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# Determination of better insulating oil for power transformer oil application using Analytical Hierarchy Process (AHP)

**Yanuar Z. Arief[1,2]*, Nazirah Abd Hamid[1], Mohd Hafiez Izzwan Saad[1], and Rosyid Ridlo Al Hakim[2,3]**
[1]*Department of Electrical & Electronic Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Malaysia, 94300
[2]Department of Electrical Engineering, Faculty of Engineering and Computer Science, Jakarta Global University, Indonesia
[3]*Dewan Energi Mahasiswa* (Student Energy Council) Banyumas, Indonesia, 53115

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**ABSTRACT**

The Analytical Hierarchy Process (AHP) which was developed by Saaty is a decision-making tool in the year of 1970s. The system is able to solve the complex analysis which could not be performed by the human brain. In this project, the AHP system is chosen to select a better insulating oil for power transformer oil application since the insulation is the most important part of a transformer. In this research method based on the AHP technique, there are six criteria are involved in the model, namely breakdown voltage, dissipation factor/tan delta, pour point, kinematic viscosity, density, and flash point. While, the given alternatives are palm oil, canola oil, palm fatty acid ester (PFAE) oil, corn oil, sunflower oil, and soybean oil, respectively. A spreadsheet software application (Microsoft Excel) was employed in this study. As the result, it is found that the PFAE oil is the best insulating oil that able to be used in a real power transformer oil application. All requirements as insulating oil for transformer oil of PFAE oil are met significantly.

***Corresponding Author:***

Dr. Yanuar Z. Arief
Department of Electrical & Electronic Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, Malaysia, 94300

Department of Electrical Engineering, Faculty of Engineering and Computer Science, Jakarta Global University, Indonesia

Email: ayzulardiansyah@unimas.my, yanuar@jgu.ac.id

## 1. INTRODUCTION

The development of a smart city is becoming an area of focus in Malaysia; hence, the electric power system should move towards greener technology and the improvement of energy efficiency and effectiveness. Lately, natural ester liquid such as vegetable oil has been discovered to be a good alternative for transformer insulating oil after considering some factors. These types of oil are also known as biodegradable insulating oil which contains non-toxicity and is a sustainable source of future [1]. Generally, the transformer functions as a converting tool between 2 levels of alternating current (AC) voltage and is typically known as the backbone of an electrical transmission system [2].

In the engineering field, the efficiency and effectiveness of the product become the most concerning part that needs to be calculated in an analysis. However, in order to choose the most efficient product involves many complex analyses and data. In the case of insulating oil of transformer, there are several types of insulating oil in the industry. Thus, many criteria or properties need to be considered when choosing the best insulating oil. Thereby, the presentation of the Analytic Hierarchy Process (AHP) as a potential tool in decision-making is designed through the application of this technique in selecting the best product.


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Normally, for selecting the best result, the design needs to have more than one alternative which has its pros and cons. The main goal can be achieved in a large majority of the cases. This means the selection of the goal comes from the number of possible options with the highest priority.

The implementation of the design products for the designers and the managers needs to make correct decisions during design. Various stages need to be considered in product development. Therefore, the selection of the best out of this solution itself may formulate another problem. Hence, the AHP which is firstly introduced by Saaty of the Wharton School of Business, USA. The potential of the system used for decision-making in managerial problems has been proved by him [3]. This multiple criterion decision-making tool is arranged in a hierarchical structure. The powerful weighted scoring process is analyzed to help the priorities arrangement and thereby put the best decision at the top.

