RAILWAY VEHICLE MAINTENANCE – TRANSFORMER OILS' ANALYSIS

MEGAT MUHAMMAD HAZIQ BIN OTHMAN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

RAILWAY VEHICLE MAINTENANCE: TRANSFORMER OILS' ANALYSIS

MEGAT MUHAMMAD HAZIQ BIN OTHMAN

A report submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SEPTEMBER 2020

DECLARATION

I declare this project entitled "Railway Vehicle Maintenance: Transformer Oils' Analysis" is the result of my own work except as cited in the reference.

Signature :…………………..

Name : Megat Muhammad Haziq Bin Othman

Date :…………………..

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature : ………………………

Supervisor Name : Professor Madya Ir. Dr. Mohd Azman Bin Abdullah

Date : ………………………

DEDICATION

This report is dedicated to my parents, Othman Bin Mohd and Raja Haidah Binti Raja Ali for their ongoing support and love of finishing this project report for the final year. In addition, they also taught me to believe in Allah in whatever condition we had, especially during the completion of this report. In addition, also to my family, who always support me with unconditional love, which motivates me to set a higher goal to complete this final year project. Next I devote this study to my supervisor Professor Madya Ir. Dr. Mohd Azman Bin Abdullah, since that gives me the ability to choose this project. Apart from that, he also gives me inspiration, coaching and encouragement to explain my final year project. Always dedicated to my beloved friends, this devotion has provided me with a powerful shield of love and always protects me and never allows any sorrow to enter.

Thank you

ABSTRACT

Rolling stock or train is one of the primary transportation in most of the country especially in Malaysia. Therefore, maintenance is needed for train in order to make sure that it can run smoothly without any failure occurred. The purpose of this study are to analyze the railway vehicle transformer, to analyze the transformer oil in the sampling duration is beyond the reference point or not and to make the recommendations for maintenance strategy if any error occurred in the oil sampling result. The research only focus on train transformer oil in the duration of five years. There were seven rolling stock are analyzed. Overall data for oil sampling in past five years were gain from the ERL Maintenance Support Sdn. Bhd, Sepang for all aspects that have been analyzed. The analysis consists of four main aspects which are dielectric strength, water content, acid number and interfacial tension and stated also the date of oil sampling. Next, the data gain is presented and analyzed by using bar graph so it will more easy to analyzed and present the data. Finally, the most critical maintenance issues can be analyzed using the bar graph.

ABSTRAK

Kereta api merupakan salah satu kemudahan pengangkutan dalam kebanyakkan negara terutama Malaysia. Oleh itu, penyelenggaraan adalah diperlukan untuk kereta api untuk memastikan ia dapat berfungsi dengan baiknya tanpa berlaku apa-apa masalah yang tidak diingini. Tujuan pembelajaran ini dibuat adalah untuk kenal pasti jenis pengubah yang digunakan pada kereta api, kenal pasti samada minyak pengubah melebihi nilai rujukan ataupun tidak di dalam tempoh jangka masa pengambilan minyak dan membuat cadangan untuk strategi penyelenggaraan sekiranya berlaku apa-apa kegagalan yang berlaku terhadap minyak. Terdapat empat aspek kereta api telah dianalisa. Keseluruhan data untuk pengambilan minyak selama lima tahun lepas diperolehi daripada ERL Maintenance Support Sdn. Bhd, Sepang. Analisa terhadap minyak terbahagi kepada empat aspek utama iaitu kekuatan dielektrik, kandungan air, nombor acid dan ketegangan antara muka, di samping itu tarikh pengambilan minyak juga dicatat. Kemudian, nilai yang diperoleh telah dibentangkan dan dianalisa menggunakan graf bar supaya ia senang untuk dianalisa dan membentangkan data tersebut. Akhir sekali, isu penyelenggaraan boleh dianalisa menggunakan graf bar.

ACKWNOLEDGMENT

First of all, I wish to honor and thank the Almighty God for His blessings during my research work in order to successfully complete the report. I would like to thanks for whose have been involved during completing this Final Year Project (FYP) whether it is directly or indirectly. This FYP cannot complete and produce with the help of others.

Next, I would like to express my special thanks of gratitude to my supervisor Professor Madya Ir. Dr. Mohd Azman Abdullah that gave me guidance because give me golden opportunities to do this wonderful project on title ‘Railway Vehicle Maintenance: Transformer Oils’ Analysis’. With his professional views and valuable opinions have help me to make appropriate solutions on problems that encountered during the critical stages that I had. With his patience, motivation, enthusiasm and immense knowledge also helped me a lot during completing this Final Year Project report.

Finally, a lot of thanks also for my beloved parents and family because advise and motivate me from time in making this project, although they quite busy with their duties, they always give me opinion in making this report interesting.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABRREVIATIONS

PM	-	Preventive Maintenance
CBM	-	Condition Based Maintenance
EMU	-	Electrical Multiple Unit
TAN	-	Total Acid Number
TBN	-	Total Base Number
FTIR	-	Fourier-Transform Infrared Spectroscopy
VI	-	Viscosity Index
ISO	-	International Organization for Standardization
ASTM	-	American Society for Testing and Materials
ERL	-	Express Rail Link
TT	-	Traction Train
HEP	-	Head-End Power

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Railway vehicle is one of the pioneers of modern mechanical transportation around the world including Malaysia. The movement of the railway vehicle is using track and monitored by the railway maintenance workers to make sure that all the moves are smooth. In Malaysia, the railway transport is owned by the Malaysian government and is operated by the Keretapi Tanah Melayu Berhad (KTMB). Therefore, the railway played its significant role in the economic, social and political development. It also can reduce traffic congestion and not wasting time in traffic jams. In Malaysia have several types of railway vehicle such as KTM, Light-Rail Transit (LRT), Mass Rapid Transit (MRT) and Electric Train Service.

Next, maintenance is one of the important parts to make sure that the railway vehicle is in good condition and can reduce the operating cost for transportation companies. Therefore, the preventive maintenance scheduling is very important in maintaining the reliability for the railway vehicle maintenance. The aim is focusing on the medium-term planning, to identify the preventive maintenance that will be performed within the periods (month/week/hours) that have been scheduled (Budai et al., 2006). Moreover, this preventive maintenance can be divided into small routine works and projects that consist of inspection and repairs for example inspection of rails, level crossing, switch, signaling system and switch lubricating.

Besides that, the transformer also important for all railway vehicle, and it is located below the railway vehicles. The transformer is used to transfer electric power from the catenary to the motor by lowering the network's high voltage to low voltage for use by the converters (Ho et al., 2006). For the transformer oil, it has several types of oil are used as insulators such as mineral, ester and silicon oils. The insulator is very important to maintain the reliability of the transformer because its function as a conductor for the electricity. Therefore, the insulating liquids contain their own dielectric constant, particle counts and viscosity reading. On the other hand, it is important to do preventive maintenance for the insulating liquid to get the best performance transformer.

1.2 Problem Statement

Power transformers are one of the most costly and critical electrical power system components (Murugan & Ramasamy, 2019). A better maintenance planning allows for higher utilization of railway infrastructure and improved services and customer quality (Shift2Rail, 2015). According to D'Ariano et al. (2017) during the growing demand for railway transportation, the safety, punctuality, reliability of the freight and passenger service are important. Therefore, the scheduling maintenance or Preventive Maintenance (PM) will increase the availability of rail transportation and also reduce the maintenance cost during the breakdown. The study of the transformer oil analysis issues for the railway vehicle can improve the performance of the railway vehicle because the transformer oil is one of the important liquid functions as an insulator.

1.3 Objectives

This study has three main objectives that must be accomplished in order to complete the study. The first objective is to analyze the railway vehicle transformer oil. Second objective is to study the trend for the transformer oil. Lastly, the third objective is to make the recommendations for transformer oil whether the oil still can be used, need to replace or need to filter.

1.4 Scopes of study

To achieve this aims of the research, the study has been done in local commuter rail transit company. This study is focusing on the railway transformer oil analysis between the new and used oil. Then, it focused on general transformer oil analysis which investigate the different between general transformer and railway transformer. Lastly to achieve this aims, comparison between the used transformer oil and new transformer oil is needed to investigate the reliability of the oil.

1.5 General Methodology

In order to realize the objectives in this study the explanation and details for methodology will be show. The flow of this project experiment also be shown in this section.

1. Literature review

   Collecting data from previous journals, websites, articles and any related material for the project.

2. Monitoring

   The monitoring will focus more on transformer oil analysis issues for local railway vehicle.

3. Data collection of oil analysis

   Determine and tabulate data from local railway vehicle based on their previous analysis for transformer oil.

4. Interview

   To investigate and determine the problems occurred for the local railway vehicle transformer oil.

5. Analysis

   The analysis is obtained from their previous oil analysis data and for the new oil analysis is obtained from the experiment that be made.

6. Writing report

   All the information and data for this study will be write at the end of this project.

The methodology of this study is simplified in the flow chart as shown in **Figure 1.1**.

`

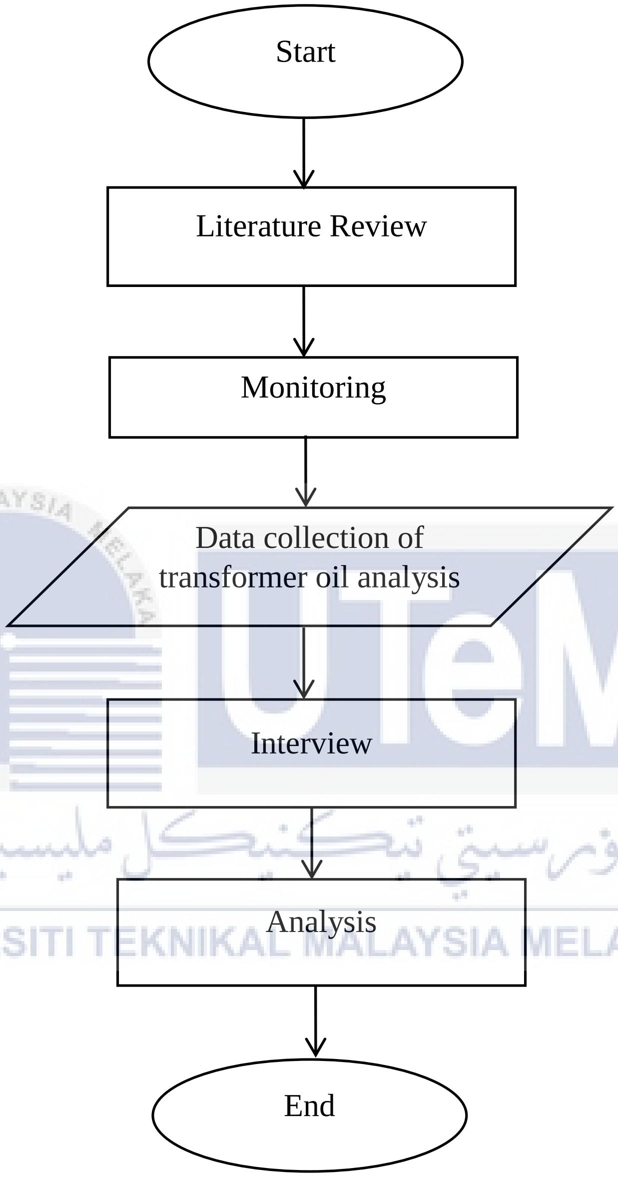

Figure 1.1: General methodology for the overall study

CHAPTER 2

LITERATURE REVIEW

2.1 Railway Maintenance

Railway maintenance is one of the main importance to be a well-functioning transportation system. Electrical rail networks are widely regarded as an important alternative for public transport to minimize energy consumption and pollution in urban areas (Santiyanon et al., 2016). Maintenance of the real work need a large number of different activities that required significant resources and large budgets. A careful maintenance plan is therefore necessary and very successful trains frequently go under maintenance when requested for regular service operations (Mira et al., 2020). The goal of successful preventive maintenance is to eliminate unplanned failures, in example to reduce long and expensive failures saving the maintenance and loading costs (Mijailovic, 2008) . The maintenance is important things in order to pursue the highest level of safety and reliability. The maintenance required a lot of parts to be check in order to be sure that all the components are in good condition. Dennis et al (2012) stated that the specific tools also needed to track down the premature failure or behavior in order to prevent from multiples failure at the later stage.

Condition based maintenance (CBM) can be one of the initiatives to be merged or combine to the daily operations (Lee et al., 2012). Other than that, CBM measurements that can be used such as vibration, oil contamination, temperature, electric current and voltage are sampled in order to monitor and confirm whether the equipment in electrical or mechanical is operating normally. The CBM can be used as proactive maintenance which optimizing the maintenance frequency and thus minimizing the overall total life cycle. Moreover, with this method it can increase the reliability of the equipment, the less breakdown cost and capital spare utilization.

In this chapter, will discuss about the railway maintenance for transformer, maintenance of the transformer oil, the transformer oil analysis and the comparison of the dielectric in the oil. There have variety type of maintenance practices that can be apply in this research, the practices that used in the commuter rail will be verified and the advantages of the practice could be done will be discussed and analyzed.

2.2 Railway transformer maintenance

Transformer is one of the crucial part that need to be monitored in order to make the rolling stocks get sufficient supply. A power transformer failure may also cause cascading failure and systemic outage on the power grid (Liang & Parlikad, 2018). There are several types of locomotives application in railway applications such as electro-locomotives with traction train AC and DC transformers, diesel-locomotives with traction TT HEP transformers and high-speed trains and electrical multiple unit (EMU) with traction transformer transformers. TT is mean by traction train while HEP stand for head-end power. **Figure 2.1**, **Figure 2.2**, **Figure 2.3** and **Figure 2.4** shows an example of transformer that have been used in daily locomotive transportation. Therefore, the **Figure 2.5** shows a simple diagram for transformer which function as 'step-up' and 'step-down' the voltage. The step-up transformer working principle is the increasing of the voltage between the primary to secondary windings while the step-down transformer is decrease voltage between primary to secondary windings (Agnihotri, 2017).

