Analysis of Mixing Oil (Diala B with S2-ZUI) for Cooling Systems Used in Power Transformers

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Abstract. The Diala B oil used as a cooling system for transformers is an old product from the manufacturer and is no longer being reproduced. To maintain the oil level in the transformer under normal conditions, S2-ZUI oil is added which is a new product from the manufacturer. Before being mixed with old oil, new oil is tested in the laboratory to meet the test parameters in the IEC 60296 standard. In this paper, several important parameters are measured such as viscosity, breakdown voltage, water content, acidity, density, flash point, pour point, corrosive sulfur, interfacial tension, dielectric dissipation factor, total acidity, and sludge. Besides, the properties of mixed oil are also tested in the laboratory before mixing them in the transformer. The results showed that the new oil (100% S2-ZUI) and the mixture of Diala B with S2-ZUI (50%: 50%) tested in the laboratory still meet the quality requirements according to IEC 60296 standards. Laboratory test results indicate that this new oil can be used as an addition to Diala B oil in transformers for cooling and insulation systems.

1. Introduction
To increase the reliability of the transformer performance in supplying the load, maintenance measures are required. One of the maintenance measures on the transformer cooling system is the maintenance of oil. The oil used in transformers is an old product from the manufacturer and has not been re-manufactured. Meanwhile, in the series of maintenance of oil on the transformer, it is necessary to add oil (makeup) because of the reduced oil level due to leakage in the radiator, one of which. To keep the oil level at normal conditions, new oil was added to the conservator tank. The new oil added to the conservator tank is not of the same type as the one in the tank because the oil is no longer produced, but its function remains the same as a coolant, insulation, and anti-corrosive. The solution is a substitute for pure mineral oil using mixed oil [1][2].

Power transformers are used to convert voltage and power transmission in power systems and are one of the most important equipment in the power grid [3]. The main insulation system in power transformers consists of cellulose and insulating oil [4]. Petroleum produces mineral insulating oil in transformers which is non-renewable and takes a long time to obtain [5]. The type of oil used in the utility transformer is Diala B because the oil is no longer reproduced, so to add oil to the conservator tank, S2-ZUI type oil is used, which is a new product from the manufacturer. Before being mixed with old oil, the new oil must be tested in the laboratory to meet the test parameters in the IEC 60296 standard. Then for mixing with the old oil it must also be tested in the laboratory before adding to the transformer. In this paper, a laboratory-tested for testing new S2-ZUI oils (100%), a mixture of
insulating oil is Diala B: S2-ZUI (50%: 50%).

It is generally agreed that the electrical and dielectric requirements for any new insulating fluid must meet the following requirements [2] [6]:

1. Chemical and thermal stability
2. Good electrical and thermal properties
3. Low viscosity
4. Good properties at low temperature
5. Compatibility with other transformer materials
6. Low flammability
7. Environmental acceptability

2. Experiment Methods

In this paper, Table 1. shows the methods used for the application of mineral insulating oil to transformers according to the interpretation of IEC 60296 [7] such as viscosity, breakdown voltage, water content, acidity, density, flash point, pour point, corrosive sulfur, interfacial tension, dielectric dissipation factor, total acidity, and sludge.

| Property                                      | Unit      | Limit                      |
|-----------------------------------------------|-----------|----------------------------|
| Viscosity at 40 °C                            | mm²/s     | Max. 12                    |
| Breakdown voltage                             | kV/2.5mm  | Min. 30 kV / 70 kV a       |
| Water content                                 | mg/kg     | Max.30 (bulk supply)       |
|                                               |           | Max.40 (in drum)           |
| Acidity                                       | mgKOH/g   | Max. 0,01                  |
| Density at 20 °C                              | g/ml      | Max. 0,895                 |
| Flash point                                   | °C        | Min.135                    |
| Pour point                                    | °C        | Maks. -40                  |
| Corrosive sulfur                              | ASTM scale| Not corrosive              |
| Interfacial tension                           | mN/m      | Min. 40                    |
| Dielectric dissipation factor at 90°C          | -         | Max. 0,500                 |
| Total acidity                                 | mgKOH/g   | Max. 1,2                   |
| Sludge                                        | %         | Max. 0,8 %                 |