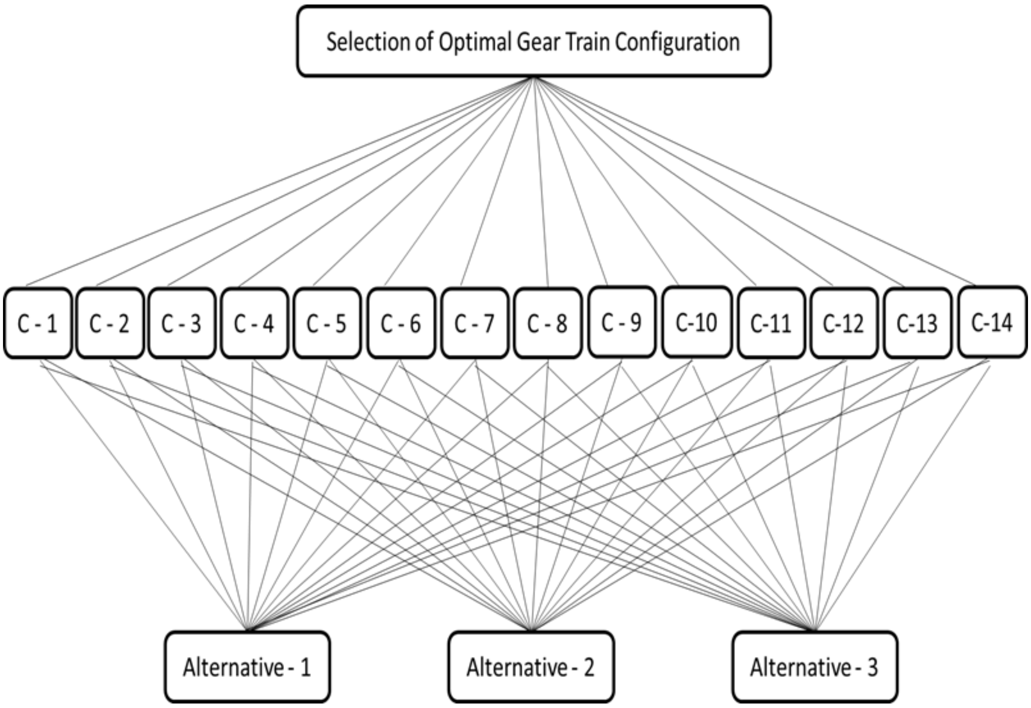


Figure 1. The example of the hierarchy structure of AHP [4].

The AHP consists of 3 (three) main processes, firstly is structuring the complex decision problem in a hierarchy structure. At the top is the goal, criteria are in the middle, and alternatives are located at the bottom. Secondly is the pair-wise comparison matrix of the elements of each level of the hierarchy concerning each criterion on the preceding level. Lastly is vertically synthesizing the judgments over the different levels of the hierarchy [5].

To select a better insulating oil for the transformer, there are so many criteria that need to be considered for the selection. This is very confusing for the human brain to decide. The human brain has limitations in performing complex analyses and collecting and saving data. Hence, the Analytic Hierarchy Process (AHP) is chosen as a decision-making tool to help the decision maker decide the best insulating oil from the given alternatives.

The objectives of this work are:

1) To determine the best insulating oil which depends on some of the electrical and physical properties.
2) To design the framework of the AHP system.
3) To develop and analyze the AHP system by using Microsoft Excel.

## 2. INSULATING OIL FOR POWER TRANSFORMER

A transformer is the most important equipment in the transmission and distribution system. The transformer is able to change the voltage level of the transmission line to reduce the losses during the supply of the power from the generator to the load. Therefore, every component in the transformer should be chosen from the best materials based on its function to the transformer. One of the important components in a transformer is the insulating oil, which is commonly known as the backbone of insulation systems in the transformer. Generally, insulating oil has three important functions for the transformer to work efficiently. The functions are to insulate the active part of the transformer, as a cooling system by transferring the heat from conductors to the radiators, and lastly to give diagnostic support to evaluate the health of the transformer through regular inspection [2].

The current electrical industry has used several types of insulating oils which commonly come from types of mineral oil. Paraffinic oil and Naphthenic oil are two examples of mineral oil which is commonly used as transformer oil. The low amount of n-paraffin in naphthenic oil has made it more soluble and able to create a good cooling system for the transformer. Inversely paraffinic oil contains a high amount of n-paraffin. Even though the paraffinic oil has a lower oxidation rate compared to the naphthenic, the oxidation product or sludge is insoluble and expedited at the bottommost of the tank and blocks the transformer cooling system [6].

There are 6 properties of transformer insulating oil covered in this chapter. The properties are breakdown voltage, dissipation factor, flash point, pour point, kinematic viscosity, and density. The breakdown voltage and dissipation factor are part of electrical properties while the 4 properties left are part of the physical properties.

### 2.1. Breakdown Voltage

The breakdown voltage standard can be referred to as the IEC 60156, which can be measured by using the Breakdown Voltage Kit [7]. Hence, the term breakdown voltage can be defined as the maximum voltage required for the arc to occur. The dielectric strength of transformer oil is another term used for breakdown voltage. An insulating oil is required to have a high value of breakdown voltage to withstand an electric field between the conductors [8]. The increase of breakdown voltage value results from a good property of insulating oil. However, the presence of additional moisture in oil may decrease the breakdown voltage value. Figure 2 shows three types of insulating oils that have lower breakdown voltage when a high percentage of moisture is added into the oil if compared to the low level of moisture that has high breakdown voltage [9].

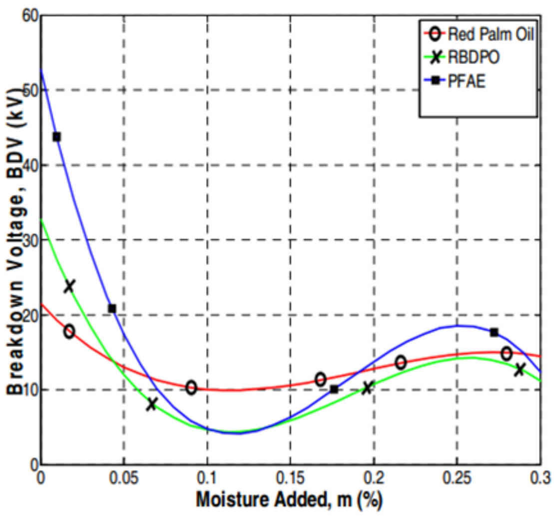


Figure 2. Breakdown voltage vs moisture increase in palm-based insulation oil curve [9].

