Prediction for Biodiesel Quality using the Dielectric Properties

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Abstract. Measurement of the quality of biodiesel during the purification process is necessary to ensure biodiesel meets the required standards. Water and glycerol concentrate critical parameters of the quality of the final product of biodiesel. The impurities of biodiesel (water and glycerol) have a strong correlation with dielectric properties due to polarity changes. Measurement of electrical properties produces 14 dielectric parameters namely impedance (Z), Modulus Young (Y), Phase, Capacitation series (Cs), Parallel capacitance (Cp), Displacement (D), Series Inductance (Ls), Parallel Inductance (Lp), Electric charge (Q), Series Resistance (Rs), Conductance (G), Parallel Resistance (Rp), electric susceptibility (X) and induction field (B). Parameters selection are needed for the efficiency of determining the quality of biodiesel. The research objective is to predict the quality of biodiesel during the purification process using the selected dielectric parameter analysis. The process of selecting parameters uses feature selection (Relief) and quality classification using Support Vector Machine (SVM). The selection results show the parameters related to the purity of biodiesel are parallel capacitance (Cp), series resistance (Rs), and impedance (Z) and parallel inductance (Lp) at weights greater than 0.05. Based on the test, the AUC (Area under ROC) value is 0.87, the accuracy is 0.94 for the quality that meets (YES) and that does not meet (NO) biodiesel quality requirements.

1. Introduction
Methyl ester from the transesterification process called crude biodiesel containing impurities can cause problems in use and storage, so the process of refining biodiesel is a critical technology that must be applied. In general, the purification of biodiesel to remove impurities using two methods, namely wet and dry washing. Researchers generally use water washing, filtration with membranes, adsorbents and ion exchange resins to remove impurities such as soap and glycerin [1]. Wet washing techniques are very effective in removing impurities such as glycerin, methanol, salt and soap because they are soluble in water. Wet washing technique by adding some water to crude biodiesel and slowly agitating to prevent emulsion formation [2]. The most effective technique for removing glycerol and methanol from crude biodiesel is a wet washing method because glycerol and methanol are very soluble in water. Wet washing methods are widely used to remove excess and residual chemical contaminants from biodiesel production, but this method has weaknesses, including the high consumption of water that becomes waste and increased production time.

Dielectric measurements to identify the physical properties of biodiesel because dielectric properties have a correlation to the physical and chemical properties of biodiesel. Dielectric properties describe the interaction between matter and electromagnetic waves. Although the properties of oils and fats used as raw materials are different, the properties of biodiesel which indicate the quality of biodiesel must be the same and in accordance with the requirements set by international standards[3]. Previously Rahmawati, et al. [4]had implemented an identification for biodiesel fatty acid using a dielectric sensor.
Dielectric properties have a strong correlation between general properties and chemical biodiesel such as pH value, water content and glycerol which are critical parameters of the quality of the final biodiesel product. According to Romano and Sorichetti [5], removal of contaminants in oil after refining is reflected in a reduction in dielectric values and permittivity, because the impurity concentration decreases instead of the value of electrical conductivity increases. The properties of the dielectric material can be used as a measurement technique for the development of a prediction model for biodiesel purity. This study focuses on the dielectric properties of biodiesel and their use in characterizing the water and glycerol content in biodiesel.

Determination of refining conditions is very necessary for biodiesel products in order to improve energy efficiency and production costs. At present, the method of measuring the quality of the purification process is laboratory sampling and testing, which requires high costs and a relatively long time. Fast and inexpensive testing is needed to be able to sense biodiesel quality in a real-time when production takes place. Electrical properties measurement techniques using dielectric sensors have many variables and correlate to the physical and chemical properties of the material. Selection of dielectric measurement parameters that correlate with the purity level of biodiesel using weighting through feature selection using the Relief method. The purpose of this paper is to develop a biodiesel purification condition identification system using a dielectric sensor.

2. Materials and methods

2.1. Materials

The material used is biodiesel from used cooking oil, water and glycerol. The content of water and glycerol in biodiesel is the percentage of water v / v 0.02%, 0.04%, 0.05%, 0.06%, 0.10%, 0.15%, 0.20%, 0.5 % and percentage of m / m glycerol 0.20%, 0.22%, 0.24%, 0.26%, 0.28%, 0.30%, 0.50%, 1%. The quality of biodiesel according to ASTM requirements has a water content of 5 0.005% V / V, glycerol levels ≤ 0.24% m / m.