2.1 Viscosity

Viscosity is an important factor in controlling heat dissipation. Aging and Oxidation of oils tend to increase viscosity. Viscosity is also affected by temperature. Normal aging and oil oxidation do not significantly affect their viscosity. Only in extreme conditions, the release of corona or oxidation can affect the viscosity. Oil viscosity or viscosity affects heat transfer, so it can affect the temperature increase of the equipment. The lower the viscosity (dilute) value, the easier the oil will circulate and improve the heat transfer process. At low temperatures, the viscosity of the oil is higher (thicker) and this is a critical Phase when the new transformer operates shortly after energizing because the oil cannot circulate properly so that overheating is possible at certain hot points.

2.2 Breakdown Voltage

Breakdown voltage is a measure of the ability to insulate oil to withstand electrical stress and is very important for the safe operation of electrical equipment. The breakdown voltage is very dependent on the temperature at the time of sampling the oil. The condition of the oil is dry and clean, it can be ascertained that the oil has a high breakdown voltage. Free water and solid particles or their combination with dissolved water tend to move to areas with high electrical stress so that they can drastically reduce the breakdown voltage. The breakdown voltage measurement is carried out to
determine the presence of contaminants such as water and particles. A low breakdown voltage value may indicate contaminants. However, a high breakdown voltage value does not necessarily indicate a complete absence of contaminants. The breakdown voltage value is significant when the oil sample is taken at the transformer operating temperature.

2.3 Water Content

The water content is insulation oil that will affect the breakdown voltage of the oil, solid insulation, and the aging tendency of liquid and solid insulation. The effect depends on the amount of water, temperature, and soil conditions. The water content in liquid and solid insulation greatly affects the actual operating conditions and lifetime of the transformer. There are 2 (two) main sources of increase in water content in transformer insulation, namely humidity through the airway and insulation degradation. The water in electrical equipment containing oil moves with the oil moving. This water can take the form of dissolved water and as a liquid which is absorbed by polar aging products (bound water). Particles, such as cellulose fibers can bind water.

2.4 Acidity

The acid content (neutralization value) of oil is a measure for the component of acids or contaminants in the oil. The acid content in used oil is the result of the formation of acidic oxidation products. Acids and other oxidation products, together with the presence of water and solid contaminants, will affect dielectric and other properties of the oil. Acid has an impact on the degradation of insulation materials and can cause corrosion of metal parts in the transformer. The rate at which the acid content increases in an operating transformer is a good indicator of the aging rate. The acid level is used as a general rule of thumb to determine whether oil should be replaced or reclaimed.

2.5 Density

To prevent ice resulting from freezing free water from floating the surface of the oil in cold climates the density of the oil must be low enough and conductor jumps may cause disturbance conditions to develop. Density must be measured according to ISO 3675 (reference method).

2.6 Flashpoint

Oil damage caused by electrical discharge or prolonged exposure to very high temperatures can produce sufficient quantities of low molecular weight hydrocarbons to cause a decrease in the flashpoint of the oil. A low flash point is an indication of the presence of the flammable product in the oil. This may be the result of contamination by solvents, but in some cases, can be caused by excessive sparking discharge. Testing the flashpoint or flashpoint is done using a device the functions to heat oil manually (heater). Where above the heating cup is placed on the fire source which comes from the gas. This fire source functions as a fishing rod when the oil starts burning. Along with the length of the healing process, the oil temperature will also increase. At a certain temperature, the oil will burn with a fire source as a burning medium. The temperature is the flashpoint of fire.

2.7 Pour Point

The lowest temperature at which the oil will simply flow is the pour point for the mineral insulating oil. The recommended pour point should be at least 10 K below the lowest cold start energizing temperature. The pour point shall be measured following ISO 3016.