Meanwhile, the limit of rated breakdown voltage is 40 kV for a 2 mm test gap. This can be measured by using the method according to the ASTMD877 or ASTMD1816 [10].

### 2.2. Dissipation Factor

The dissipation factor is to indicate the level of quality of the insulating oil. Generally, the variation of moisture and temperature changes will certainly affect the dissipation factor of insulating oil in a transformer. The value of the dissipation factor can be determined by measuring the capacitances and tan δ between the transformer windings and the earthing and also between the different windings of a transformer. The tan δ shows the quality of insulation and also the power losses due to the aging of insulating oil. Figure 3 shows the dielectric dissipation factor (DDF) is increased as the surrounding becomes dry [11].

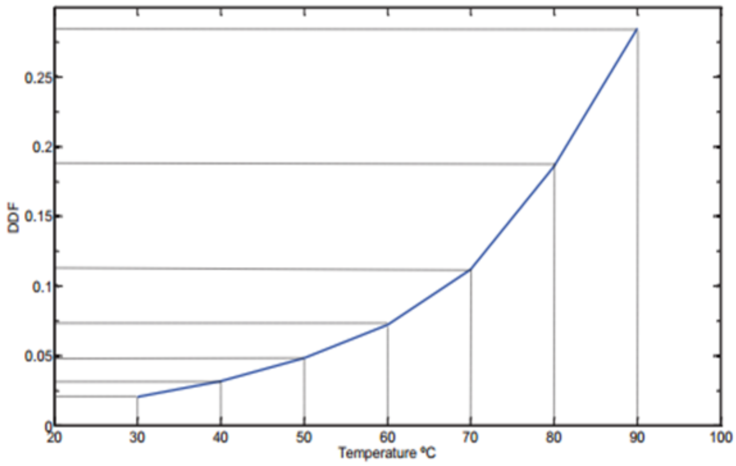


Figure 3. The dielectric dissipation factor vs the amount of moisture depends on temperature [11].

The standard value of the dissipation factor is equal to 0.1% at the temperature of 90ºC [12]. However, based on the standard of IEC 247, the dissipation factor should be 0.0005 at the temperature of 90°C [13], [14]. A lower value for the dissipation factor is better in terms of the quality of the insulating oil.

### 2.3. Flash Point

Flash point is defined as the minimum temperature at which enough vapor pressure is able to form an ignitable mixture with air near the surface of the liquid. According to IEEE standards, the flash point should be above 275ºC [2]. However, the increase in temperature is resulting from a lower viscosity of the oil. Thus, the temperature of the flash point cannot be too high above the standard requirement to prevent too much lower viscosity in oil [15]. Good insulating oil should have low viscosity and high flash points. But still, the value cannot be too much from the rating standard [16].

### 2.4. Pour Point

Based on the standard of IEEE and ASTM, the maximum temperature of the pour point is -10ºC for the insulating oil to be accepted. The pour point is defined as the level of the fluid that does not flow at a certain temperature level. Hence, the insulating oil should have been poured point which is below the freezing point [2].

### 2.5. Kinematic Viscosity

In general, kinematic viscosity is defined as the internal resistance of the fluid to flow. Hence, it is a very important property to interpret the flow of oil [17]. Based on the standard value of kinematic viscosity, when the temperature is at 40°C the value of viscosity should be 13 $mm^2s^{-1}$ [12]. The high value of kinematic viscosity is unacceptable since the temperature is too low. From Figure 4, as the temperature increase, the kinematic viscosity is getting lower which is simultaneous with the property of insulating oil [18].

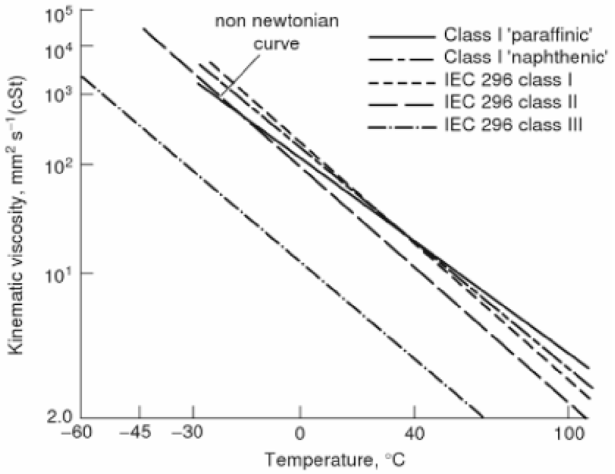


Figure 4. The variation of kinematic viscosity to the temperature for IEC standard [18].

**2.6. Density**

The density means the ratio between the weight of an equal volume of insulating oil to the weight of water at 20ºC. The standard value of density is maxed at 1 g/ml. At a lower temperature or 0° temperature, the ice tends to float above the insulating oil if the density is above 0.917. Hence, a lower density is needed to prevent that situation happen. The standard of IEC and ASTM suggests that the density value is between the range of 0.875 – 0.88 g/cm³ at the temperature of 15°C [2].

