiesel production. Most of the studies performed were about optimal blending of biodiesel [4] and the earlier ones were based on AHP approach [5], which is inherently incapable of handling ambiguity. Each linguistic term is assigned a triangular fuzzy number, which is used for the calculation of weights.

In the proposed model, a symmetric triangle approach is used for the sake of simplicity and ease of computation. In Buckley's method [6], the element of negative judgment is treated as the inverse of the corresponding judgment. Since it requires complex calculations, each negative judgment is assigned a characteristic fuzzy number as done in Table 1.Thus a simplified form of Buckley's method as illustrated by an inspiring work by Nang-Fei Pan [7] is used. The author has further simplified Nang-Fei Pan's method by using a symmetrical triangle

* Corresponding author.
E-mail address: senthilkumarp@ssn.edu.in (P. Senthil Kumar).

http://dx.doi.org/10.1016/j.susmat.2017.03.002
2214-9937/

Table 1
Fuzzy number to linguistic value mapping.

Linguistic term	Explanation	Fuzzy number
Very unimportant (VU)	Former is least important	(0,1,2)
Less important (LI)	Former is less important	(1,2,3)
Equally important (EI)	Both are equally important	(2,3,4)
More important (MI)	Former is more important	(3,4,5)
Very important (VI)	Former is most important	(4,5,6)

membership function instead of the trapezoidal system and by omitting the α-cut method. Furthermore a different approach to calculating the final overall weight of each method has been discussed.

2. Methods

2.1. Biodiesel production methods

The different biodiesel production methods used industrially were referred Singh and Singh [8] and Marchetti et al., [9]. The different methods of biodiesel production considered in this research are alkali catalyst, acid catalyst, enzymatic catalyst, microwave assisted, ultrasonic assisted, micro emulsion and supercritical process. A common problem in the field of biodiesel research is that each researcher works separately on one particular production method and hence causes biodiesel production to be somewhat disorganized and causes difficulty in unifying the methods. The current research work tries to create a comparison between different methods of biodiesel production and express numerically the importance of each parameter and method.

2.2. Proposed method

The parameters that are needed to be considered are arrived at by Delphi approach [10]. Finally the parameters that need to be considered are acid value, viscosity, glycerol separation, conversion, sulphur content, emission characteristics and cost.

2.3. Model

The hierarchy is formed such that the upper level is the overall goal, the intermediate level as the parameters and the bottom most level as production methods (Fig. 1). With the hierarchy and the linguistic variables, a questionnaire was created and opinions of 7 candidates were taken and used for calculation of the weights. The questionnaire compared the parameters with each other separately, and then compared production methods with each other based on the parameters. With the data from questionnaire a fuzzy comparison matrix was formed. The linguistic terms were mapped to its corresponding fuzzy number using a modified Chen's definition [11–12]. Since Chen's method is tedious because of the use of negative inverse elements, the proposed method uses a simplified triangle approach as illustrated by Fig. 2.

Accordingly a fuzzy comparison matrix was constructed,

$$A = \begin{bmatrix} 1 & (x_{12L}x_{12M}x_{12U}) & \cdots & (x_{1nL}x_{1nM}x_{1nU}) \\ (x_{21L}x_{21M}x_{21U}) & 1 & \cdots & \vdots \\ \vdots & & \cdots & \cdots \quad \vdots \\ (x_{n1L}x_{n1M}x_{n1U}) & \cdots & \cdots & 1 \end{bmatrix} \tag{1}$$

where, x_{ij} is the fuzzy number mapped to the particular linguistic term.

The fuzzy comparison matrix was further divided to 3 matrices, lower bound (A_L), most-likely (A_M) and upper bound (A_U).

For example lower bound matrix is given by,

$$A = \begin{bmatrix} 1 & \cdots & x_{1nL} \\ \vdots & \ddots & \vdots \\ x_{n1L} & \cdots & 1 \end{bmatrix} \tag{2}$$

The normalized geometric mean method as defined by Buckley's method is used to calculate local weight given by,

$$w_i = \frac{g_i}{\sum_{i=1}^{n} g_i} \tag{3}$$

$$g_i = \left(\prod_{j=1}^{n} r_{ij} \right)^{\frac{1}{n}} \tag{4}$$

where g_i is the geometric mean of the criterion i and r_{ij} is the value of the fuzzy number obtained when criterion i is compared with criterion j.

In order to compile all the opinions into one, the opinions are aggregated and are then defuzzified. In Buckley's method, fuzzy operations are performed to arrive at fuzzy weights of each criterion. Since fuzzy operations are complex and time consuming, the max-min operation and Centre-of-gravity (COG) method is used for defuzzification.

The fuzzy maximum-minimum [13] operator is given by,

$$\mu_A(x) = \max[\min\{\mu_1(x), \mu_2(x), \cdots \mu_n(x)\}] \tag{5}$$

where $\mu_A(x)$ $\mu_A(x)$ is the membership value of x in the aggregated subset A and $\mu_1(x)$, $\mu_2(x)$ … $\mu_n(x)$ $\mu_1(x), \mu_2(x) \cdots \mu_n(x)$ are the membership values corresponding to the 1st, 2nd…n^{th} opinion respectively.

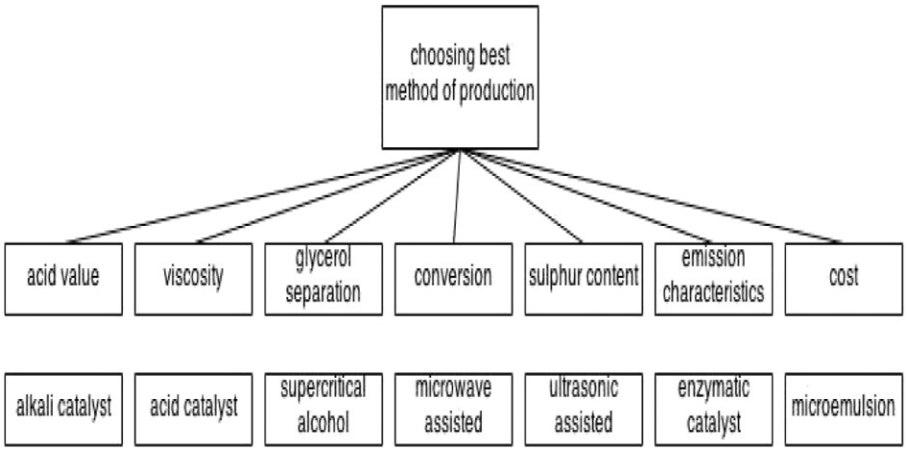

Fig. 1. Hierarchy of production methods.