2.8 Corrosive Sulfur

The amount of sulfur in the oil depends on the refining process of the oil, the degree of refining, and the type of crude oil. It generally appears as organic sulfur, but contamination with sulfur itself can also occur. The presence of reactive compounds that cause corrosion at normal operating temperature is due to poor refining or contamination. At relatively high temperatures, sulfur-containing oil molecules can decompose and react with metal surfaces to form metal sulfides. This reaction occurs
inside the switching equipment and will affect the conductivity of the contacts. Some sulfur contains molecules that can cause the formation of copper sulfide (Cu$_2$S) deposits in paper insulation in electrical equipment. This phenomenon can reduce the electrical properties of the insulation and ultimately result in equipment damage. Cu$_2$S deposition in paper-insulated electrical equipment will occur if the oil containing corrosive sulfur compounds and cooper is used not coated or protected, the operating temperature and/or ambient temperature is high and the amount of oxygen is very low. The compounds in the oil that can cause this phenomenon are disulfides, such as dibenzyl disulfide.

2.9 Interfacial Tension
The interface tension between oil and water is used to detect the presence of dissolved contaminants and degradations products. The property changes very rapidly in the early stages of aging but becomes constant when the deterioration of oil is in the moderate category. The rate of IFT reduction is very much influenced by the type of oil, oil without inhibitor generally shows a higher IFT reduction rate than oil with an inhibitor. The rapid decrease in IFT can be interpreted as an indication of a compatibility problem between the oil and some other material in the transformer (varnish, gasket), or unexpected contamination that may have occurred during the oil filling process. In transformers with more loads, the material will break down more quickly and IFT can be used as a parameter to detect the damage. Because the IFT value is in line with the aging process of the transformer insulating oil, the IFT value can be used as a confirmation after an abnormal acid level is found.

2.10 Dielectric Dissipation Factor
The parameter is very sensitive to the presence of dissolved polar contaminants, aging products, or colloids (sediment, sludge) in the oil. Changes in contaminant levels can be monitored by measuring these parameters even if the contaminants are very small or within the limits of their chemically detectable capability. The accepted limit values for these parameters are highly dependent on the type of equipment. However, high DDF values, or low resistivity values, have a very negative impact on dielectric losses and/or insulation resistance in electrical equipment. There is a general relationship between DDF and resistivity, as the resistivity value decreases, the DDF value increases. Normally there is no need for both tests to be carried out on the same oil and the DDF test is the more common test. Resistivity and DDF depend on temperature and humidity. The figure below illustrates a typical change of resistivity to temperature and water content in insulating oils which are generally free from solid contamination.

2.11 Total Acidity
The ability of the new insulating mineral oil to resist oxidation at elevated temperatures in the presence of oxygen and cooper catalysis is called oxidation stability. The provides information on the estimated oil life under the operating conditions of the equipment. This Property is defined as the resistance to the formation of acids, sludge, and compounds the effect DDF under certain conditions. For oils according to IEC 60296, these conditions are described in IEC 61125 method C and the value limits are according to IEC 60296. The oxidation stability depends primarily on the purifier process and the conditions for which it is stored. Refined mineral oil contains natural compounds, in certain ingredients, which act as oxidation inhibitors. These are known as natural antioxidants. The oil that contains only natural antioxidants is known as oil without inhibitors. Synthetic oxidation inhibitors can be added to improve oxidation stability. The effectiveness of adding an inhibitor will vary depending on the chemical composition of the base oil. Oil oxidation without inhibitors can be seen from the formation of dissolved or insoluble acid and sludge compounds in the oil. An increase in DDF and a decrease in IFT also sign the oil has oxidized.

2.12 Sludge
This test distinguishes between sediment and mud. Sediment is material not dissolved in oil. Sediments include Insoluble degradation or oxidation products of solid or liquid insulating materials,
solid product arising from the operating conditions of the equipment; carbon and metal particles, metal oxides and sulfides; fiber, and other substances. Sludge is the result of a degradation process that occurs in both solid and liquid insulation. Sludge can dissolve in oil to some extent, depending on the characteristics of the oil solubility level and temperature. The level of sludge is above the solubility limit, then the sludge will settle and contribute to the formation of sediment. The formation of sediment and/or sludge can change the electrical properties of the oil, and can further inhibit heat transfer, thereby triggering thermal degradation of the insulation material. Many materials can contaminate transformer oil, such as carbon and sludge. This sediment test aims to measure how much (%) the impurity is against the transformer insulating oil. This test compares the weight of the filtered precipitate with the weight of the oil under test.