**3. ANALYTICAL HIERARCHY PROCESS (AHP)**

AHP is a decision-making tool that developed a hierarchy structure. Consist of three levels, the goal is at the top and criteria are in the middle, and at the bottom are the alternatives for the goal. The application of AHP is widely used in many areas such as government, industry, medical, and health. The rationale of AHP is developed by three principles which are the principle of preparing the hierarchy, the principle of setting the priorities, and lastly the principle of logical consistency [19].

The AHP is defined as the multi-criteria decision-making (MCDM) method which is used to select one alternative as the goal based on the difference of several criteria [20]. The hierarchy comes from the Greek word which means holy origin or holy rule. The development of the system may create a level of elements from the highest part to the lowest part. The principle of control is used as acquires the effective functioning of the organization. In decision making, AHP is the basic method designed to cope with both the rational and intuitive to determine the best choice from the given alternatives to the number of criteria [21].

## 3.1 Advantages of AHP

The main function of the analytic hierarchy process (AHP) is to solve the problem related to human perception. AHP is the best alternative to solve the complex decision and unstructured problems which need to solve in a group. Hence, there are some advantages of using the AHP system: The system is developed in a hierarchy structure that analyzed the overall criteria and into the deepest sub-criteria. The tolerance limit of validity up to the inconsistency from the overall criteria selected alternatives. All of the resistance or strength are considered during the analysis. Moreover, the AHP is able to solve multi-objective and multi-criteria problems based on the judgment of each element in the hierarchy [18].

The AHP always become a favorite as a decision-making tool, because the system not only made a comparison of each alternative and each criterion by criteria but also the AHP is allowed to calculate the importance of one criterion compared to the other, resulting in a coupled decision making which helps to ensure the final selection is the optimal one [20].

Saaty has defined the consistency ratio (CR) as CR = CI/RI. CI is the consistency index while RI is the random index which is the value already given based on Table 1. The value of CR must be below 0.1 to prove that the pair-wise comparison matrix is valid and fair [4], [19], [22].

Table 1. The value of random index [23].

| N | RI |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0.58 |
| 4 | 0.9 |
| 5 | 1.12 |
| 6 | 1.24 |
| 7 | 1.32 |
| 8 | 1.41 |
| 9 | 1.45 |

### 3.2. Weaknesses of AHP

The process of AHP can be defined as the solving of quantitative problems into qualitative analysis. Hence, the inconsistency analysis can be happened during entering the rating value of a 1 to 9 scale. Scale number 3 means, that the subjected alternative is of moderate importance compared to the other alternative. Next, the scale of 5 means the subjected alternative is strongly important compared to the other. Since the main purpose of AHP is to solve qualitative problems, the decision maker cannot accurately translate the qualitative judgment into the scale number [24].

Moreover, the system can be judged by a person or in a group. The different opinions of each person may geographically disperse or have a time constraint in order to get the best result. At the same time, the decision maker needs to do a repeating evaluation over the pair-wise comparison which can reduce the effectiveness of the system itself.

Another limitation of the AHP system is the rank reversal problem. The new criteria or alternatives are difficult to add to or delete from the initial set of the AHP system. The best alternative might differ if the worst one is included or excluded [25].

### 3.3. Development of AHP Using Microsoft Excel

Measuring the strength of each criterion as compared to other criteria and prioritizing the most important subject is a difficult process, at the same time the human brain is not able to save large data. Hence, by using Microsoft Excel as a statistical tool to collect and analyze the data, all the calculations can also be done by using software. It means that the AHP is better developed by using Microsoft Excel [26, 27].

## 4. METHOD

Based on Figure 5 is the flowchart of the AHP for this project, it starts with implementing the level of hierarchy structure, making the pair-wise comparison matric for each of the criteria and alternatives, do normalization or judgment of the pair-wise comparison matric. Then, calculate the consistency ratio by using the Eigenvector method (EVM). The consistency ratio should be below the value of 0.1 for the judgment to be valid and fair. Lastly, compare all the priorities in ranking and then define the goal of the problem.

Next, the steps of implementing the AHP system will be explained in detail include with the table, formula, and picture involved in this project.

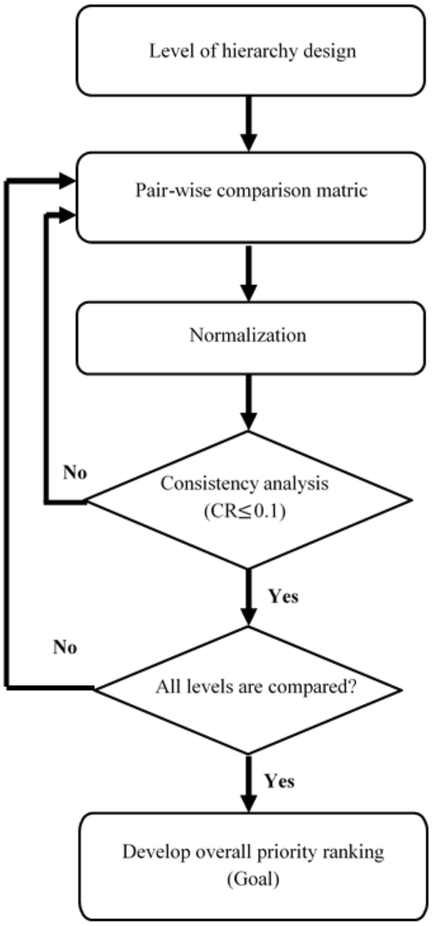


Figure 5. The typical flowchart of AHP.