Figure 2.1: TT AC and DC transformers for electro-locomotives

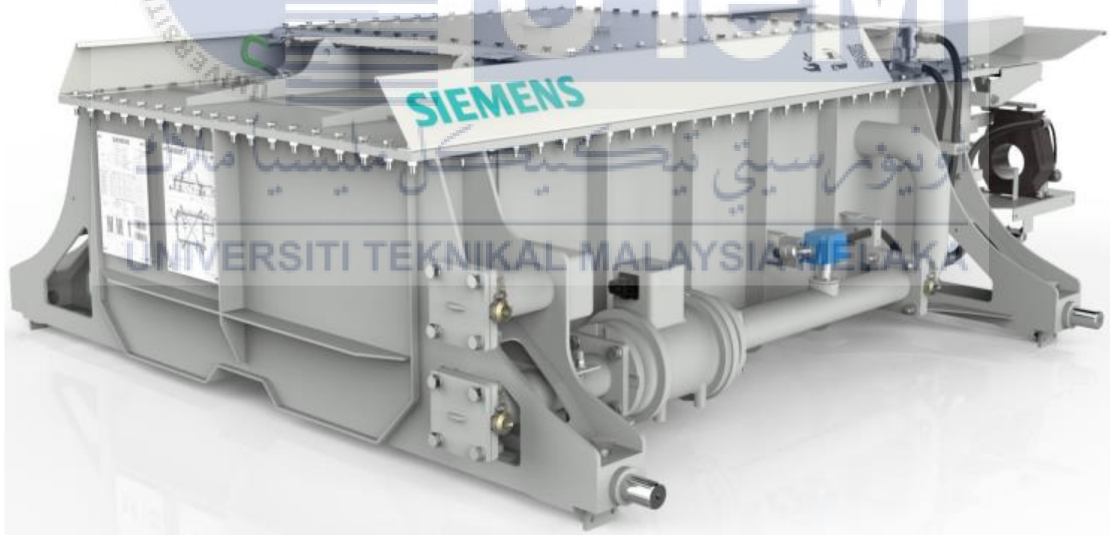

Figure 2.2: TT HEP transformers for diesel-locomotives

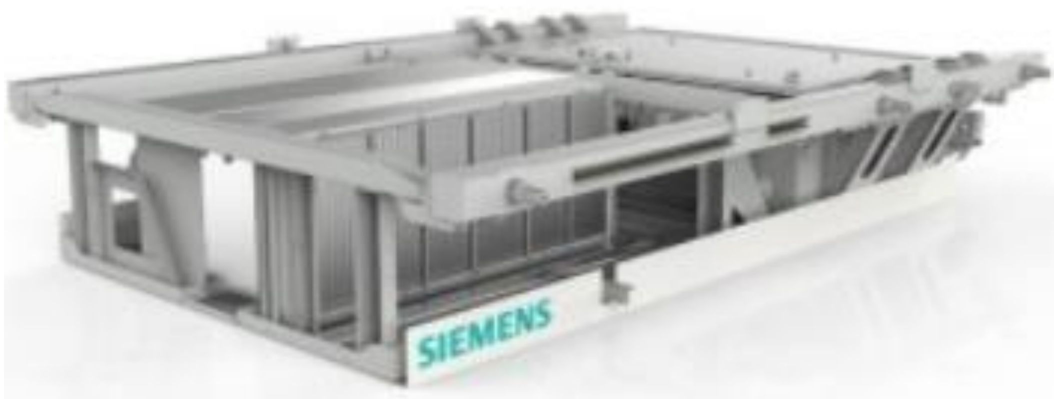

Figure 2.3: TT transformers for high-speed trains

Figure 2.4: TT transformers for electrical multiple unit (EMU)

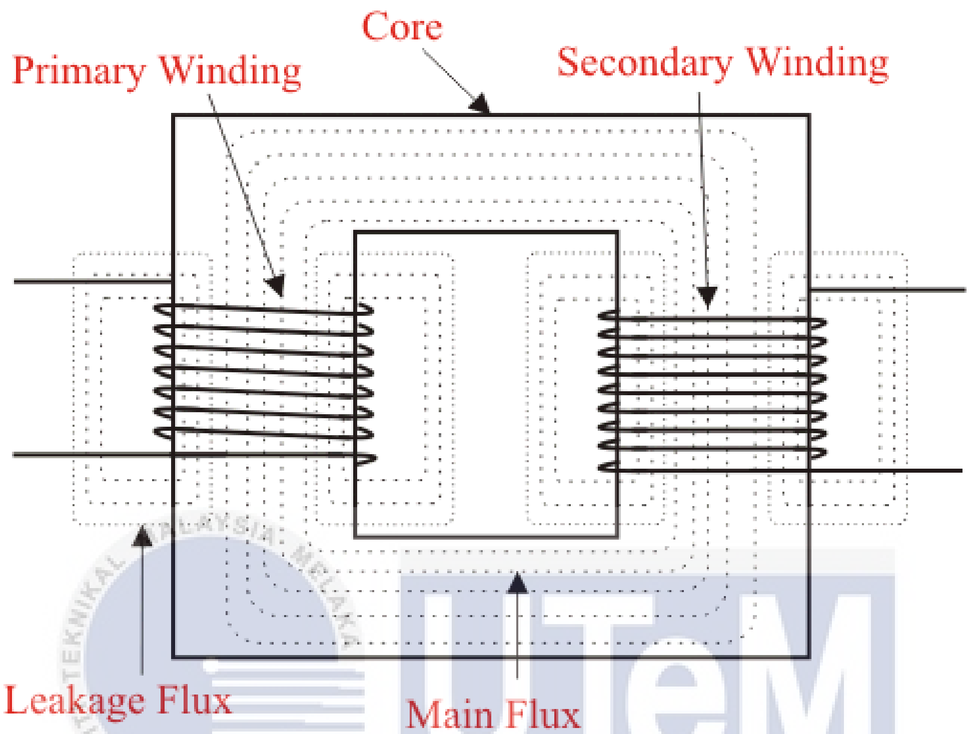

Figure 2.5: Basic diagram for transformer

In Malaysia, many types of railway vehicle or rolling stocks are used electric locomotives rather than other types such as diesel-hydraulic, diesel-electric and diesel-mechanical. Sen et al. (1975) stated that, this is because the maintenance cost for diesel locomotives is three times greater than maintain the electric counterpart, and electric locomotives cause lower operational cost per mileage than run on diesel. Therefore, the traction transformer contains some example that can be applied for application such as electro-locomotives, diesel- locomotives, electrical multiple unit (EMU) and system trans.

Figure 2.6 shows that the standard block diagram of electric locomotive that have been used in Malaysia and other countries. Other than that, the main transformer of rolling stock is one of the important part that need to be maintenance because it carries the electric power supply to the train. In the transformer, it also contains oil which act as cooling agent to the transformer. Right now, there were no dry transformers oil rail vehicle because the oil is very good in insulating at the high voltages and also an excellent coolant (Agnihotric, 2019). Agnihotric (2019) states that HSR team developed an air-cooled system that are effective which can avoid any water in the ambient air from condensing in the transformer and causing a shirt circuit. Next, by using the electric locomotive it will reduce the cost of maintenance, the cleanliness also will be free from smoke and flue gasses and will saving in high grade coal.

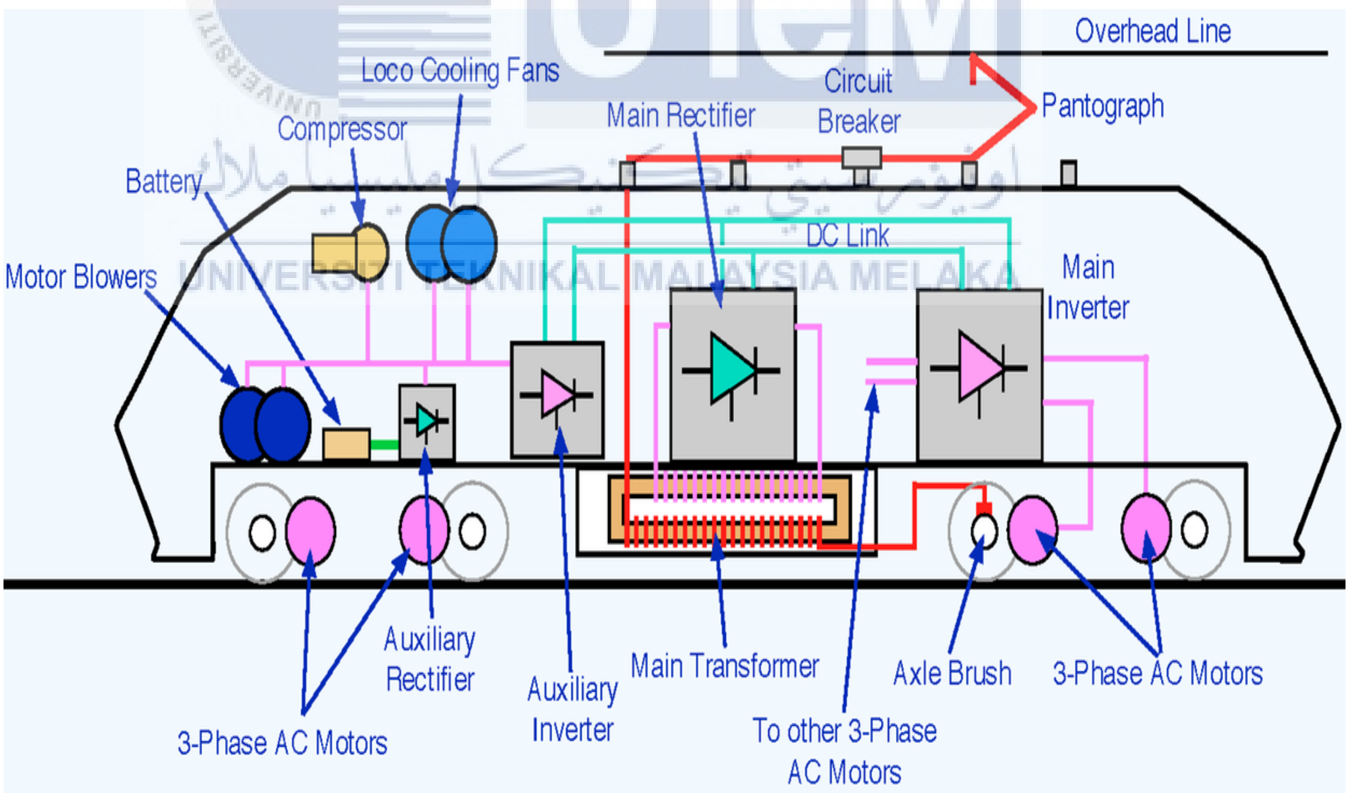

Figure 2.6: Block diagram of electric locomotive

2.3 Transformer oil

Oil is lubricant that have base fluid and the base fluid usually petroleum origin, mixture with an additive chemical that inflate the various beneficial properties for a base fluid (Gidhar & Scheffer, 2004). Transformer oil is one of the oil that can remain safe at the high temperatures compared to other oil although it is also the best in insulating properties, the good in degeneration stability, low number of votality which is a substance's propensity to evaporate at normal temperatures, and grease formation. Next, before the oil need to be maintenance, the **Figure 2.7** shows the information provided by in-service oil analysis. Cade (2017) briefly states that the transformer oil mainly has two functions which are it acts as liquid insulation in electrical power transformer and secondly, it eliminates the heat produced by the transformer and act as a coolant. Moreover, with the good insulator of oil, the performance of transformer is increasing which can reduce the maintenance cost and also increase the distance travel.

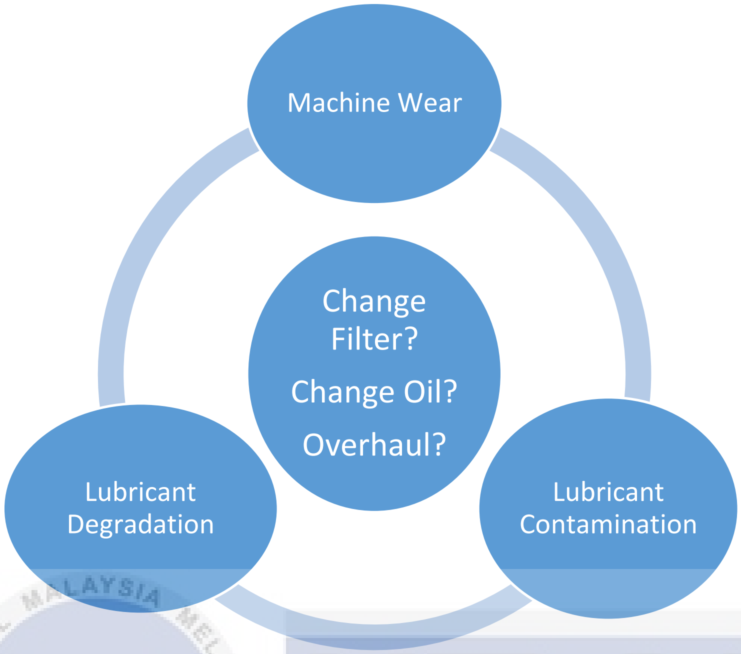

Figure 2.7: Information provided by in-service oil analysis

Solid and liquid form are an example of contamination in oil. Particle counts and sizing techniques are some ways that can be used to monitor the solid contaminants like sand and dirt. By less monitoring toward the oils, the number of contaminations will be increase although reduce the useful life of the oil and machine wear. They need to be avoided proactively with proper seals and proper filtration system and also need to be monitored regularly. By monitoring the lubricant degradation helps to decide whether the oil is fit to use or need to be changed. Then, the viscosity of the oil also can be monitored in order to determine whether the oil viscosity is in good condition or the oil need to be changed. Moreover, usually the viscosity of the oil is test by 40˚C for rotating machine while 100 ˚C for engines (Zhao, 2017).

For the transformer oil, the oxidation and acidity of the oil (Total Acid Number or TAN) and oxidation, nitration, sulfation and total alkaline additive reserve in oil (Total Base Number or TBN) not quite important because it is only involved in rotating machine that will occurred corrosion. In order to keep the oil is long lasting, oil conditions are to be monitored regularly to make sure the oil is used within its performance specification. In addition, to make a well balanced oil analysis the well monitoring on wear condition, oil contamination and oil degradation. If one of the key parameters ore more exceeds the alarm limits or a change in the trending rate is detected, the problems should be resolve to maintains its reliability. The test of the oil can be run by following the flow chart in **Figure 2.8**.

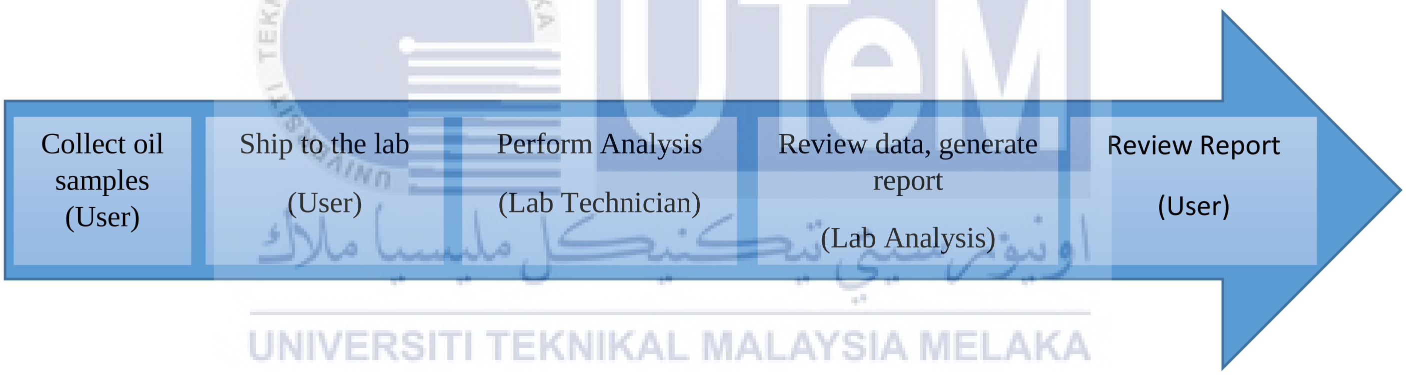

Figure 2.8: Off -site oil analysis flow chart.

2.3.1 Condition Based Maintenance (CBM) on oil analysis

Condition based maintenance (CBM) or predictive maintenance is one method to planned the maintenance based on the knowledge of the state of equipment using condition monitoring techniques (Raposo et al., 2019). Next, the maintenance can be planned before the failure risk become too high. Meanwhile, the CBM have various technologies are used to monitor the signs of problems such as wear debris and oil analysis, vibration analysis and thermography. Furthermore, this method can be applied in order to increase the reliability of the machine. With CBM also, it enhances the machine to run as long as possible before conducting the maintenance and will reducing the cost by eliminating other unnecessary maintenance actions.

2.3.2 Proactive Maintenance on oil analysis

The problem of rolling stock scheduling is a classic and critical issue in the operational planning and implementation of rail activities (Zhong et al., 2019). Proactive maintenance is a maintenance which action is taken ahead of time to minimize the chance of failure rather than waiting for the machine to fail. In other words, the proactive maintenance is to predict and solve the problems before they become a problems or worst. Proactive maintenance is different that predictive maintenance because the proactive maintenance objective is to find the root cause of failure and veracious the problems.