3. Results And Discussion
The research was conducted on the GT 2.1 power transformer at PLTGU Belawan, with the ONAF cooling system type, 172 MVA was made in 1993. This study aims to determine the chemical, physical, and dielectric properties according to the IEC 60296 interpretation, only 12 parameters are used in testing characteristics of oil before processing. Table 2 displays the result of testing the characteristics of transformer oil with the shell Diala S2 ZU-I type before processed in the laboratory. The oil tested with a composition of 100% without mixture with existing oil, namely Diala B. the results of the 12 test parameters are still within normal limits according to IEC 60296 standards and can be used insulating oil and cooling systems on power transformers. However, apart from testing the characteristics of the 12 oil parameters, other tests are needed, such as gassing tendency, 2-furfural PCA, PCB content, total sulfur, antioxidant additive, and color.

Table 2. New Shell Diala S2 ZU-I oil test results (100%)

| Property                        | Unit   | Result   |
|---------------------------------|--------|----------|
| Viscosity at 40 °C              | mm²/s  | 10,5     |
| Breakdown voltage               | kV/2,5mm| 46       |
| Water content                   | mg/kg  | 27,1     |
| Acidity                         | mgKOH/g| 0,0084   |
| Density at 20 °C                | g/ml   | 0,8734   |
| Flash point                     | °C     | 142      |
| Pour point                      | °C     | -63      |
| Corrosive sulfur                | ASTM scale | Not corrosive |
| Interfacial tension             | mN/m   | 47       |
| Dielectric dissipation factor at 90°C | - | 0,0018   |
| Total acidity                   | mgKOH/g| 0,055    |
| Sludge                          | %      | 0,149    |

Table 3 shows the result of testing characteristics of a mixture of Shell Diala S2 ZU-I and Shell Diala B transformer oil before being processed in the laboratory. Oil tested with a composition of 50% shell Diala S2 ZU-I and 50% Shell Diala B. The result of the 12 test parameters are still within normal limits according to the IEC 60296 standard and can be used as an insulating oil and cooling system for power transformers. However, apart from testing the characteristics of the 12 oil parameters, other tests are needed, such as gassing tendency, 2-furfural PCA, PCB content, total sulfur, antioxidant additive, and color.

Mixed insulating oils different types have been investigated for use in transformers. The short and long-term behavior of the oil mixture must also be examined to obtain an accurate result so that the transformer reliability can be maintained. If shell Diala S2-ZUI oil is mixed with shell Diala B and used for cooling and isolation systems on power transformers, an infrared thermograph test is necessary to determine the state of the transformer oil temperature during operation.
Table 3. New insulation oil test results Diala S2-ZUI:Diala B (50% : 50%)

| Property                          | Unit       | Result |
|-----------------------------------|------------|--------|
| Viscosity at 40 °C                | mm²/s      | 10.3   |
| Breakdown voltage                 | kV/2.5mm   | 50     |
| Water content                     | mg/kg      | 25.0   |
| Acidity                           | mgKOH/g    | 0.0084 |
| Density at 20 °C                  | g/ml       | 0.8758 |
| Flash point                       | °C         | 138    |
| Pour point                        | °C         | -60    |
| Corrosive sulfur                  | ASTM scale | Not corrosive |
| Interfacial tension               | mN/m       | 46     |
| Dielectric dissipation factor at 90°C | -       | 0.0020 |
| Total acidity                     | mgKOH/g    | 0.067  |
| Sludge                            | %          | 0.280  |

4. Conclusion
In this paper, oil testing is carried out in a laboratory. The laboratory test results for 12 parameters taken indicate that the insulating oil sample is a new type. Dial S2-ZUI (100%) and a new mixture of insulating oil, Diala S2-ZUI: Diala B (50 %; 50 %) meet new insulating oil specifications before processing.

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