## 4.1. Identify Levels and Elements within the Level of Hierarchy Design

There are 6 criteria and 6 alternatives involved in this project. All the criteria will be declared as C1, C2 C3, and so on. While the alternatives are declared as A1, A2, A3, A4, A5, and A6 as shown in Figure 6.

## 4.2. Construct the Pair-Wise Comparison Matrix

The judgment of the pair-wise comparison matrix should be made between each criterion compared with other criteria. The weight of the importance can be referred to the table of the fundamental scale in Table 2 which develop by Saaty.

Table 2. The fundamental scale [3], [5].

| Ratio | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two elements contribute equally to the objective. |
| 3 | Moderate importance | Experience and judgment slightly favor one element over another. |
| 5 | Strong Importance | Experience and judgment strongly favor one element over another. |
| 7 | Very strong importance | One element is favored very strongly over another, its dominance is demonstrated in practice. |
| 9 | Extreme importance | The evidence favoring one element over another is of the highest possible order of affirmation. |
| | | 2,4,6,8 can be used to express intermediate values. |

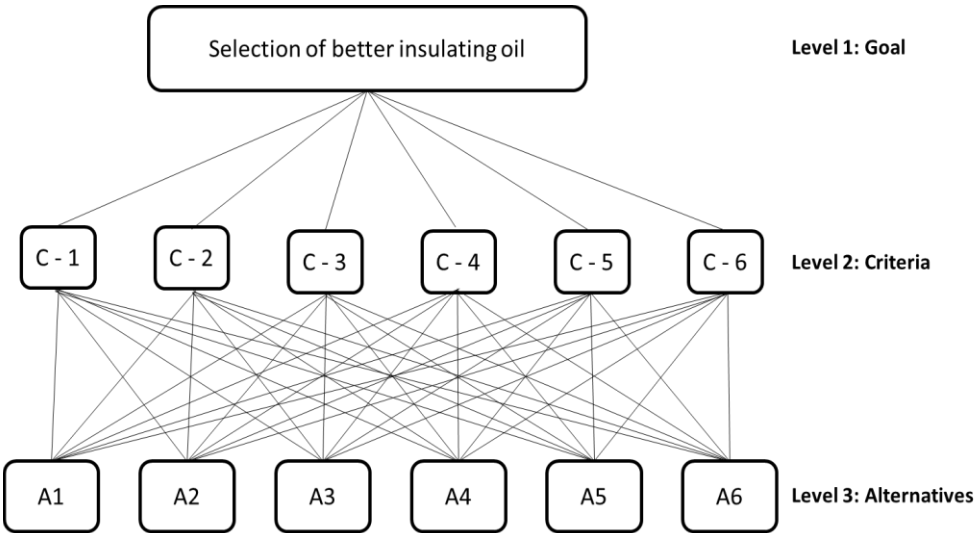


Figure 6. AHP's design for hierarchy structure which was performed in this work.

The matric can be developed by using the matric equation (1).

$$A_C = \begin{array}{c} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \end{array}, i = 1,2,\ldots n;\ j = 1,2,\ldots n \quad (1)$$

Table 3. Example of pair-wise comparison matric.

| Factor | C1 | C2 | C3 | C4 | C5 |
|---|---|---|---|---|---|
| **C1** | **1.00** | 3.00 | 0.33 | 5.00 | 7.00 |
| **C2** | 0.33 | **1.00** | 0.20 | 3.00 | 5.00 |
| **C3** | 3.00 | 5.00 | **1.00** | 7.00 | 9.00 |
| **C4** | 0.20 | 0.33 | 0.14 | **1.00** | 3.00 |
| **C5** | 0.14 | 0.20 | 0.11 | 0.33 | **1.00** |

### 4.3. Normalizing the Pair-Wise Comparison Matrix

By using the following formula (2), the normalizing calculation can be calculated to get the highest priority among the criteria.

$$Wi = \frac{1}{n}\, \Sigma\, \frac{aij}{\Sigma aij} \quad (2)$$

W*i* is the weight of the criteria, n is the number of criteria involved in the pair-wise comparison, and a*ij* is the value of judgment of C*i* to the C*j*.

### 4.4. Consistency Analysis by Eigen Vector Method (EVM)

The importance of calculating the consistency ratio is to ensure fairness in pair-wise comparison. The calculation can be used in the following formula (3).

$$CR = \frac{CI}{RI} \quad (3)$$

CR is the consistency ratio; CI is the consistency index and RI is the random index. The value of RI will depend on the number of criteria used in the system which can be referred to the Table 1. However, the value of CI can be calculated by using the formula (4).

$$CI = \frac{(\lambda max - N)}{N - 1} \tag{4}$$

The value of CI should be less than 0.1 for the pair-wise comparison to be valid and accepted. But if the CR value is greater than 0.1, the pair-wise comparison matric should be reconstructed again.