2.4 Oil Analysis

The main reason to perform the oil analysis is to find out the condition of the oil, but it is also to planned to know the condition of the machine where the oil sample was taken (Fitch, 2013). **Table 2.1** shows how the test are used in three main oil analysis which are fluid properties, contamination and wear debris. In fluid properties, it is only focuses the oil's current physical and chemical state while the contamination is only detecting the appearance of destructive contaminants and compact their expected sources. Therefore, the contaminants are only focusing to determine the existence and distinguishing of particles generate as a result of mechanical wear, corrosion or other machine surface mortification.

Table 2.1: How test is used in three main oil analysis categories

Oil Analysis Category	**Tests**
Fluid Properties	Viscosity, Acid/Base Number, FTIR, Elemental Analysis
Contamination	Particle Counting, Moisture Analysis, Elemental Analysis
Wear Debris	Ferrous density, FTIR, Elemental Analysis

A complex laboratory equipment is required to determine the quality of the oil such as viscosity, refractive index, density, base number (BN), acid number (AN), water content, metal (additives and wear metals), but the simple test that can be done on-site is dielectric constant. Oil analysis is not solely an equipment to determine the of a lubricant (Girdhar & Scheffer, 2004). In oil analysis, the good oil can minimize the production of wear to great extent. Therefore, it includes some techniques to evaluate the types and concentration of particles such as viscosity, water content, total acid number (TAN) and total based number (TBN).

Another facet that can be used in oil analysis maintenance program is oil sampling. Reliable of oil analysis can be done by this method and it is vital that the collected sample is allowed to designate the true condition of machine. Viscosity in one of the important test that need to be analyze because the critical oil's analysis will cause to other problems such as oxidation, glycol ingression or thermal stressors. The reading of viscosity that too high or low might cause from the existence of incorrect lubricant, oil oxidation or solvent contamination. Furthermore, at low temperature, the chain of molecules is contracts and does not give impact to the viscosity, but at the high temperature the chain is relaxes and indirectly increase the viscosity. Oil has its limits for viscosity changes and the average of the limit is within 10 percent is marginal limit to 20 percent which is critical limit.

Therefore, in circulating oil systems the best methods to collect the sample oil in live location is in live zone of the system, upstream of filters where the particle is entrance and wear debris is concentrated. Moreover, the new oil must be checked same as used oil, because the new oil is not necessarily clean due to internal and external sources such that the ISO grade quality for cleanliness of oil that acceptable for applications (Girdhar & Scheffer, 2004). **Figure 2.9** shows the standards of the ISO cleanliness code for oil analysis.

By referring to this fluid cleanliness ISO 4406:99 standards, a code number that usually used in the particle count values that acquire at three different micron levels which are greater than 4 microns, greater than 6 microns and greater than 14 microns.

In this example, you can see how the particles measured at the given micron levels are assigned the specific code based on where that value falls in the table. For this example, the ISO code would be 20/17/13.

Table 1

	PARTICLES/ML	ISO CODE
>4 microns	9,721	20
>6 microns	1,254	17
>10 microns	326	
>14 microns	73	13
>21 microns	12	
>38 microns	5	
>70 microns	0	
>100 microns	0	

MORE THAN (p/ml)	UP TO AND INCLUDING (p/ml)	ISO CODE
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8

Figure 2.9: ISO Cleanliness Code

2.5 Dielectric Comparison

Dielectric constant is a quantity that test a substance's ability to store electrical energy in an electrical field. This is important because it allows the materials to hold their specific amount of electric charge for long periods of time. Carey (2019) briefly explained that the function of dielectric constant is to calculate the capabilities to transfer electrical potential energy. The presence of the contaminants such as water or particle or chemical changes of the oil can be compared between the new oil and used oil in the dielectric test. The temperature also affects the value dielectric constant although the effects are small for lubrication oils.

Table 2.2 shows the dielectric constant common materials while **Table 2.3** shows the dielectric constant for lubrication oils. This result can be measured by using common technology which is Fourier-transform infrared spectroscopy (FTIR), but it need an expensive instrument and expert diagnosis. By using FTIR also it promotes the faster, simple, low-cost alternative to permit the divergence between different classes of oil.

Table 2.2: Dielectric Constant common materials

Types of materials	**Dielectric constant value**
Vacuum	1.0
Metals	Infinite
Water	87.9 (0˚C) to 55.5 (100˚C)
Hexane	1.8865 (20˚C)
Cyclohexane	2.0243 (20˚C)
Benzene	2.285 (20˚C)
Hydrocarbon lubricating oils	2.1 to 2.4 (room temperature)

Table 2.3: Dielectric Constant of Lubrication Oils

Types of oil class	**Dielectric constant value**
Hydrocarbon	2.1-2.4
PAO	2.1-2.4
PAG	6.6-7.3
Polyol Ester PAG	4.6-4.8
Diester	3.4-4.3
Phosphate Ester	6.0-7.1

The difference of dielectric between the new oil and used oil also can give crucial data on oil quality. The increasing of bulk dielectric constant is unpleasant and stipulate the presence of some types of contaminant or changes the chemistry for oil, such as oxidation. Furthermore, the factors that will affect the dielectric constant are increasing the viscosity changes in acid number or base number and additive depletion. Other than that, the dielectric constant can reduce by losing or shear down the viscosity-index (VI) improver in example during runs, the VI improvers can shear down and break apart. Moreover, the multi-grades oils cannot stand with high heat. If the oil is runs at extreme high temperature it can begin to crack thermally. The effect of the high temperature will cause the crack or shear of the oil molecules, which affect the viscosity reading.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter will describes the methodology used in this study to gain the data for transformer oil analysis. The general methodology for this study have been shown in Chapter 1. This chapter will describe the flow and details for each method that involved in order to complete the study from the beginning to the end of this project. This study is start by studying the type of transformer and the specification for the transformer before know the type of oils that used for the transformer. There are several methods used with the ends goals to achieve the objectives of the study. The data for railway vehicle maintenance based on the transformer oils' analysis also will be analyzed and study.

3.2 Literature Review

The first important method before started this study is literature review. The important to start this study by literature review because from reviewing the articles and journals from the previous research about the transformer oils' analysis on the railway vehicle maintenance a lot of information and understanding will be gain in order to increase the knowledge and achieve the objectives for this study. From the information collected, the main important in this study that need to be highlight is the quality and performance of the transformer oils' based on the result gain after the experiment have being done.

3.3 General Experimental Setup

Figure 3.1 and **Figure 3.2** show the experimental setup for transformer oils' analysis. For **Figure 3.1** can be used for three experiment which are chemistry test for dielectric, wear and contamination and count contamination. While for **Figure 3.2** is 52DV digital viscometer uses a rotating ball to measure the viscosity if the sample oil. The result will be display in the desktop and it will be analyzing when the test is fully done and can be compared with the reference and other samples. After each of the experiment is done on **Figure 3.1**, the pump is function as flush out the sample oil from chamber to the oil tank in order to remain the cleanliness of the chamber. For the **Figure 3.2** the cleaning process is did manually by take out the ball magnet using magnet pen and dry up the equipment by using tissue paper.

Figure 3.1: Front view of model 5200

Figure 3.2: 52DV model for viscosity test

3.4 Procedure and Result for Oil Analysis

In this stage, the result is collected from the test experiments that have been done, before the real transformer oils' is used for this study. The test is make from several types of sample oil such as engine oil and gearbox oil. Therefore, for the actual test for this experiment should be the sample transformer oil from the local commuter rail transit company that located at Sepang, Malaysia. In this data, it will display the values for the dielectric, wear or contamination, particle count contamination and viscosity test. From the data gain, the analysis will be performing by observing the collecting data to determine the critical parts in the oils' and its maintenance strategy. The result will be discussed on the next chapter.

3.5 Procedure for the Test

This Spectro 5200 Trivector minilab model consist of three experiment while 52DV contain one experiment which are:

1. Chemistry test

a. The empty sample bottle is weighted at the electronic weighing scale.

b. The sample is weighted bottle with the 10 ml new oil NASA DEXRON III.

c. The sample bottle with mixture of 10 ml of new oil and 10 ml of diluted is weighted.

d. Bottle sample of oil is shake to get an equal mixture.

e. The mixture is poured into test 1 chamber.

f. The next button is press on the flashing Test 1 LED. This will take about 5 seconds. Then it will change to red solid red color and the results will automatically read and saved to the database.

g. When LED turns to yellow color, the test place need to be clean Test 1. This may occur immediately after Test 1, if it is the only test in sequence, or at some later time if other tests are being run.

h. Test 1 is flushed. Foot pedal is used to removed out the liquid form the Test 1 to the waste tank.

i. Test 1 is cleaned. Pour lamp oil to the chambers to remove out the oil. This process will occurred around 5 to 10 seconds and the vacuum air will use through the chamber to dry it.

j. Check the chamber by clicking the yellow color button in order to check the chamber cleanliness. It will give result for the cleanliness of the chamber.

k. Next test can be proceed if the first chamber is clean enough.

2. Wear and Contamination

a. The empty sample bottle is weighted at the electronic weighing scale.

b. The sample bottle is weighted with the 10 ml new oil NASA DEXRON III.

c. The sample bottle with mixture of 10 ml of new oil and 10 ml of diluted is weighted.

d. Dilute the sample approximately 1:1 in its original sample bottle, using the appropriate solvent.

e. The lid is replaced on the sample bottle and vigorously shake until the LED turns to green color that will indicate the sample may be added.

f. The diluted oil sample is poured into the chamber of Test 2 up to the top of the tapered cone- this takes about 20 ml. The sensor senses the fluid automatically, begins the check by itself and finishes blinking the Light.

g. This test takes approximately four minutes to complete.

h. When the test is finished, the yellow LED will flash and the chamber can be clean.

i. Test 2 is cleaned by pouring the lamp oil to the Test 2 chamber in order to flush out flush out the sample. This will take around 5 to 10 seconds to clean it up.

j. The chamber is checked by pressing the Test 2 button. Then it will give result towards the chamber cleanliness.

3. Particle Counts

a. Visually inspect the undiluted sample to determine whether additional dilution is required, using the same solvent as for Test 2 when diluting for high contamination or dark oils. If diluting is caused by water pollution because the sample is cloudy or milky, instead using water-masking solvent. Decision must be made before the test started.

b. When using the scale, the software will prompt you for re-weighing after filling Test 2 if additional dilution has been selected. If not using the scale, you must type in the relatives volumes to give the correct dilution ratios.

c. The diluted oil sample is shake with mix the solvent and re-suspend the particles.

d. New syringe package is opened and 30 ml is extract of diluted sample from the bottle.

e. Fully extend the syringe plunger to create an air gap, until the plunger hits the built-in stop.

f. The syringe is inserted at the spacer to hold the plunger out and place the tip of the syringe into degassing port.

g. The valve is turned on the 5200 on the degas position pointing up.

h. The foot pedal is used to run the vacuum pump so that any air bubbles in the oil can be removed by the syringe. This will take from 15 seconds up to a minute depends upon the viscosity of the dilution. For thicker dilutions, you will see a wave bubbles rise to the top.

i. Button for Test 3 is pushed in order to give information the degassing is complete. After a few seconds the LED start flashing green.

j. The syringe is removed into Test 3 test port and clip the body in place.

k. The Test 3 button is pushed next to the flashing green LED. The LED should stop flashing and the stepper motor arm will come down and drive the syringe plunger at a constant rate. The first 10 ml pushed through the syringe is flush volume, the next 15 ml are Counted as the fluids goes through the laser sensor and approximately 5 ml are left in the syringe at the end and can be discarded.

l. At the end of the test, the Test 3 LED will change from the green to red indicating that the data has been automatically saved to the database. The motor will reverse and return the arm to the top, home position.

m. Removed used syringe. The syringe cannot be used because has been contaminated.

4. Viscosity

a. 20 ml of the new oil of NASA DEXRON III oil is poured to the 52DV model.

b. The button start for Test 4 is pushed at the software.

c. This test will take around 10 to 20 seconds to get the reading.

d. The step a, b and c is repeated for the used oil.

e. The viscosity reading will appear in the software for new and used oil.

3.6 Preliminary Result for Oil Analysis

NASA automatic transmission Dexron oil is shown in **Figure 3.3**. Four test is done by using NASA automatic transmission Dexron oil such as chemistry test, wear and contamination test, particle count test and viscosity test. The objective of this test to analyze and compare the new and use oil result.

Figure 3.3: NASA automatic transmission Dexron oil

Experiment 1: Chemistry test result

Table 3.1 shows the chemistry test result for Dexron oil. The chemistry test shows the new oil data and also used oil data in order to make comparison between the oil

Table 3.1: Result for chemistry test (Dexron oil)

Test	Unused Oil	Used Oil	Unit
Dielectric	2.13	1.12	-

Experiment 2: Wear and Contamination Test

Table 3.2 shows the wear and contamination test result for Dexron oil. The objective for this test is to determine the contamination and non-ferrous index for both Dexron oil.

Table 3.2: Result for wear and contamination test (Dexron oil)

Test	Unused Oil	Used Oil	Unit
Contamination Index	1	0	
Non-Ferrous Index	1	0	

Experiment 3: Contamination (Particle Count) Test

Particle count test result for used and new oil for Dexron oil is shown in **Table 3.3**. This result is used to know the quantity of particle counts/ml contained in the oil. Therefore, new and used oil is test to compare the result.

Table 3.3: Result for particle count test (Dexron oil)

Test NIST Size µm(c)	**Unused Oil**	**Used Oil**	**Unit**
> 4	1024	7901	Counts/ml
> 6	249	868	Counts/ml
> 10	53.5	82.9	Counts/ml
> 14	21.9	19.6	Counts/ml
> 18	12.0	10.2	Counts/ml
> 22	8.1	6.7	Counts/ml
> 26	7.5	6.3	Counts/ml
> 32	6.7	5.7	Counts/ml
> 38	6.0	5.1	Counts/ml
> 56	n/a	n/a	Counts/ml
> 70	5.1	4.0	Counts/ml

Experiment 4: ISO Cleanliness Data Test

Table 3.4 shows the ISO cleanliness data test for Dexron oil. The test is done by comparing two oil which are used and new oil for Dexron oil. Result is used to make comparison for both oil.

Table 3.4: ISO cleanliness data test (Dexron oil)

Test NIST Size µm(c)	**Unused Oil**	**Used Oil**	**Unit**
ISO > 4	17	20	-
ISO > 6	15	17	-
ISO > 14	12	11	-

Experiment 5: Viscometer Test

Viscosity test is used to check the lubricant's resistance to flow in specific temperature. Therefore, **Table 3.5** shows the viscometer test in Dexron oil for new and used oil.

Table 3.5: Result for viscometer test (Dexron oil)

Test	**Unused Oil**	**Used Oil**	**Unit**
Viscosity at 40C	13.5	13.5	cSt
Viscosity at 100C	4.8	4.8	cSt
Viscosity index	335	335	cSt
Specific gravity	0.87	0.87	-
Final Result :			
-Viscosity at 40C	50.3	51.0	cSt
- % Viscosity change	272.9	277.6	-

Figure 3.4 shows the Motul oil Technosynthese 4T. The Motul oil Technosynthese 4T is used to make some test toward it such as chemistry test, wear and contamination test, particle count test and viscosity test. The result from new and used oil is compared and has being analyzed.