2.2. Measurement of dielectric values

The research procedure begins with the identification of impurities in a 2L volume biodiesel tube at room temperature. Each sample was measured using two copper electrodes coated with gold. Dielectric value measurement using LCR meter consists of 14 parameters (Z, Y, P, Cs, Cp, Ls, Lp, Q, Rs, Rp, G, X, B). Dielectric measurements are carried out by combining water and glycerol impurities in biodiesel. Dielectric parameter measurements using 3-step calibration are testing biodiesel, glycerol and water. Measurements are carried out at a frequency of 50 Hz - 5 MHz.

Dielectric measurements have multiple advantages when compared with other measurement methods. As a simple, rapid and non-destructive measuring technique for the determination of the properties of materials, dielectric measurements are non-hazardous and due to the use of low power levels [6].

The properties of electricity from the purification process are measured using LCR meter. In general, liquids are distinguished based on the dipole moment which is polar which has a relatively high permittivity and non-polar which has relatively low permittivity[7]. In the dielectric characterization of materials, the simplest measurements are capacitance and resistance then converted to dielectric constants and electrical resistance or conductivity. The capacitance C (farads) of a parallel plate capacitor of area A (m2), the separation between the plates separated by empty space (or air) is:

\[
C = \frac{\varepsilon_0 A}{t}
\]

where is the permittivity of free space (8.85 x 10-12 F/m, where F is farads), t is the separation between the plates (meter). If the empty space is replaced by a dielectric, capacitance increases. The dielectric constant \(\varepsilon\) is a physical measure of the electric polarizability of a material. The dielectric constant can be calculated using:
where \( C_s \) is the capacitance with the specimen as the dielectric, and \( C_v \) is the capacitance with a vacuum as the dielectric. Experimentally it was found that capacitance \( C \) increases when the space between the conductors is filled with dielectrics. To see how this happens, suppose a capacitor has a capacitance \( C_v \) when there is no material between the plates. When a dielectric material is inserted to completely fill the space between the plates, the capacitance increases to:

\[
C = K_\varepsilon C_0
\]

where \( K_\varepsilon \) is called the dielectric constant.

### 2.3. Relief features selection

Feature Selection has been used in many applications because it is effective in reducing the influence of irrelevant data, eliminating excessive data, reducing dimensions, improving learning accuracy, and increasing comprehensive results [8]. Selection of attributes of biodiesel dielectric measurements during the purification process using the Relief algorithm based on available data [9]. This is to select several dielectric sensor parameters that have a strong correlation with the quality of biodiesel. The measurement class is the impurity received and which is not received. Data analysis to select a feature that has an impact (hit) and ignore features that have no effect (missed) uses the weighting technique (weight) to produce a ranking list by examining the nearest example of the same and different classes.

\[
W_i = W_i - \text{diff} \left( x_{i, \text{near-hit}_i} \right)^2 + \text{diff} \left( x_{i, \text{near-miss}_i} \right)^2
\]

where:
- \( W_i \): attribute weight
- \( \text{Near-miss} \): estimated difference with \( x_i \)
- \( \text{Near-hit} \): an approximate equation with \( x_i \)
- \( x_i \): attribute

### 2.4. Support Vector Machine (SVM)

A Support Vector Machine (SVM) is a discriminative classifier formally defined by a separating hyperplane. In other words, given labeled training data (supervised learning), the algorithm outputs an optimal hyperplane which categorizes new examples. The concept of SVM is to find the best hyperplane that serves as a separator of two data classes by measuring their margins and maximum points. The margin is the distance between the hyperplane and the closest pattern of each class. The closest pattern is called support vector [10]. SVM maximizes margin which is the distance between data classes, using kernel tricks to work on high-dimensional datasets. We use classification SVM Type 1 also known as C-SVM classification. For this type of SVM, training involves the minimization of the error function. A form of the equation defining the decision surface separating the classes is a hyperplane of the form:

\[
w^T x + b = 0
\]

\[
w^T x + b \geq 0 \text{ for } d_i = 1 \text{; } w^T x + b < 0 \text{ for } d_i = -1
\]

The class \( y \) is determined as follows:

\[
y_i = \begin{cases} 
-1 & \text{if } w^T x_i + b \leq -1 \\
1 & \text{if } w^T x_i + b \geq 1 
\end{cases}
\]

Note:

\( w \) is a weight vector
x is input vector  
b is bias  
w^T is the transpose of w  
d is the margin (gutter) of a separating hyperplane  
y is the output of the SVM

The margin of Separation (d) is the separation between the hyperplane and the closest data point for a given weight vector w and bias b. Optimal Hyperplane (maximal margin) is the particular hyperplane for which the margin of separation d is maximized.