### 4.5. All Priority Ranking is Developed

The final pair-wise comparison matrix should be done by normalizing all of the criteria and alternatives concerning each other. The goal can be recognized by the value from the overall priority calculation.

### 4.6. Goal Achieved

The goal is achieved by choosing the alternatives with the highest priority.

## 5. RESULTS AND DISCUSSION

### 5.1. Properties Value of Insulating Oil for Power Transformer

Following are the standard properties value of the current transformer in Table 4 and other vegetative oils in Table 5 which were obtained by reviewing and summarizing the literature sources. All of the values are following the ASTM (American Society for Testing Materials) and IEC (International Electrotechnical Commission) standards to ensure the validity of the result.

The criteria of breakdown voltage and flash point are better with the higher value. Meanwhile, the dissipation factor, kinematic viscosity, pour point, and density should be lower for better insulating oil in a power transformer.

Table 4. Standard properties of insulating oil [2], [13], [14].

| PARAMETER | STANDARD | VALUE |
|---|---|---|
| Breakdown voltage | IEC 60156 | > 30 kV |
| Dissipation factor at 90 °C | IEC 274 | 0.0005 |
| Flash point | ASTM D93<br>IEEE | > 145 °C |
| Pour point | ASTM D97<br>IEEE | ≤ -10 °C |
| Viscosity at 40°C | ASTM D445 | 13 $mm^2s^{-1}$ |
| Density at 15°C | ASTM D941 | 0.875 – 0.88 |

### 5.2. AHP system Develop using Microsoft Excel

Referring to Figure 6, the framework of the AHP system is successfully developed, involve with the 6 criteria and 6 alternatives. At level 1, the goal of this project is to choose a better insulating oil for the power transformer which comes from the given alternative oil. For level 2, there are 6 criteria called C1: breakdown voltage, C2: dissipation factor, C3: flash point, C4: pour point, C5 kinematic viscosity, and C6: density. Next, all alternatives are attached to each criterion in level 3. The 6 alternatives chosen in this project are Palm Fatty Acid Ester (PFAE) oil: A1, palm oil: A2, corn oil: A3, canola: A4, soybean oil: A5, and sunflower oil: A6.

The following part shows the AHP system which was already developed using Microsoft Excel. The framework of a hierarchy of the AHP system above is applied and presented in Microsoft Excel.

Table 5. Properties value of vegetative oil [9], [14], [16], [28], [29], [30], [31], [32], [33], [34].

| TYPE OF OIL | BREAKDOWN VOLTAGE (KV) | DISSIPATION FACTOR AT 90°C | FLASH POINT (°C) | POUR POINT (°C) | KINETIC VISCOSITY AT 40°C (MM²/S) | DENSITY AT 15°C (G/CM³) |
|---|---|---|---|---|---|---|
| | **IEC 60156** | **IEC 247** | **ASTM D93** | **ASTM D97** | **ASTM D445** | **ASTM D941** |
| **PFAE** | **81.00** | **0.0080** | 186.0 | **-32.5** | 5.060 | **0.860** |
| **Palm** | 16.52 | 0.0545 | 131.5 | 12.5 | 4.445 | 0.875 |
| **Corn** | 24.74 | 0.0284 | 181.5 | -1.5 | **4.183** | 0.884 |
| **Canola** | 24.30 | 0.1730 | 130.0 | -7.0 | 4.360 | 0.883 |
| **Soybean** | 56.00 | 0.0300 | **316.0** | -21.0 | 34.00 | 0.920 |
| **Sunflower** | 12.75 | 0.0500 | 166.0 | -1.5 | 4.225 | 0.884 |

#### 5.2.1. Pair-wise comparison matrix between the criteria

First of all, the comparison had been made between the criteria in order to recognize which criteria contribute the highest weightage in selecting a better insulating oil for a power transformer.

Based on Table 6, the scale values are inserted by the decision maker while the other half below are inverted from the inserted values. As an example, the scale of 3.00 in the first row, and second column means the C1 (breakdown voltage) is moderately important if compared to C2 (dissipation factor). Next is the scale of 0.33 in the second-row third column, which means the C3 (flash point) is moderately important compared to C2 (dissipation factor).