Figure 3.4: Motul oil Technosynthese 4T

Experiment 1: Chemistry Test

Table 3.6 shows the chemistry test result for Motul oil. The dielectric strength result is compared between new and used oil.

Table 3.6: Result for chemistry test (Motul oil)

Test	**Unused Oil**	**Used Oil**	**Unit**
Dielectric	1.12	1.12	-

Experiment 2: Wear and Contamination Test

Table 3.7 shows the comparison between new and used oil for Motul oil. The objective for thus test to check the contamination index and non-ferrous index in the oil.

Table 3.7: Result for contamination test (Motul oil)

Test	Unused Oil	Used Oil	Unit
Contamination Index	1.2	1.5	-
Non-Ferrous Index	0	0	-

Experiment 3: Contamination (Particle Count) Test

Table 3.8 shows the particle count test result. This test is used to know the most particle count test in the oil.

Table 3.8: Result for particle count test (Motul oil)

Test NIST Size µm(c)	**Unused Oil**	**Used Oil**	**Unit**
> 4	1024	7901	Counts/ml
> 6	249	868	Counts/ml
> 10	53.5	82.9	Counts/ml
> 14	21.9	19.6	Counts/ml
> 18	12.0	10.2	Counts/ml
> 22	8.1	6.7	Counts/ml
> 26	7.5	6.3	Counts/ml
> 32	6.7	5.7	Counts/ml
> 38	6.0	5.1	Counts/ml
> 56	n/a	n/a	Counts/ml
> 70	5.1	4.0	Counts/ml

Experiment 4: ISO Cleanliness Code Test

ISO cleanliness code is used to check the cleanliness of the oil. Therefore, the test is done for both oil and the result is shown in **Table 3.9**.

Table 3.9: Result for ISO cleanliness code test (Motul oil)

Test NIST Size µm(c)	**Unused Oil**	**Used Oil**	**Unit**
ISO > 4	22	23	-
ISO > 6	21	21	-
ISO > 14	15	15	-

Experiment 5: Viscometer Test

Table 3.10 shows the viscometer test result for Motul oil. The new and used oil are tested and the result is compared for both oil.

Table 3.10: Result for viscometer test (Motul oil)

Test	**Unused Oil**	**Used Oil**	**Unit**
Final Result :			
-Viscosity at 40C	155.5	89.6	cSt
- % Viscosity change	546.0	1051.7	-

CHAPTER 4

RESULT and DISCUSSION

4.1 Introduction

Chapter 4 are discussed on the findings towards the data that obtained from the transformer oil analysis report towards the maintenance railway vehicle issues that only focused on express and transit train. Bar graph method is used in order to analyze the result obtained that causes the decreasing of quality of transformer oil such as increasing and decreasing dielectric strength. Every of the transit and express train transformer have their own maintenance issues that need to be focus on in order to increase the reliability of the transformer oil. The example of the maintenance issues that focused are dielectric strength of the transformer oil, water content in the oil, the interfacial tension in the oil, the quantity of methane in the oil and the acid amount. This maintenance issues also need to monitor in order to reduce the maintenance and labor cost. In this part, each of transit and express train transformer maintenance issues that found are being discussed by using bar graph. The name of train is labelled with capital T and capital X that shows T for transit while X is for express. As example the T101 A1, T101 B1, X101 A1 and X101 B1 is function as ID number for the train. Furthermore, each of train consist a couple of transformer that labelled as A1 and B1.

4.2 Result for Oil Analysis

In this part the oil analysis for transit and express train has been analyzed. Therefore, it consists four main aspects such as dielectric strength, water content, acid number and interfacial tension. This part also important to make discussion whether the transformer oil for all train still can be used, need to be filter or changed the oil.

4.2.1 Transit Train T101 A1 and T101 B1

The dielectric strength of oil is function as an electrical insulator towards transformer devices in the high electrical fields (Aberoumand et al., 2018) or in order words is the oil ability to transmit electrical potential energy. **Table 4.1** shows the dielectric strength result for transit train T101 A1 and T101 B1. The highest value than reference point means that the oil still reliable to use.

Table 4.1: Dielectric strength result for transit train T101 A1 and T101 B1

Dielectric Strength (kV)		
Type of Train Transformer / Sampling Date	T101 A1	T101 B1
08.4.15	31	54
17.11.15	31	50
09.5.16	40	57
23.11.16	40	42
24.5.17	40	48
22.11.17	35	36
15.5.18	45	53
13.11.18	33	38
08.07.19	40	32
Reference Point	>30	

From the **Figure 4.1** shows that, the lowest reading value for dielectric strength for T101 A1 is 22 kV at 15th May 2018 while for the T101 B1 also at 15th May 2018 which is 21 kV. The highest value for the T101 A1 is 34 kV while for T101 B1 is 32 kV. The average value of dielectric strength for T101 A1 is 34 kV while for T101 B1 is 31 kV. The decreasing value of dielectric strength as the density decrease, because of the temperature increase. Other than that, dielectric strength is an important part need to be measure because it acts as insulator in transformer devices that worked under high electrical fields (Aberoumand & Jafarimoghaddam, 2018). The reference point or minimum value for the dielectric strength is 30 kV.

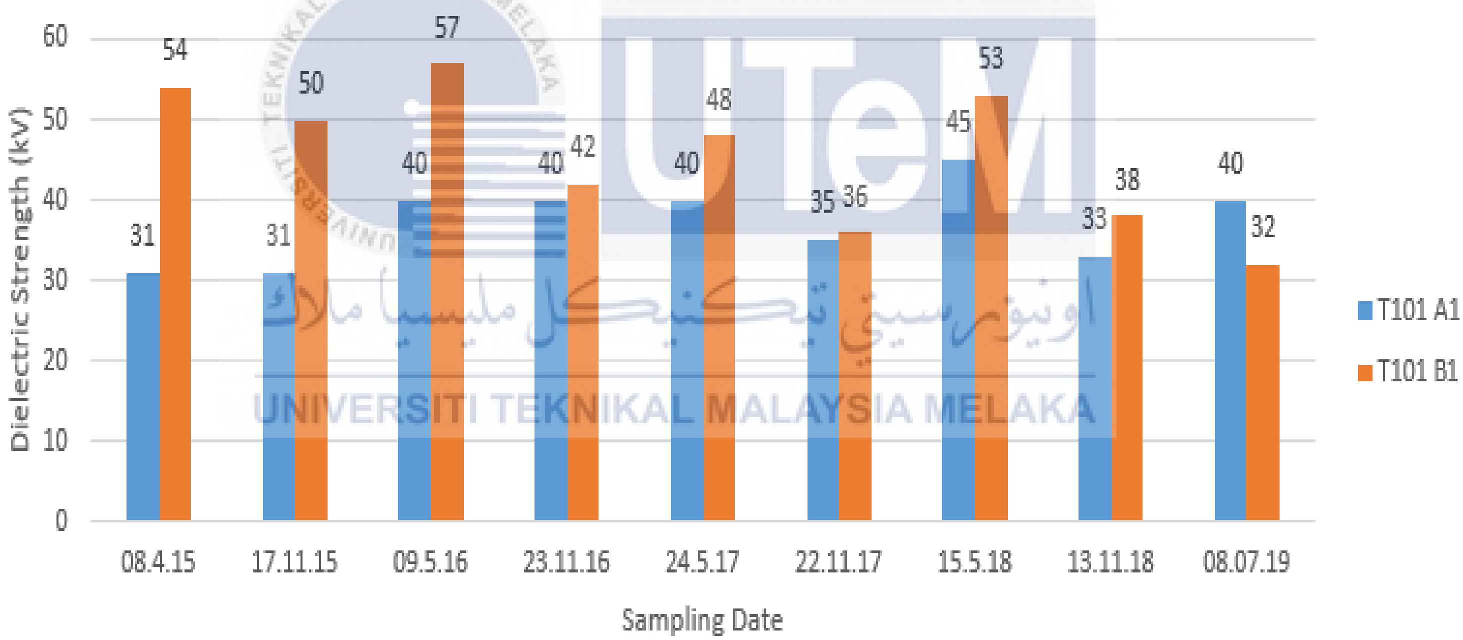

Figure 4.1: Dielectric Strength for transit train T101 A1 and T101 B1

Table 4.2 shows the water content result for transit train T101 A1 and T101 B1. The water content can cause oxidation and reduce dilution for oil that may affect the quality of oil.

Table 4.2: Water content result for transit train T101 A1 and T101 B1

Water Content (ppm)		
Type of Train Transformer / **Sampling Date**	**T101 A1**	**T101 B1**
08.4.15	34	22
17.11.15	30	25
09.5.16	30	28
23.11.16	34	32
24.5.17	34	31
22.11.17	34	31
15.5.18	22	21
13.11.18	35	31
08.07.19	26	25
Reference Point	<50	

The water content is one of the important part need to be avoided and removed from the oil because the water content will cause the oil viscosity reduced. Other than that, the water content also is one of the oxidation root cause. The maximum point or reference point for water content can be in transformer oil is 50 ppm. For T101 A1, at 15th May 2018 got the lowest reading than the others while the highest reading is 35 ppm at 13th November 2018. From the **Figure 4.2** shows that the average, 34 ppm of water content for T101 A1 is still under the maximum limit. So, the water content at T101 A1 not at the critical point. Therefore, for T101 B1 the lowest value for the water content at 14th May 2018 which is 21 ppm. While the highest reading at 23rd November 2016 which is 32 ppm.

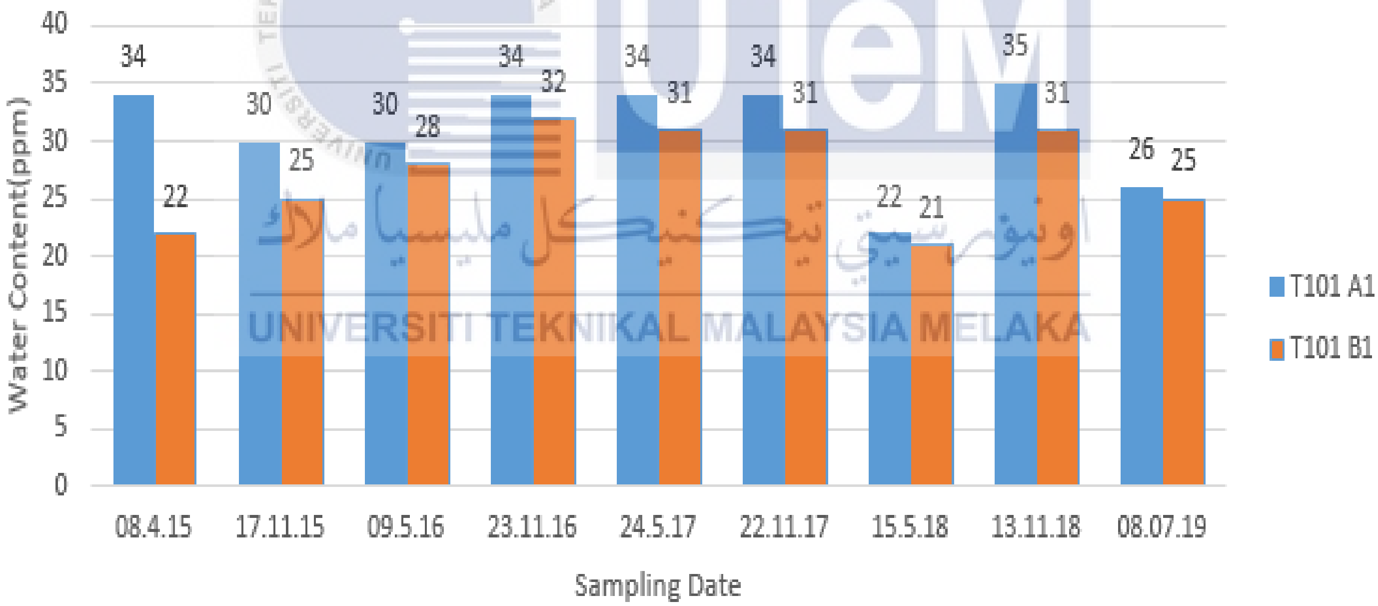

Figure 4.2: Water Content for Transit Train T101 A1 and T101 B1

Table 4.3 shows the acid number for transit train T101 A1 and T101 B1. The exceeding number for acid number can cause oxidation, reduce the quality of oil and its performance.

Table 4.3: Acid number in transformer for transit train T101 A1 and T101 B1

Interfacial Tension (mN/m)		
Type of Train Transformer / Sampling Date	**T101 A1**	**T101 B1**
08.4.15	0.1	0.1
17.11.15	0.1	0.1
09.5.16	0.1	0.1
23.11.16	0.1	0.1
24.5.17	0.1	0.1
22.11.17	0.1	0.1
15.5.18	0.1	0.1
13.11.18	0.1	0.1
08.07.19	0.1	0.1
Reference Point	>0.2	

Figure 4.3 shows the acid number for both T101 ERL transformers for A1 and B1 are constant. Therefore, it is still safe to use because still under the reference value which is 0.2. If the value for acid number is exceeding the reference value it will cause secondary damage not only on the oil but also the component in the transformer. So, the acid number is one of the important part need to be monitored and controlled in order to reduce the maintenance cost.

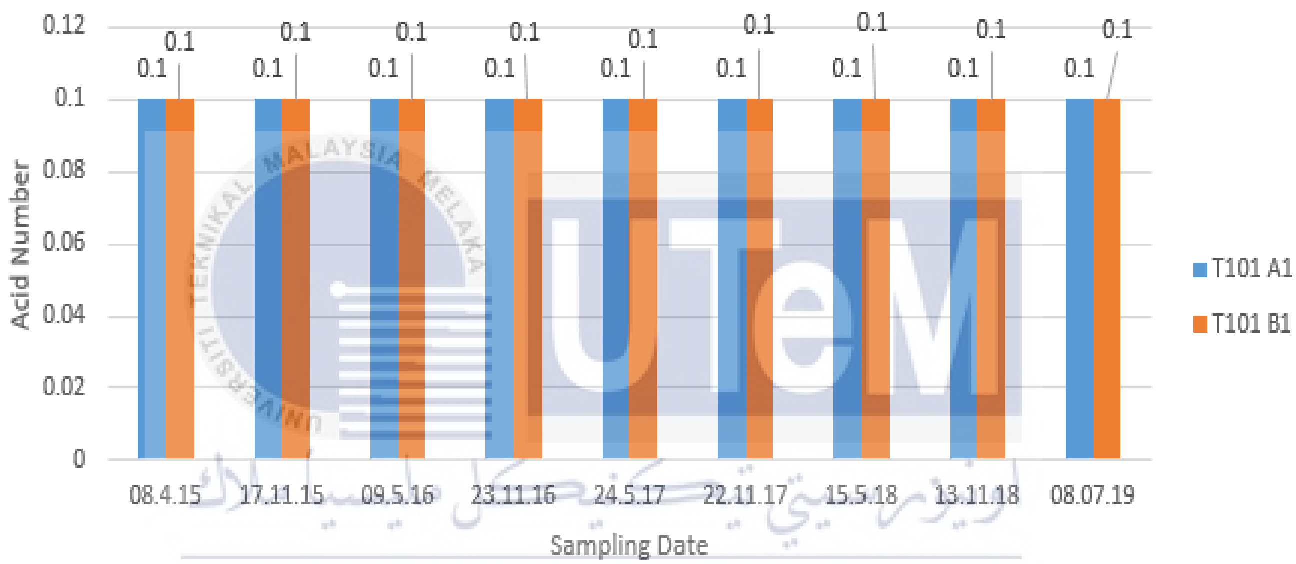

Figure 4.3: Acid Number for T101A1 and T101 B1

Table 4.4 shows the interfacial tension number in transformer train for T101 A1 and T101 B1. The decreasing number for interfacial tension might reduce the quality of oil. Therefore, by reducing the number it will cause the water more diluted.