3. Results and discussion

3.1. Purification biodiesel

The wet washing applied is first using water and 3% phosphoric acid, then with deionized water and using mixing. The water used is 60 ºC and the water-biodiesel ratio is 0.5 (v / v). Repetition of the washing process until the pH of the remaining washing water is neutral [7]. After the washing process is complete, continue at the drying process stage to meet the requirements of the minimum amount of residual water in biodiesel. The impurities have a heavier phase and are at the bottom, while the light phase biodiesel is supplied to the drying tank. Characteristics of purification results are known by analyzing parallel capacitance (Cp), series resistance (Rs), impedance (Z) and parallel inductance (Lp). Of the four attributes with experimental data carried out in the purification process grouped based on quality standards accepted and not accepted. Processing data using Python Orange as was done on the prediction of quality of glycerol monolete[11].

3.2. Dielectric feature selection of biodiesel quality

The properties of a dielectric are the ability of a material to store, transmit and reflect electromagnetic wave energy. Feature selection is an effective way to reduce data and become a necessary step for successful data mining applications [12]. The feature selection method with the Relief algorithm uses the appropriate impurity content measurement class (YES) and that is not according to the requirements (NO). The ranking is done to ensure that the parameters are most strongly related to the quality of biodiesel. This is adjusted to the need for a sensor design formulation that only measures the selected parameters. Relief ranks several features based on weight to differentiate between near and far classes, namely the correlation between dielectric parameters and biodiesel quality targets. Feature selection method using Orange Software in Figure 1.

![Figure 1. Feature selection at Orange software](image)

The file uses 14 sample data and 14 attributes. Select data uses data files to generate matching and unmatched data to rank. Input rank of select data, the output is reduced data. Dielectric parameter correlation with biodiesel quality uses feature selection (Relief) in Table 1. In the approach using weight values above 0.05, the selected attributes are parallel capacitance (Cp), series resistance (Rs), impedance (Z) and parallel inductance (Lp).
Table 1. The weight and results of the ranking of biodiesel quality dielectric parameters

| Attribute | Weight | Ranking |
|-----------|--------|---------|
| Cp        | 0.106  | 1       |
| Rs        | 0.060  | 2       |
| Z         | 0.053  | 3       |
| Lp        | 0.052  | 4       |
| Phase     | 0.038  | 5       |
| Y         | 0.025  | 6       |
| D         | 0.016  | 7       |
| Cs        | 0.012  | 8       |
| B         | 0.002  | 9       |
| Ls        | -0.004 | 10      |
| G         | -0.006 | 11      |
| X         | -0.024 | 12      |
| Rp        | -0.032 | 13      |
| Q         | -0.032 | 14      |

The factor that is affected by the change in frequency is capacitive reactance. Its capacitive impedance which decreases, when the frequency is increased. Capacitive Reactance has the electrical symbol “X<sub>c</sub>” and has units measured in Ohms the same as resistance (R). The following equation describes the relationship between frequency and capacitive impedance.

\[
X_c = \frac{1}{2\pi fC}
\]  

Where:
- \(X_c\) = Capacitive Reactance in Ohms, (\(\Omega\))
- \(\pi\) (pi) = 3.142
- \(f\) = Frequency in Hertz, (Hz)
- \(C\) = Capacitance in Farads, (F)