Table 6. Pair-wise comparison matrix for all criteria.

| Factor | C1 | C2 | C3 | C4 | C5 | C6 |
|---|---|---|---|---|---|---|
| **C1** | 1.00 | 3.00 | 2.00 | 5.00 | 5.00 | 7.00 |
| **C2** | 0.33 | 1.00 | 0.33 | 3.00 | 2.00 | 5.00 |
| **C3** | 0.50 | 3.00 | 1.00 | 5.00 | 2.00 | 7.00 |
| **C4** | 0.20 | 0.33 | 0.20 | 1.00 | 0.33 | 3.00 |
| **C5** | 0.20 | 0.50 | 0.50 | 3.00 | 1.00 | 4.00 |
| **C6** | 0.14 | 0.20 | 0.14 | 0.33 | 0.25 | 1.00 |

Table 7. Normalize the pair-wise comparison matrix.

| FACTOR | C1 | C2 | C3 | C4 | C5 | C6 | PRIORITY |
|---|---|---|---|---|---|---|---|
| **C1** | 0.4208 | 0.3734 | 0.4789 | 0.2885 | 0.4724 | 0.2593 | **0.3822** |
| **C2** | 0.1403 | 0.1245 | 0.0798 | 0.1731 | 0.1890 | 0.1852 | 0.1486 |
| **C3** | 0.2104 | 0.3734 | 0.2395 | 0.2885 | 0.1890 | 0.2593 | 0.2600 |
| **C4** | 0.0842 | 0.0415 | 0.0479 | 0.0577 | 0.0315 | 0.1111 | 0.0623 |
| **C5** | 0.0842 | 0.0622 | 0.1197 | 0.1731 | 0.0945 | 0.1481 | 0.1136 |
| **C6** | 0.0601 | 0.0249 | 0.0342 | 0.0192 | 0.0236 | 0.0370 | 0.0332 |

Then, the data is normalized, and the priority values have outputted the result as shown in Table 7. The C1 which is breakdown voltage is recognized to be the most important criterion which needs to be considered when selecting a better insulating oil. The ranking of most important criteria to less important criteria has been developed as shown in Figure 7.

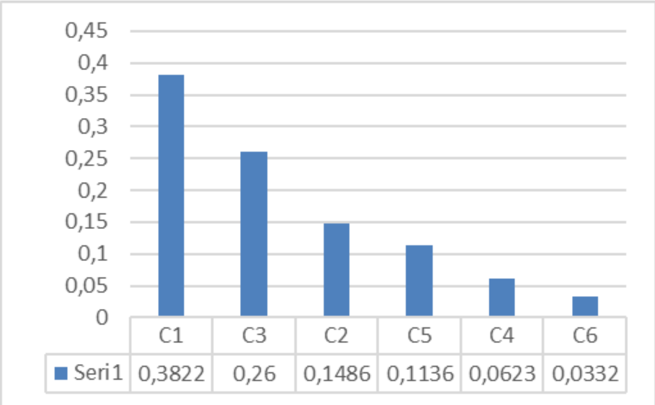


Figure 7. Ranking developed among the criteria.

From the obtained result, the first and the third place goes to the breakdown voltage and dissipation factor. These two criteria are from the electrical properties which certainly need to be more important compared to other physical properties. However, the flash point is in the second place even though it is a physical property, this is because it ensures the safety of the power transformer from a sudden burn.

Table 8. Consistency ratio.

| | |
|---|---|
| CI= | 0.0561 |
| RI | 1.2400 |
| **CR** | **0.0453** |

From Table 8 the consistency ratio (CR) is 0.0453 which is below 0.1. This means the comparison made for the criteria is fair and the produced result is valid.

### 5.2.2. Pair-wise comparison matrix for given alternatives concerning each criterion

Following are the results of which alternative is chosen as a better insulating oil for power transformer based on the specific criteria. There are 6 (six) criteria involved in this part.

The designed system for this part is the same as the design for the comparison between the criteria. But this time, the AHP system is made a comparison between the alternatives to each criterion as the result in Table 9.

Table 9. The priority value of all alternatives with respect to each criterion.

| | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** |
|---|---|---|---|---|---|---|
| **A1** | 0.4631 | 0.3973 | 0.1655 | 0.3930 | 0.0665 | 0.4118 |
| **A2** | 0.0513 | 0.0632 | 0.0407 | 0.0293 | 0.0950 | 0.2229 |
| **A3** | 0.1180 | 0.2334 | 0.1494 | 0.0627 | 0.4236 | 0.0881 |
| **A4** | 0.1071 | 0.0351 | 0.0324 | 0.1627 | 0.1340 | 0.1320 |
| **A5** | 0.2310 | 0.1712 | 0.5100 | 0.2878 | 0.0252 | 0.0570 |
| **A6** | 0.0295 | 0.0998 | 0.1020 | 0.0645 | 0.2556 | 0.0881 |

Table 10. Summary result of alternatives with respect to each criterion.

| CRITERIA | TYPE OF OIL | CR |
|---|---|---|
| C1 – Breakdown voltage | PFAE | 0.0609 |
| C2 – Dissipation factor | PFAE | 0.0465 |
| C3 – Flash point | Soybean oil | 0.0570 |
| C4 – Pour Point | PFAE | 0.0308 |
| C5 – Kinematic viscosity | Corn oil | 0.0642 |
| C6 - Density | PFAE | 0.0241 |

Based on Table 10, shows the type of oil chosen as the best insulating oil based on each criterion. The majority of oil selected as better insulating oil based on each criterion is Palm Fatty Acid ester (PFAE) oil.

Meanwhile, soybean oil is better in terms of flash points and the kinematic viscosity of corn oil is the most suitable for insulating oil. Besides that, the consistency ratio (CR) has also been ensured to be below 0.1.