Table 4.4: Interfacial Tension in transit train for T101 A1 and T101 B1

Interfacial Tension (mN/m)		
Type of Train Transformer / **Sampling Date**	**T101 A1**	**T101 B1**
08.4.15	27.43	20.48
17.11.15	26.49	20.47
09.5.16	26.00	20.81
23.11.16	25.41	18.46
24.5.17	23.78	19.46
22.11.17	24.5	19.7
15.5.18	25.25	21.12
13.11.18	23.06	19.52
08.07.19	22.57	21.65
Reference Point	>20	

The interfacial tension minimum reference point is 20 mN/m. The interfacial tension is attraction force between molecules at the interface of two fluids. From **Figure 4.4** shows that the highest value of interfacial tension is 27.43 mN/m for T101 A1 while for the T101 B1 is 21.65 mN/m. For the T101 B1 shows that the interfacial tension value for the transformer oil need to be monitored because the reading is low. Moreover, the lowest value for interfacial tension of T101 A1 is 22.57 mN/m while T101 B1 is 18.46 mN/m.

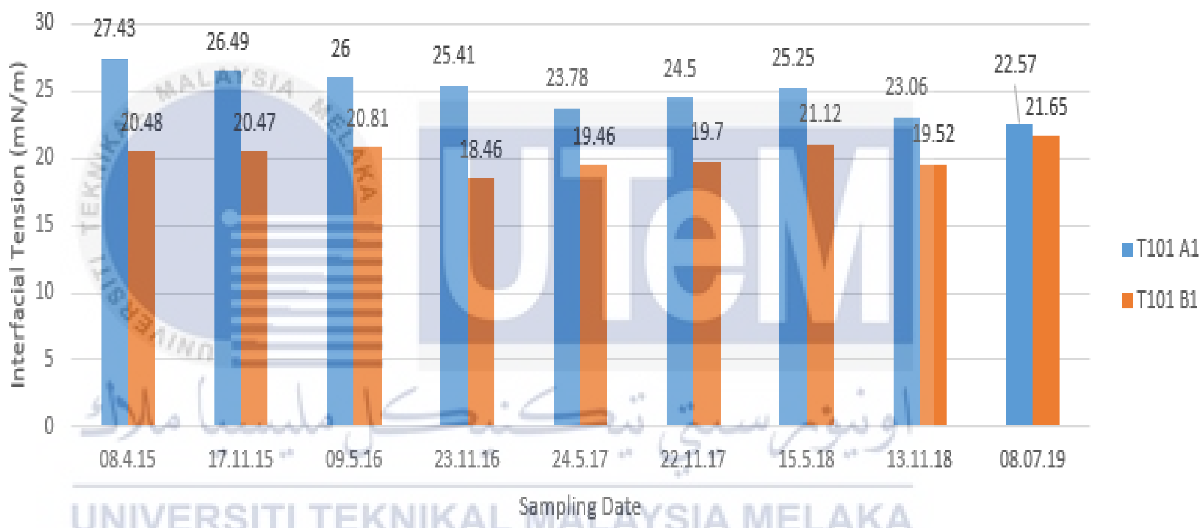

Figure 4.4: Interfacial Tension for T101 A1 and T101 B1

4.2.2 Transit Train T102 A1 and T102 B1

Table 4.5 shows the dielectric strength for transit train for T102 A1 and T101 B1. Dielectric strength is an important part to monitor in order to maintain its insulation and coolant for the transformer.

Table 4.5: Dielectric strength reading for transit train T102 A1 and T102 B1

Dielectric Strength (kV)		
Type of Train / Transformer / Sampling Date	**T102 A1**	**T102 B1**
06.4.15	37	34
16.11.15	45	33
09.5.16	34	32
22.11.16	37	24
22.5.17	35	39
22.11.17	46	39
15.5.18	32	32
12.11.18	34	34
08.7.19	36	40
Reference Point	>30	

From **Figure 4.5** shows that the value for dielectric strength for both transformers in T102. The lowest value for the T102 B1 is 24 kV. At this point, the transformer oil has done the filtering process in order to increase back the dielectric value more than 30 kV. Next, the lowest point for T102 A1 is 32 kV. The point or data that reach or near the minimum point need to be monitored in order to maintain or sustain the reliability of the transformer oil.

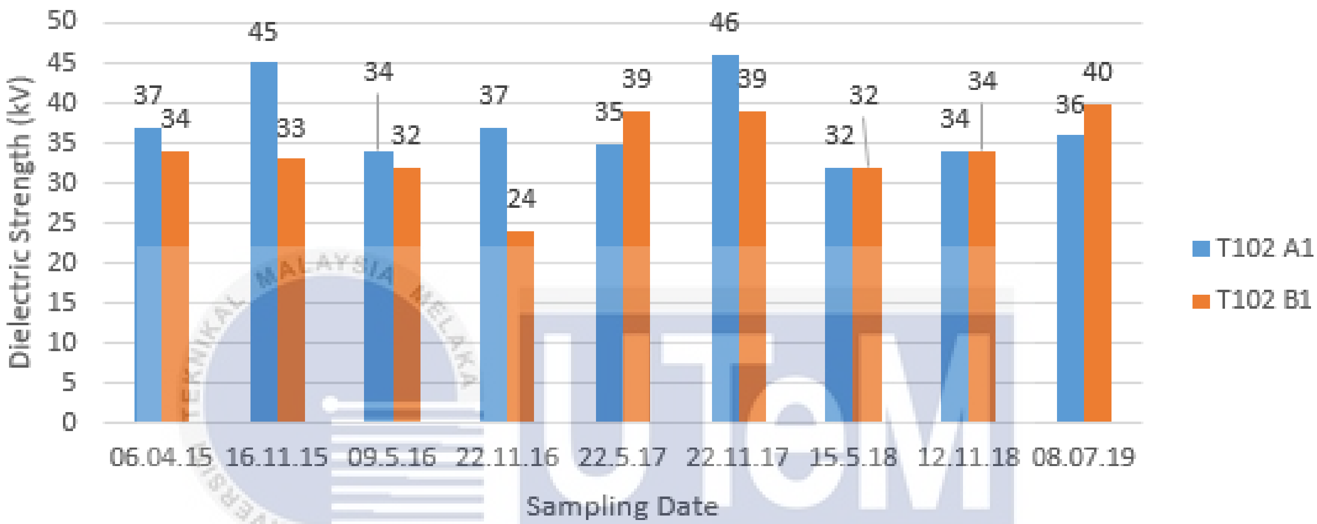

Figure 4.5: Dielectric Strength for T102 A1 and T102 B1

Table 4.6 shows the water content in the oil for both type of transformer. Therefore, the water content in the oil cannot exceed the reference point which is 50 ppm.

Table 4.6: Water content in transit train for T102 A1 and T102 B1

Water Content (ppm)		
Type of Train Transformer / **Sampling Date**	**T102 A1**	**T102 B1**
06.4.15	31	28
16.11.15	25	21
09.5.16	40	40
22.11.16	37	39
22.5.17	33	36
22.11.17	37	39
15.5.18	39	42
12.11.18	40	46
08.7.19	41	34
Reference Point	<50	

Figure 4.6 shows that the water content vs sampling date for both transformers in T102. It shows that the highest value for water content is 41 ppm for T102 A1 while the lowest is 25 ppm. Therefore, for T102 B1 the highest value is 46 ppm and the lowest is 21 ppm. For the highest data in T102 B1 need to be monitored because it near to the maximum point which is 50 ppm. Beyond the maximum point, it will cause the oxidation in the oil that cause more effect such as rusting and foaming of bubble.

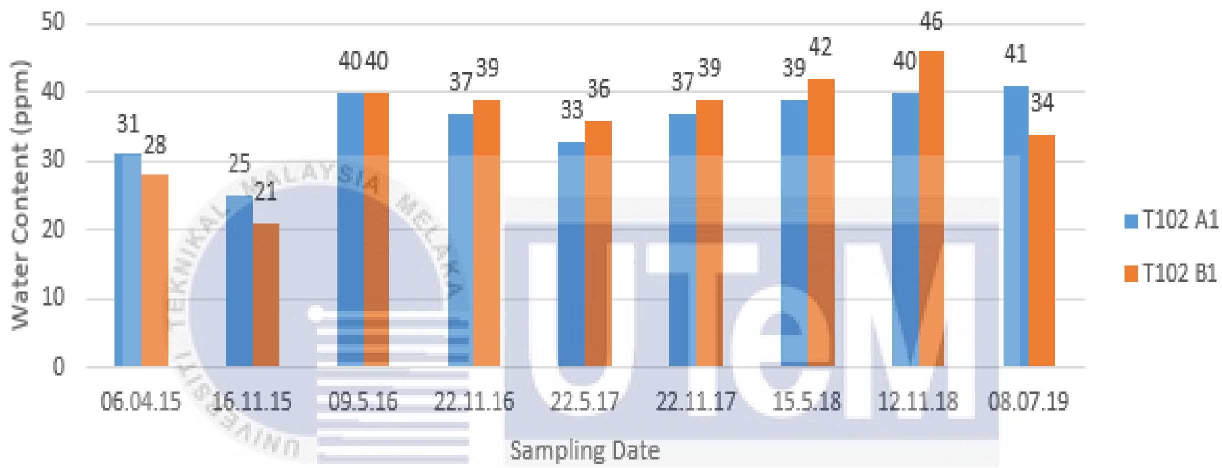

Figure 4.6: Water Content for T102 A1 and T102 B1

Table 4.7 shows the acid number in the transformer oil in transit train T102. The lower the acid number, the lower the oxidation number occurred.

Table 4.7: Acid number in transformer oil for transit train T102

Acid Number		
Type of Train Transformer / Sampling Date	**T102 A1**	**T102 B1**
06.4.15	0.1	0.1
16.11.15	0.1	0.1
09.5.16	0.1	0.1
22.11.16	0.1	0.1
22.5.17	0.1	0.1
22.11.17	0.1	0.1
15.5.18	0.1	0.1
12.11.18	0.1	0.1
08.7.19	0.1	0.1
Reference Point	<0.2	

The reference point for acid number in the transformer oil is 0.2. **Figure 4.7** shows that all the value in the sampling oil is below than 0.2 which are 0.1. So, this oil can be used and will not affect more on the oil properties. The increasing acid number can make the components on the transformer damage such as corrosion and leakage. So, the acid number is one of the important part need to be monitored to ensure the reliability of the oil and the components.

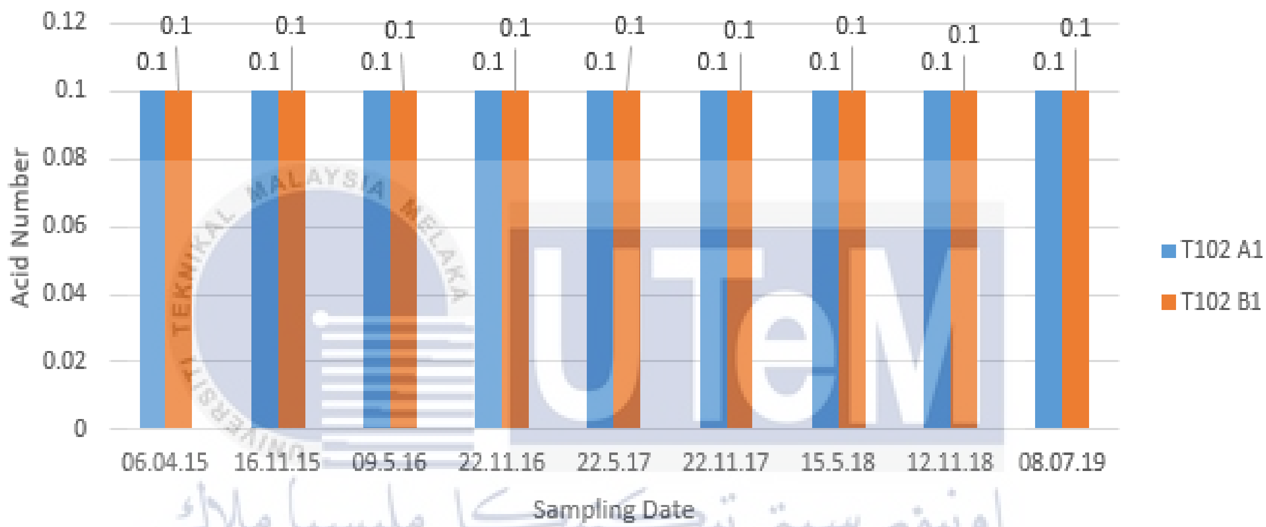

Figure 4.7: Acid Number for T102 A1 and T102 B1

Interfacial tension data for transit train transformer, T102A1 and T102 B1 is shown in **Table 4.8**. Interfacial tension data is used to check the quality of the oil. The higher value for interfacial tension is the best.

Table 4.8: Interfacial tension for transit train oil T102

Interfacial Tension (mN/m)		
Type of Train Transformer / Sampling Date	**T102 A1**	**T102 B1**
06.4.15	23.35	20.2
16.11.15	24.15	20.53
09.5.16	22.75	20.13
22.11.16	22.64	21.43
22.5.17	20.17	19.86
22.11.17	22.78	20.66
15.5.18	23.75	21.75
12.11.18	21.07	23.3
08.7.19	19.5	21.59
Reference Point	>20	

This **Figure 4.8** shows the data obtained based on the interfacial tension vs same sampling date for both transformers. Other than that, for T102 A1 the highest value for interfacial tension is 24.15 mN/m on 16th November 2015 and the lowest value is 19.7 mN/m on 8th July 2019 which is lower than reference point. Next, for T102 B1 the highest value is 21.75 mN/m on 15th May 2018 and the lowest value is 19.86 mN/m on 22nd May 2017 also lower than the reference point. The value that lowest than reference point need to monitored in order to avoid from other foreign particle enter the oil that can cause contaminated.

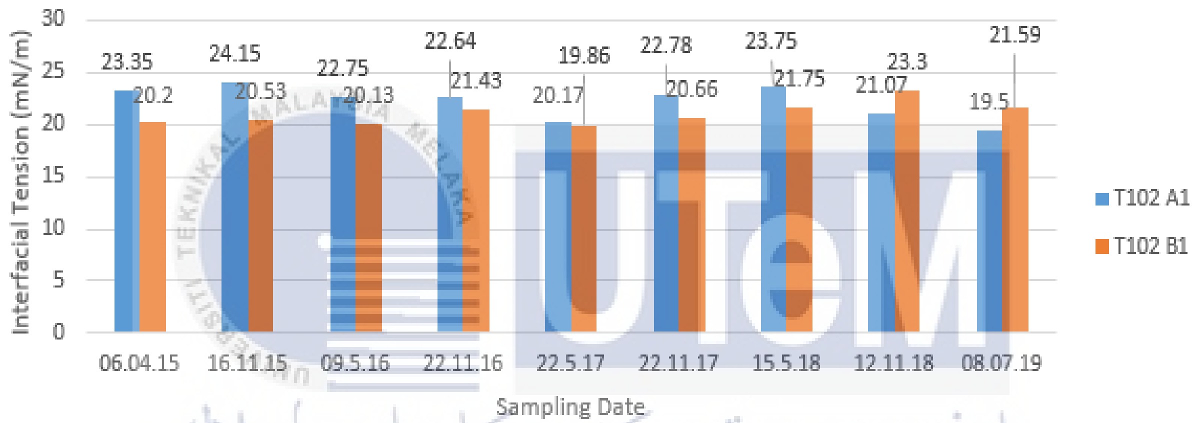

Figure 4.8: Interfacial Tension for T102 A1 and T102 B1

4.2.3 Transit Train T103 A1 and T103 B1

This part is analyzed for transit train T103 transformer, which are A1 and B1 in four major aspects, such as dielectric strength, water content, acid number and interfacial tension. **Table 4.9** shows the dielectric strength for T103 transit train. Dielectric has two function which are as insulator and coolant.