Capacitance is the ability of a capacitor to store energy in an electric field. From the measurement results show the capacitance decreases at a higher frequency and the capacitance increases with increasing amount of biodiesel impurities. Biodiesel after the washing step reflects its lower polarity compared to methanol, both with respect to the permittivity value at room temperature, permittivity in all temperature ranges is higher in biodiesel that is not washed than biodiesel after washing [13]. Air and glycerol are more polar than biodiesel, biodiesel capacitance is smaller in the number of pollutants that is more in accordance with the previous research levels of biscuit capacitance with more air content, more with biscuits that have more air content [9]. This is consistent with Nelson and Trabelsi [14] which states that with the frequency ratio will decrease the value of capacitance and Sosa-Morales, et al. [15] states that an increase in air content will increase the dielectric value of the material. Capacitance is a dielectric parameter that correlates with the impurity content in biodiesel. Among the things that affect variations in capacitance values are temperature and frequency, the chemical and physical characteristics depending on composition and density[16]. The measurement results obtained (Figure 2) show that the increasing frequency, biodiesel capacitance decreases.
3.3. Prediction of biodiesel quality

Data processing with the SVM method on Orange Software uses stages of processing according to [17]. Data processing scheme in Figure 3. This model determines the quality of biodiesel products in the purification process.

The file contains 25 samples with 4 attributes \( C_p, R_s, Z \) and \( L_p \) and 2 targets namely the quality of biodiesel meets the requirements (YES) and does not meet the requirements (NO). Support vector machine (SVM) in machine learning is a supervised classification method. SVM processes input data and pre-process produces classifiers and support vectors. SVM only uses a number of selected contributing data points (Support Vector) to form the model used in the classification process [18]. The quality of biodiesel in the purification process is not linear, so the SVM is modified by entering the Kernel Sigmoid \( C: 0.8 \), function with the values of \( g: 0 \) and \( c: 0 \). The sigmoid Kernels:

\[
K(x, x_i) = \tanh \left( (x, x_i) + 1 \right)
\]

Then the new function to classify the data are [19]:

\[
f(x) = \text{sign} \left( \sum_{i=1}^{N} y_i a_i . K(x, x_i) + b \right)
\]
Predictions to predict the quality of biodiesel and grouped on a scatterplot display (Figure 4).

![Figure 4](image)

**Figure 4.** Grouping the quality of biodiesel

ROC (Receiver Operating Characteristic) analysis to evaluate the results of data and test SVM predictions. The test described in a curve with a vertical axis is the true level of positive (sensitivity), meaning that a class that is entered into a positive class and the results are correct. Horizontal axis label is the level of false positive (1 - sensitivity), meaning that the data class predicted to enter the positive class and the results are wrong. To determine a good classification presented with the method of calculating the area of the AUC area (Area Under the Curve).

Evaluation of biodiesel quality prediction classification performance based on dielectric parameters using the SVM method in Table 2. The proportion of training data and testing data of 60:40 resulted in classification accuracy in each high-value positive and negative class. Test data shows that the model built has a good accuracy of 94%. Test data from 25 samples contained 1 error, namely the quality of biodiesel (\( Z = 5,251,200 \) ohms, \( C_p = 94 \) pF, \( R_s = 4.9 \) Mohm, \( L_p = 15 \) kHenry) predicted the classification of YES in fact the quality is the classification of NO.

| Parameters                  | NO     | YES    |
|-----------------------------|--------|--------|
| Classification Accuracy     | 0.94   | 0.94   |
| Sensitivity                 | 0.99   | 0.83   |
| Specificity                 | 0.83   | 0.99   |
| Area under ROC (AUC)        | 0.87   | 0.87   |
| Precision                   | 0.93   | 0.96   |
| Recall                      | 0.99   | 0.83   |
| Brier                       | 0.15   | 0.15   |

The ROC plot illustrates the accuracy of discrimination from a classification test to determine whether biodiesel quality is eligible or does not meet the requirements. The accuracy of the test is explained in the area under the ROC curve (AUC). The AUC value ranges from 50% - 100%, the greater the AUC value the better the classification. The acquisition of the AUC value of 87% indicates that the biodiesel quality classification using the SVM method can be done well and get high accuracy values.
4. Conclusions
Dielectric parameters selected as biodiesel quality determinants that have weights above 0.05 are parallel capacitance (Cp), Series Resistance (Rs), Impedance (Z) and parallel Inductance (Lp).

The classification results on biodiesel quality test data showed a predictive accuracy of 94% and supported by 87% AUC value. High accuracy values indicate that the SVM model that is formed can predict well. This method can be used to determine the quality of biodiesel during the purification process when using dielectric sensors and data acquisition processing.

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9

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