Table 11. The final result of the AHP system.

| | C1 | C2 | C3 | C4 | C5 | C6 | |
|---|---|---|---|---|---|---|---|
| | 0.3822 | 0.1486 | 0.2600 | 0.0623 | 0.1136 | 0.0332 | **Overall Priority** |
| **A1** | 0.4631 | 0.3973 | 0.1655 | 0.3930 | 0.0665 | 0.4118 | **0.3248** |
| **A2** | 0.0513 | 0.0632 | 0.0407 | 0.0293 | 0.0950 | 0.2229 | 0.0596 |
| **A3** | 0.1180 | 0.2334 | 0.1494 | 0.0627 | 0.4236 | 0.0881 | **0.1736** |
| **A4** | 0.1071 | 0.0351 | 0.0324 | 0.1627 | 0.1340 | 0.1320 | 0.0843 |
| **A5** | 0.2310 | 0.1712 | 0.5100 | 0.2878 | 0.0252 | 0.0570 | **0.2690** |
| **A6** | 0.0295 | 0.0998 | 0.1020 | 0.0645 | 0.2556 | 0.0881 | 0.0886 |

In Table 11, the normalization between all of the criteria and all alternatives is calculated through the AHP system. Then, the overall priority values in the last column are accepted as the final result of the AHP system.

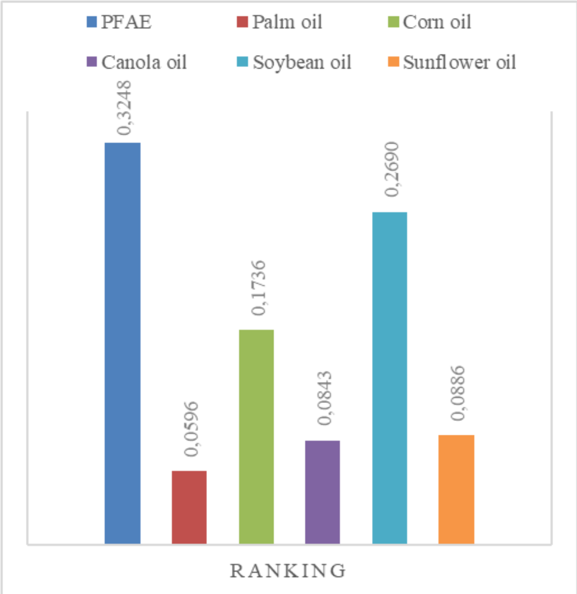


Figure 8. Developed ranking for a better insulating oil.

Referring to the bar chart in Figure 8, the ranking of a better insulating oil for power transformer is developed. The PFAE oil is acknowledged to be at the top followed by soybean oil, corn oil, sunflower oil, and canola oil, and at the bottom of the ranking is palm oil. This is because the PFAE oil is the actual transformer insulating oil that already went through the esterification process.

## 6. CONCLUSION

The analytical hierarchy process (AHP) is successfully developed by using Microsoft Excel software in this research work. From the framework of the AHP system, there are six criteria involved in this project which are dissipation factor, breakdown voltage, pour point, flash point, density, and kinematic viscosity. All of them have been declared as C1, C2, C3, C4, C5, and C6.

After making a pair-wise comparison matrix, the C1 which is the breakdown voltage is introduced as the most important criterion to select a better insulating oil. The ranking developed is followed by the flash point and then the dissipation factor, kinematic viscosity, pour point, and density. In detail, the breakdown voltage and dissipation factor are known as electrical properties which should be prioritized compared to other criteria which come from physical properties.

The project also has chosen six alternatives from the vegetable oils which are Palm Fatty Acid Ester (PFAE) oil, palm oil, corn oil, canola oil, soybean oil, and sunflower oil. The alternatives are declared as A1, A2, A3, A4, A5, and A6. The given alternatives have to go through the pair-wise comparison matrix concerning each criterion.

From the result, the PFAE oil has been chosen as the best insulating oil in terms of breakdown voltage, dissipation factor, pour point, and density. Meanwhile, based on the criteria of flash point, soybean oil is better compared with other vegetable oils. Then, corn oil is the best insulating oil in the aspect of kinematic viscosity.

The conclusion from the result is that palm fatty acid ester (PFAE) oil is selected as the best insulating oil for power transformers. The AHP system has produced the output in the last table in Microsoft Excel. The overall priority value of PFAE oil is 0.3248, has slightly different from the second choice which is soybean oil with a priority value of 0.2690. In addition, the PFAE oil is already performed the esterification process and the properties meet the requirement of the standard of insulating oil of the transformer. Inversely to the other vegetable oils which only come from the pure or origin vegetable oil.

## 7. FUTURE RECOMMENDATION

As a future recommendation for this work, the parameter involved in this project should be increased to get a more accurate result. There are several vegetable oils on market and many other properties of insulating oil that are important and need to contribute to the selection of better insulating oil using the AHP system.

Besides that, the property values should be obtained from the experiment in a laboratory instead of using other data from the literature sources. The experimental result can ensure the similarity of the property value for each type of oil.

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