Table 4.9: Dielectric Strength for transit train T103

Dielectric Strength (kV)		
Type of Train Transformer / **Sampling Date**	**T103 A1**	**T103 B1**
06.4.15	44.6	37
18.11.15	40	31
09.5.16	43	32
23.11.16	40	39
23.5.17	36	36
20.11.17	41	41
16.5.18	34	33
14.11.18	34	38
08.07.19	31	36
Reference Point	>30	

Figure 4.9 shows the data for dielectric strength for train T103 A1 and T103 B1. At 20th May 2018 and 23rd November 2016 shows that the same value of dielectric strength for both transformers which is 41 kV and 36 kV. Therefore, the lowest value for both transformers is 31 kV at 8th July 2019 for T103 B1 while 31 kV for T103 A1 at 18th November 2015. Moreover, the highest dielectric strength for both transformer is 44.6 kV, it shows that the transformer oil is at good performance in order to act as insulator for the transformer device. So, the dielectric strength data obtain in the **Figure 4.9** shows that the transformer oil can be used and do not to perform any filtration process.

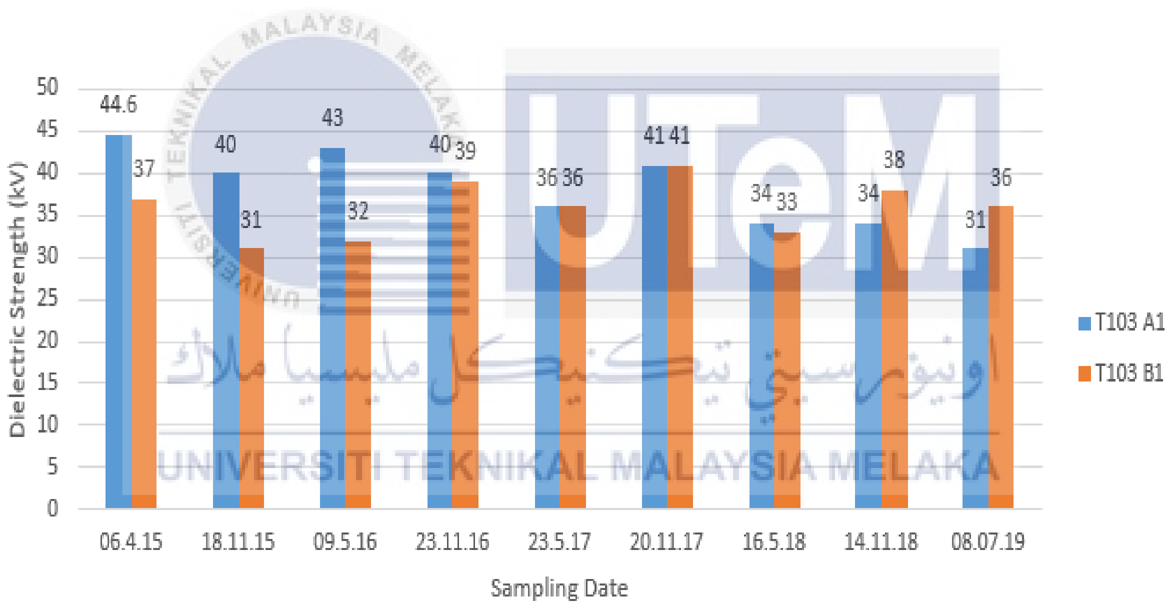

Figure 4.9: Dielectric Strength for T103 A1 and T103 B1

Table 4.10 shows the water content in the transit train for both transformers A1 and B1 for T103. The water must below the 50 ppm to ensure no oxidation and dilution of the oil can occur.

Table 4.10: Water content in transformer oil for T103

Water Content (ppm)		
Type of Train Transformer / **Sampling Date**	**T103 A1**	**T103 B1**
06.4.15	27	35
18.11.15	38	41
09.5.16	37	39
23.11.16	37	33
23.5.17	34	31
20.11.17	30	30
16.5.18	29	30
14.11.18	31	31
08.07.19	37	32
Reference Point	<50	

Water content is one of the important part need to be maintenance in transformer because, the water content will cause an oxidation and produce foam in the oil. So it will cause the corrosion hence increase the acidic number in the oil. The data shows in **Figure 4.10** shows that the water content for both transformers still under control because not reach the maximum point, 50 ppm. Therefore, every 6-month oil sampling need to be done in order to make the transformer oil in good condition and reliable. The lower the water content is good, because can avoid the viscosity more diluted and decrease the additive in the transformer oils. The highest value for T103 A1 is 38 ppm while the lowest value is 27 ppm. Next, for T103 B1 the lowest value is 30 ppm on 20th November 2017 and 16th May 2018 while the highest value is 41 ppm on 18th November 2015.

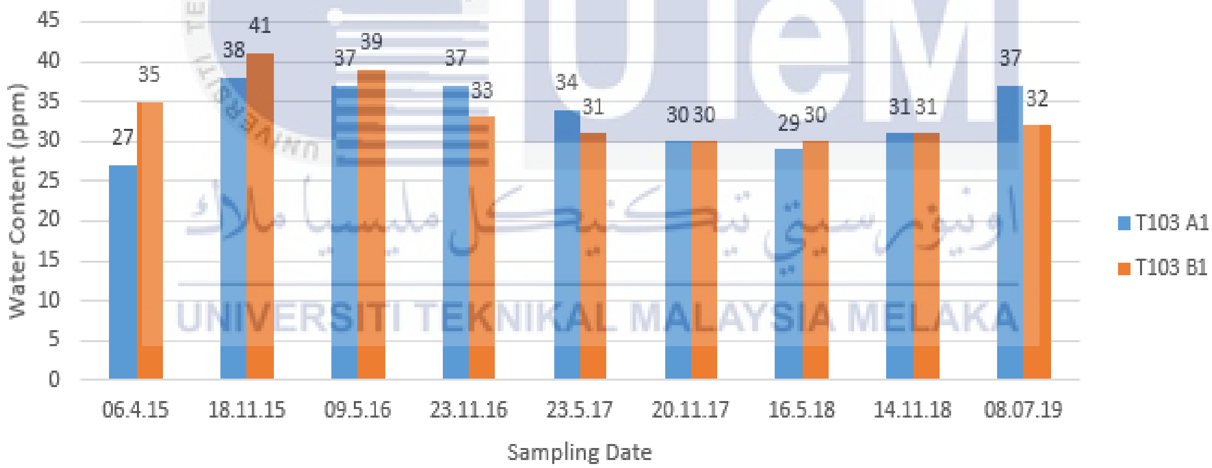

Figure 4.10: Water Content for T103 A1 and T103 B1

Table 4.11 shows the acid number for transit train T103. The oxidation can cause secondary damage towards the transformer parts and winding such as leakage and corrosion.

Table 4.11: Acid number for T103 A1 and T103 B1

Acid Number		
Type of Train Transformer / Sampling Date	**T103 A1**	**T103 B1**
06.4.15	0.1	0.1
18.11.15	0.2	0.1
09.5.16	0.1	0.1
23.11.16	0.1	0.1
23.5.17	0.1	0.1
20.11.17	0.1	0.1
16.5.18	0.1	0.1
14.11.18	0.1	0.1
08.07.19	0.1	0.1
Reference Point	<0.2	

The **Figure 4.11** shows that the value for acid number for T103 A1 and T103 B1. From the graph shows that, the value for 18th November 2015 for T103 A1 much higher than T103 B1 and also higher than others sampling data. This shows that, the sampling oil might have some contaminants that make the acid number value increase such as air contaminants. Although the value is higher than the others, the oil still safe and can be used because it not exceeding the reference point which is 0.2. Therefore, for the other data the values are remain same which is 0.1.

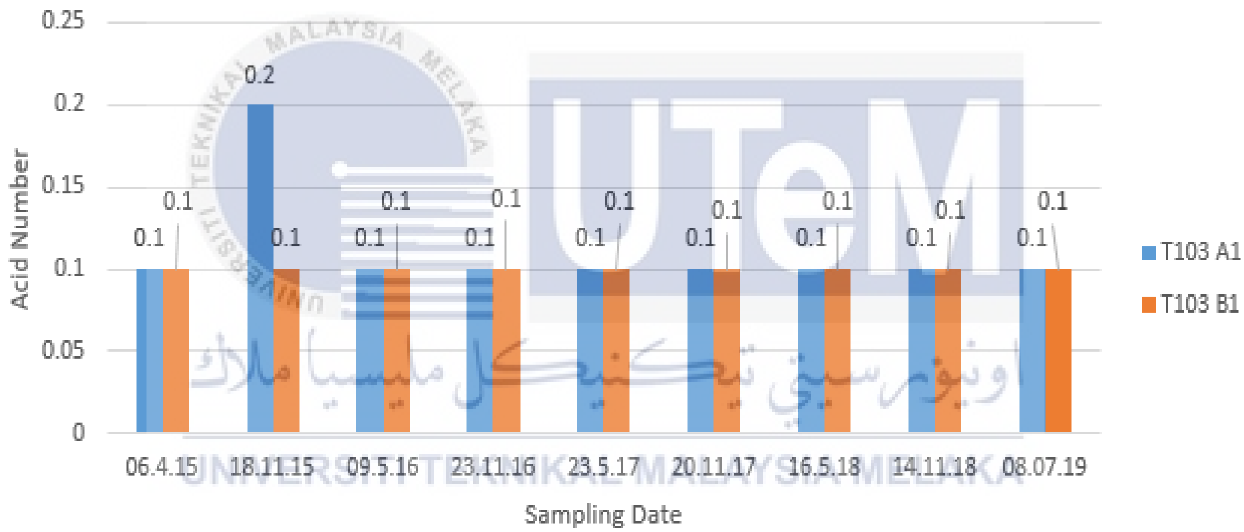

Figure 4.11: Acid Number for T103 A1 and T103 B1

Table 4.12 shows an interfacial tension value for transit train transformer A1 and B1. The interfacial result need exceed the reference point which is 20 mN/m.

Table 4.12: Interfacial tension value for transit train transformer oil, A1 and B1

Interfacial Tension (mN/m)		
Type of Train Transformer / **Sampling Date**	**T103 A1**	**T103 B1**
06.4.15	20.94	24.13
18.11.15	23.54	24.59
09.5.16	20.7	24.83
23.11.16	21.56	24.36
23.5.17	20.8	23.42
20.11.17	20.71	23.78
16.5.18	20.1	23.39
14.11.18	18.11	20.85
08.07.19	20.55	23.44
Reference Point	>20	

Figure 4.12 shows that the fluctuate data for the oil sampling point for both transformers. The fluctuation value occurred due to some contaminants that affected the interfacial tension such as moisture and particle contaminants. The reference value for this interfacial tension is 20 mN/m, so the data from the oil sampling that have less than reference point need to be monitored and analyzed in order to know the decreasing value of interfacial tension. Moreover, from **Figure 4.12** shows the lowest value is 18.11 mN/m on 14th November 2018 and the highest value is 23.54 mN/m on 18th November 2015 for T103 A1 while for the T103 B1, lowest value is 20.85 mN/m on 14th November 2018 and the highest value is 24.59 mN/m on 18th November 2015.

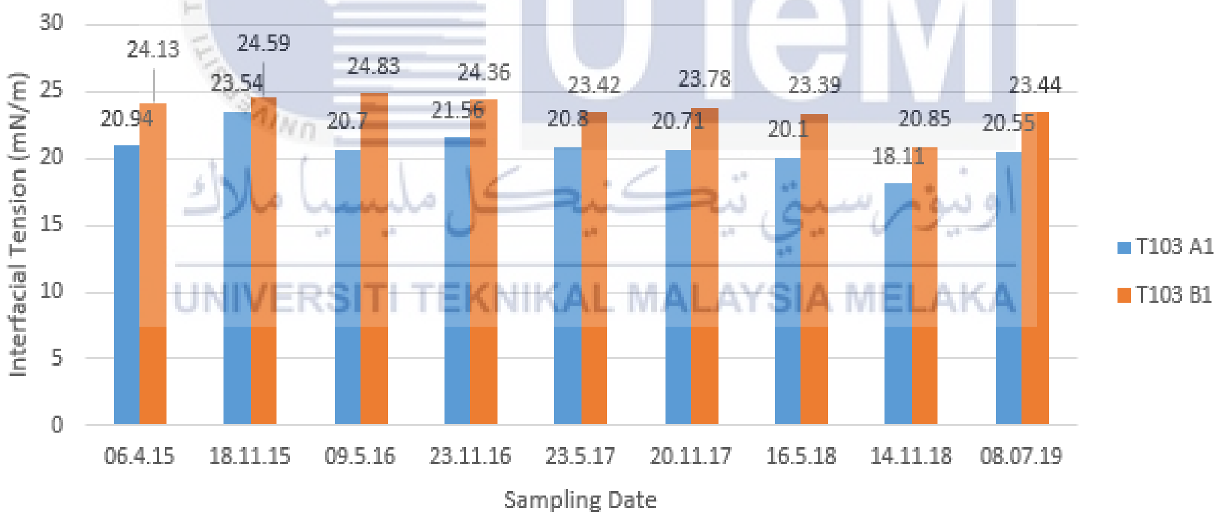

Figure 4.12: Interfacial Tension for T103 A1 and T103 B1

4.2.4 Express Train T104 A1 and T104 B1

This part is analyzed transit train T104. T104 train also has two transformers which are A1 and B1. The transformers are analyzed by using bar graph. **Table 4.13** shows the dielectric strength reading in transformer oil for both transformers.

Table 4.13: Dielectric strength for T104 A1 and T104 B1

Dielectric Strength (kV)		
Type of Train Transformer / Sampling Date	**T102 A1**	**T102 B1**
06.4.15	37	34
16.11.15	45	33
09.5.16	34	32
22.11.16	37	24
22.5.17	35	39
22.11.17	46	39
15.5.18	32	32
12.11.18	34	34
08.7.19	36	40
Reference Point	>30	

Both transformers have increasing linearly and decreasing linearly for dielectric strength. The decreasing data for dielectric strength for both customers due to low dielectric strength because of oil are diluted and have other contaminants that give effect. At 8th July 2019, the data for T104 B1 is less than the minimum reference which is 24 kV. So, the action that can be take is filtration process or cook the oil process which can increase the dielectric strength back. **Figure 4.13** data should be monitor more because the decreasing value of dielectric strength.

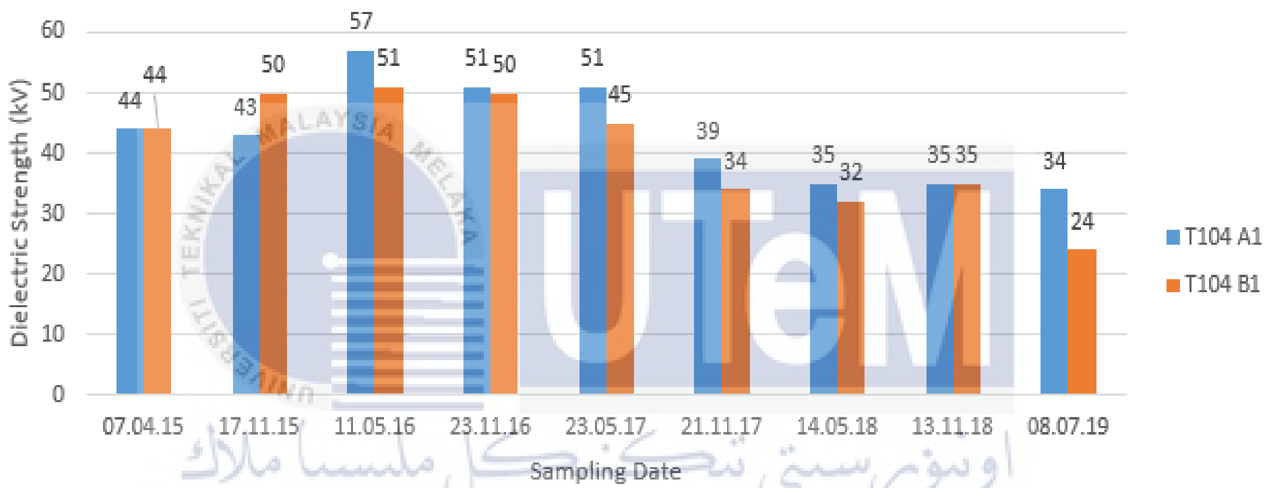

Figure 4.13: Dielectric Strength for T104 A1 and T104 B1

Table 4.14 shows the water content in transformer oil for A1 and B1 in T104. The water content in the oil need to be less than 50 ppm.

Table 4.14: Water content in T104 A1 and T104 B1

Water Content (ppm)		
Type of Train Transformer / **Sampling Date**	**T104 A1**	**T104 B1**
17.11.15	27	29
11.05.16	28	24
23.11.16	31	32
23.05.17	31	31
21.11.17	31	31
14.05.18	33	33
13.11.18	37	36
08.07.19	32	40
Reference Point	<50	

From the overall data in **Figure 4.14**, shows that the water content in the both transformers are under control because below the reference point. The highest value for water content is 40 ppm and the lowest value for water content is 24 ppm. From the graph shows that the average data for water content is 31 ppm for both transformers. Next, the less number of water shows that the oil is in good quality and give the better performance. Water content maybe came from manufacturer itself and also from the environment. Furthermore, the water content in transformer oil need to monitor in order to avoid other failure occurred during operation. This will reduce the unplanned downtime and maintenance cost. However, the transformer oil still safe to use because the reference point is 50 ppm while overall sampling point data is lower than 50 ppm.

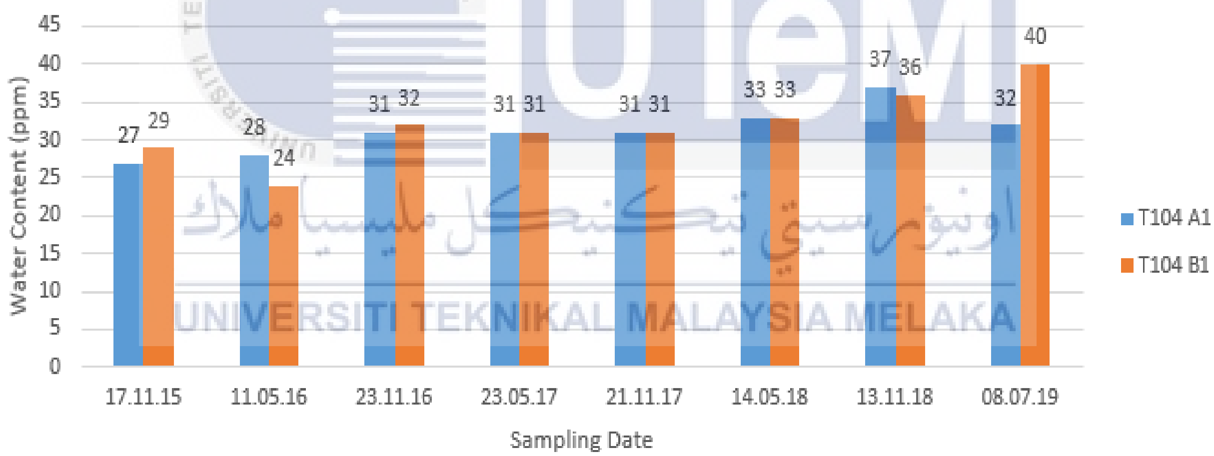

Figure 4.14: Water Content for T104 A1 and T104 B1

Table 4.15 shows the acid number for T104 A1 and T104 B1 transit train. The lowest the value for acid number is the best, in order to reduce the oxidation and increase the reliability of the oil.

Table 4.15: Acid number for T104 A1 and T104 B1

Acid Number		
Type of Train Transformer / Sampling Date	**T104 A1**	**T104 B1**
17.11.15	0.1	0.1
11.05.16	0.1	0.1
23.11.16	0.1	0.1
23.05.17	0.1	0.1
21.11.17	0.1	0.1
14.05.18	0.1	0.1
13.11.18	0.1	0.1
08.07.19	0.1	0.1
Reference Point	<0.2	

Based on **Figure 4.15** shows that the data for acid number is constant from the first sampling date, 7th April 2015 to the last sampling date, 8th July 2019. The acid number in the oil is still safe and the oil still reliable to use because it not exceeds the maximum reference point which us 0.2. Other than that, acid number that exceed the reference point will affect the oil properties hence also affect towards the components of the transformer. So, it need to be monitored to make the condition of the oil still reliable and safe to use.

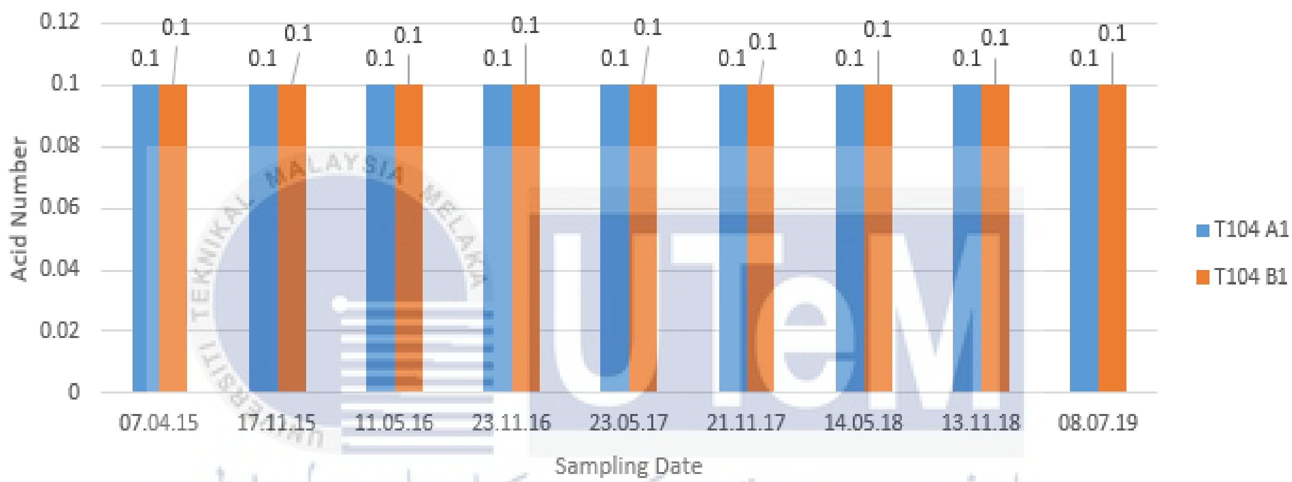

Figure 4.15: Acid Number for T104 A1 and T104 B1

Table 4.16 shows the interfacial tension for T104 A1 and T104 B1. The value for interfacial tension need greater than reference point, 20 mN/m.

Table 4.16: Interfacial Tension for T104 A1 and T104 B1

Interfacial Tension (mN/m)		
Type of Train Transformer / Sampling Date	**T104 A1**	**T104 B1**
17.11.15	22.98	20.33
11.05.16	24.35	23.22
23.11.16	24.35	20.57
23.05.17	22.51	21.04
21.11.17	24.05	22.53
14.05.18	22.14	20.43
13.11.18	21.27	20.21
08.07.19	22.29	24.6
Reference Point	>20	

The reference point for interfacial tension is 20 mN/m. From the **Figure 4.16** shows that overall data for both transformers is upper than the references point so the transformer oil still reliable to use. T104 A1 shows the lowest value for interfacial tension is 21.27 mN/m while the highest value is 24.35 mN/m. Therefore, for the T104 B1 transformer the highest value for interfacial tension is 24.6 mN/m and the lowest value is 20.21 mN/m. Moreover, if the interfacial tension for sampling oil is lower than the reference point, it might easily contaminate with others particle.

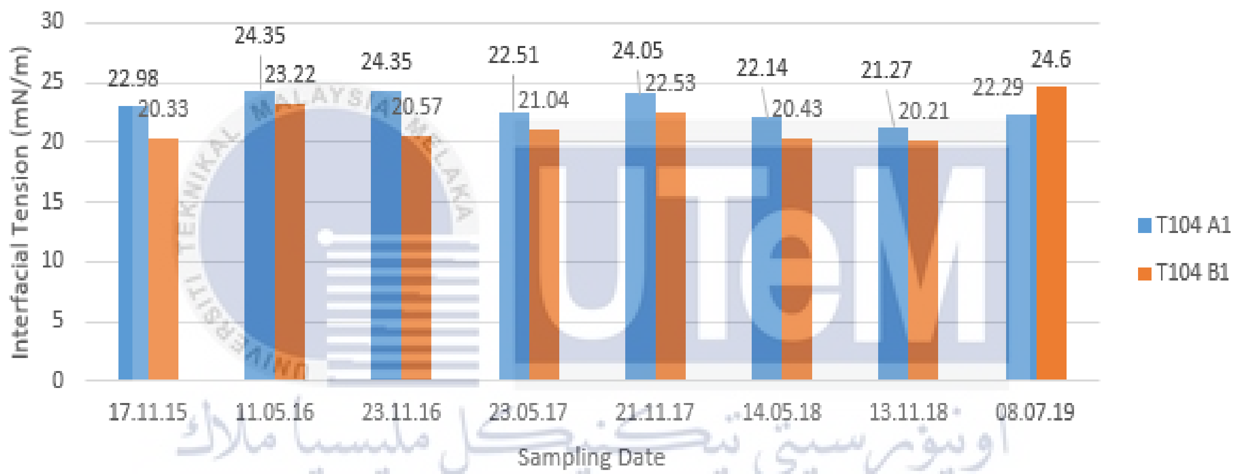

Figure 4.16: Interfacial Tension for T104 A1 and T104 B1

4.2.5 Express Train X102 A1 and X102 B1

Express train is used for far destination and the number of stops is less. Express train is difference from transit train because transit train usually stop at most of the station along the routes. **Table 4.17** shows the dielectric strength for X102 A1 and X102 B1.

Table 4.17: Dielectric strength for express train X102 for transformer A1 and B1

Dielectric Strength (kV)		
Type of Train Transformer / Sampling Date	**X102 A1**	**X102 B1**
07.4.15	32	49
16.11.15	38	41
12.5.16	30	41
22.11.16	46	42
23.5.17	46	36
21.11.17	35	43
15.5.18	31	32
12.11.18	33	36
10.7.19	29	29
Reference Point	>30	

Figure 4.17 shows that the data for the dielectric strength vs sampling date for X102 A1 and X102 B1. From the graph that have been analyzed shows the average value for all dielectric strength still above the reference point which is 30 kV except for the last sampling date on 10th July 2019 shows that for both transformers the value is 29 kV. For the last sampling point, an action must be taken in order to increase back the dielectric strength value for the oil, this is because to ensure that the oil have capability to reach its performance. If the value is lower than reference point, an action such as filtration process need to be done to increase back the dielectric strength value.

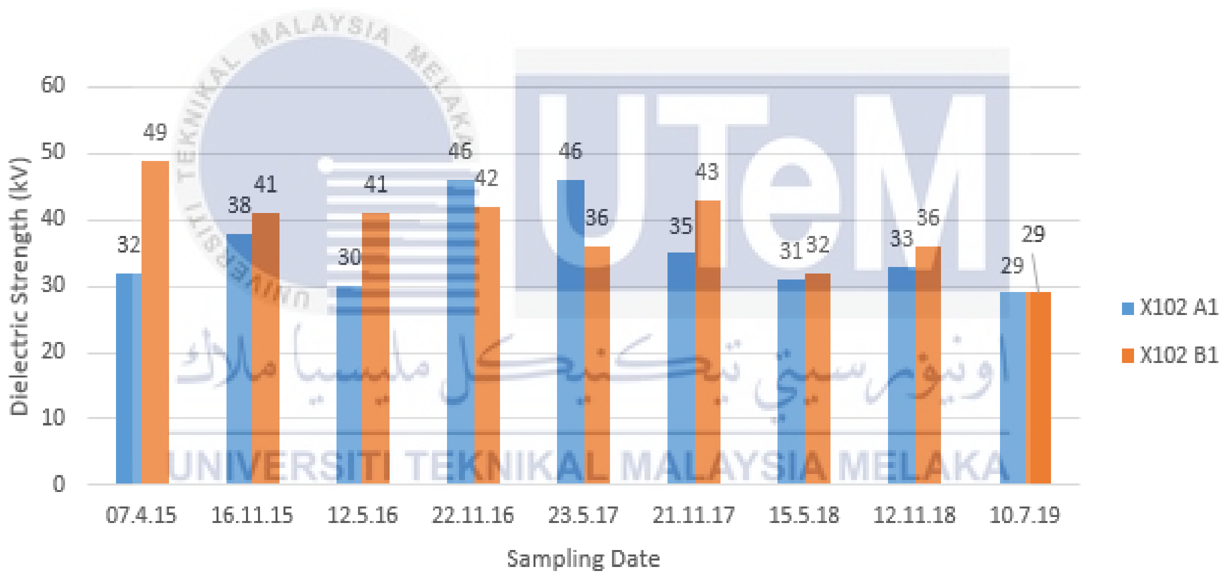

Figure 4.17: Dielectric Strength for X102 A1 and X102 B1

Table 4.18 shows the water content in express train X102 for both transformers A1 and B1. The transformer oil can only hold the water content below the reference point which is 50 ppm.

Table 4.18: Water content in express train for X102 A1 and X102 B1

Water Content (ppm)		
Type of Train Transformer / Sampling Date	**X102 A1**	**X102 B1**
07.4.15	27	21
16.11.15	25	14
12.5.16	36	29
22.11.16	33	30
23.5.17	31	26
21.11.17	37	31
15.5.18	43	49
12.11.18	39	42
10.7.19	33	39
Reference Point	<50	

The maximum reference point for the water content is 50 ppm. Therefore, the transformer oil that have value below than the reference point still safe to used and the oxidation number can be neglected except the oil shows the value for water content beyond the reference point. So, for **Figure 4.18** shows that most of the value still below the reference point except on the 15th May 2018 for X102 B1 show the reading beyond the reference point which is 56ppm. At this sampling point, the oil need to filter in order to reduce back the water content in the transformer oil. Water could affect the transformer oil and also components or secondary damage.

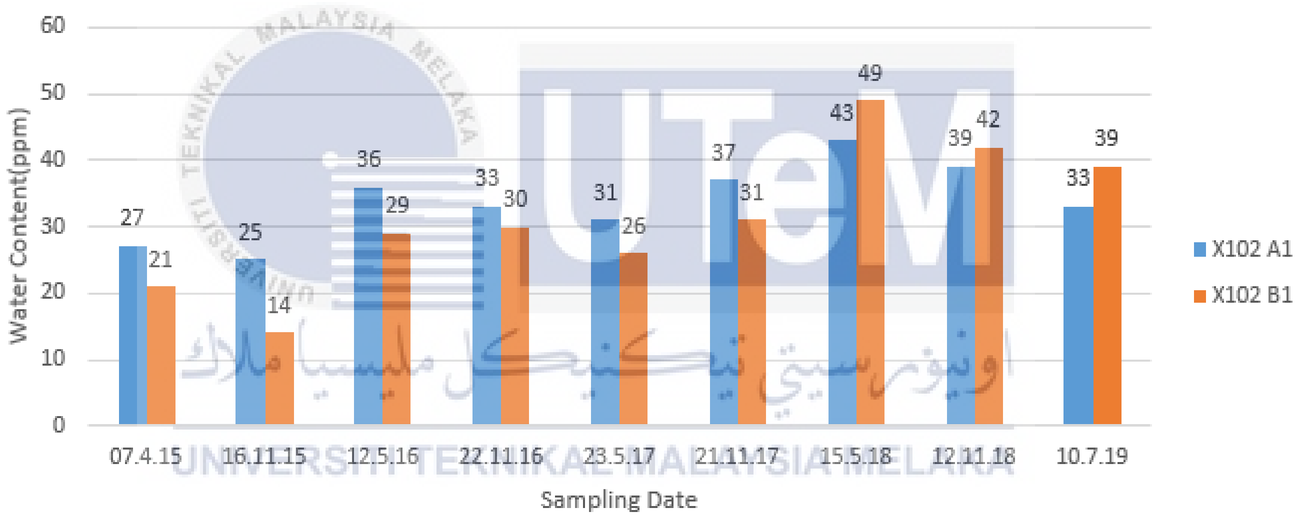

Figure 4.18: Water Content for X102 A1 and X102 B1

Table 4.19 shows the acid number for express train for both transformers A1 and B1. In order to remain the reliability of the oil , the acid number must below than 0.2.

Table 4.19: Acid number for A1 and B1 transformers for express train X102

Acid Number		
Type of Train Transformer / Sampling Date	**X102 A1**	**X102 B1**
07.4.15	0.1	0.1
16.11.15	0.1	0.1
12.5.16	0.1	0.1
22.11.16	0.1	0.1
23.5.17	0.1	0.1
21.11.17	0.1	0.1
15.5.18	0.1	0.1
12.11.18	0.1	0.1
10.7.19	0.1	0.1
Reference Point	<0.2	

Acid number one of the important part need to be monitored by do schedule maintenance because by increasing the acid number beyond the maximum reference point which is 0.2 can make secondary damage not only for the oil but transformer components also because the oxidation can make corrosion and leakage towards the transformer components which increase the maintenance cost. So, the values for **Figure 4.19** shows the safe value for acid number because below the reference point. Therefore, it will remain the performance of the oil and also reliable to used.

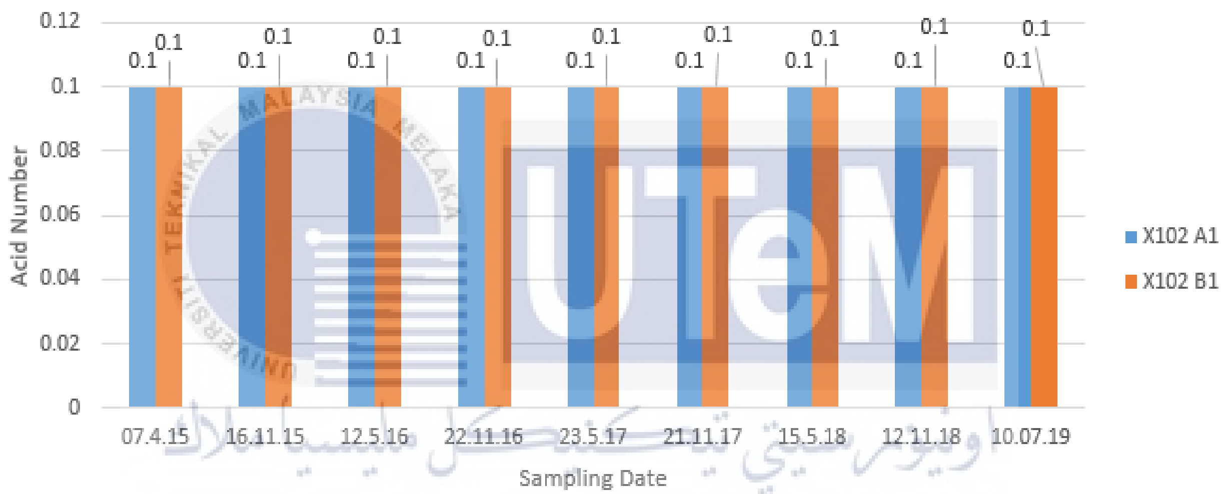

Figure 4.19 Acid Number for X102 A1 and X102 B1

Table 4.20 shows the interfacial tension result for both transformers in express train X102. The interfacial tension is used to check the quality of the oil whether it is still reliable to used or not.

Table 4.20: Interfacial tension for transformers in express train X102

Interfacial Tension (mN/m)		
Type of Train Transformer / Sampling Date	**X102 A1**	**X102 B1**
07.4.15	28.13	19.84
16.11.15	26.73	21.07
12.5.16	27.62	20.71
22.11.16	25.52	21.26
23.5.17	25.39	19.34
21.11.17	26.18	21.27
15.5.18	25.72	22.77
12.11.18	24.94	22.08
10.7.19	25.84	21.74
Reference Point	>20	

From **Figure 4.20** shows the value for interfacial tension vs sampling date for X102 A1 and X102 B1. The blue bar chart for X102 A1 while X102 B1 orange bar chart. The average value for X102 A1 shows still reliable to use because not exceed the minimum value for reference point which is 20 mN/m. Furthermore, for X102 B1 on 7th July 2015 and 23rd May 2017 shows the value is below the reference point while the others above the reference point. The interfacial tension function as to avoid any particle can come through the oil easily. If the value is below the reference point it will easily mix with foreign particle so it will reduce the performance for the oil. The filtration process need to be done to maintain or increase the performance of the oil. The lowest value for X102 B1 is 19.34 mN/m on 23rd July 2017 and the highest value is 22.77 mN/m on 15th May 2018. Therefore, for the X102 A1 the highest value is 28.13 mN/m on 7th April 2015 and the lowest value is 24.94 mN/m on 12th November 2018.

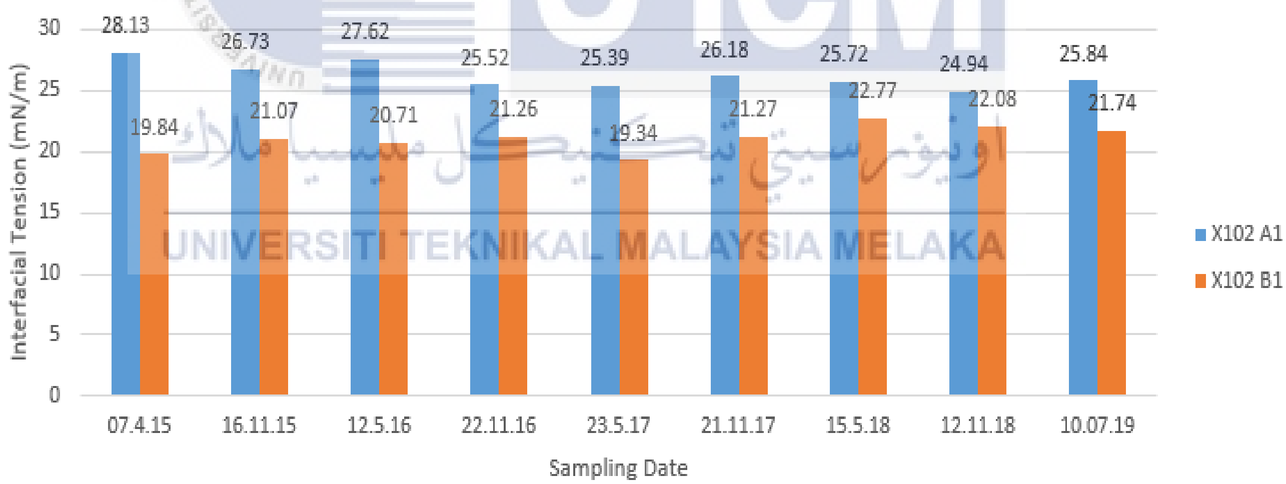

Figure 4.20: Interfacial Tension for X102 A1 and X102 B1

4.2.6 Express Train X104 A1 and X104 B1

Table 4.21 shows the dielectric strength for express train X104. Both transformers are analyzed by using bar graph.

Table 4.21: Dielectric strength for express train X104 transformers

Dielectric Strength (kV)		
Type of Train Transformer / **Sampling Date**	**X104 A1**	**X104 B1**
08.4.15	57	46
18.11.15	60	58
11.5.16	57	37
23.11.16	40	38
23.5.17	43	34
22.11.17	41	41.2
15.5.18	34	35
14.11.18	32	34
09.07.19	32	31
Reference Point	>30	

Figure 4.21 shows the data for dielectric strength vs sampling date for X104 A1 and X104 B1 transformers. As show in the **Figure 4.21**, the highest value for dielectric strength is 60 kV on 18th November 2015 and the lowest value is 31 kV on 9th July 2019. Therefore, based on the result displayed on the **Figure 4.21** shows that the dielectric strength for the oil transformer for both transformer is reliable to use because still above the minimum reference pint which is 30 kV. Other than that, the dielectric strength function as insulator towards the electricity. The lower value than the reference point will reduce the performance for the oil to remains its characteristics.

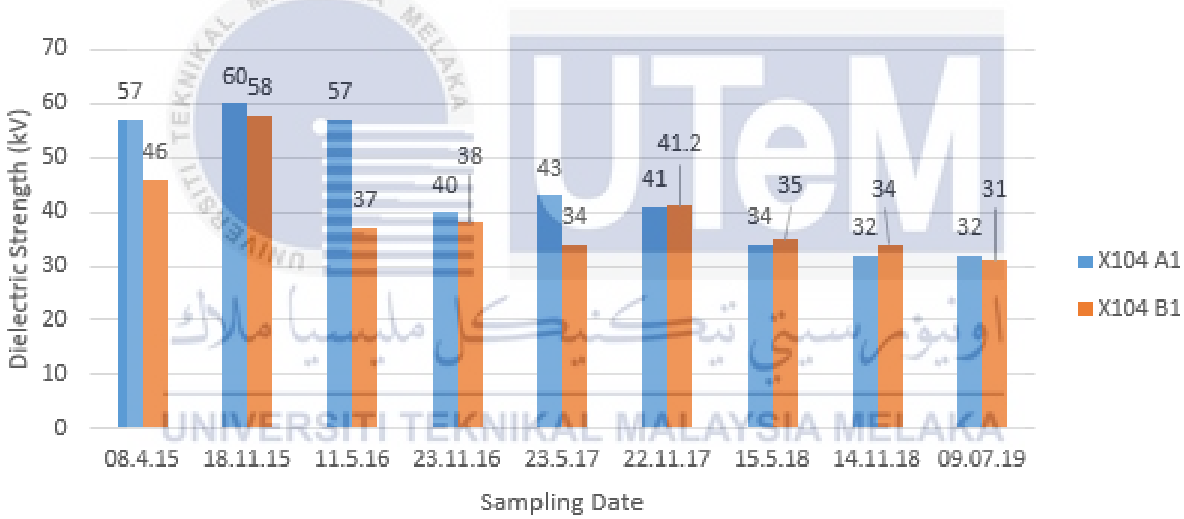

Figure 4.21: Dielectric Strength for X104 A1 and X104 B1

Table 4.22 shows the water content for express train X104 transformers. Therefore, water content for express train must below than 50 ppm to make sure the oil still can be used.

Table 4.22: Water content for express train, X104

Water Content (ppm)		
Type of Train Transformer / Sampling Date	**X104 A1**	**X104 B1**
07.4.15	21	22
16.11.15	23	27
12.5.16	33	35
22.11.16	29	37
23.5.17	32	36
21.11.17	30	27
15.5.18	40	34
12.11.18	37	30
10.7.19	39	33
Reference Point	<50	

The maximum reference point for water content is 50 ppm. The value or data that beyond the reference point need to do filtration process in order to reduce the number of water content in the transformer oil. By reducing the water content in the transformer oil, it will reduce the number of secondary damage that might occur in the transformer oil and its components. Based on **Figure 4.22** shows the overall water content value in the transformer oil still below the reference point, hence it is safe to use. The lowest value for water content is 21 ppm on 8th April 2015 while the highest value for the water content is 40 ppm on 15th July 2018. Moreover, the highest value for X104 A1 is 40 ppm while the lowest is 21 ppm. While for X104 B1, the lowest value is 22 ppm on 8th April 2015 and the highest value is 37 ppm on 23rd November 2016.

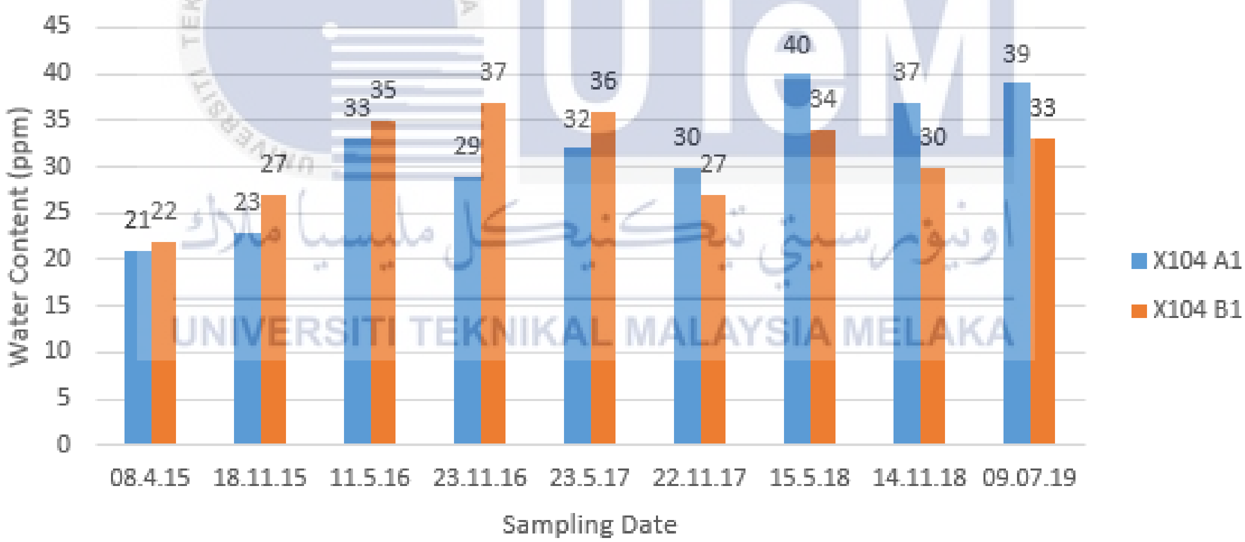

Figure 4.22: Water Content for X104 A1 and X104 B1

Table 4.23 shows the acid number for X104 A1 and X104 B1. The reference point for acid number is 0.2. The acid number for transformer oil need below than the reference point.

Table 4.23: Acid number for transformer A1 and B1 in express train X104

Acid Number		
Type of Train Transformer / **Sampling Date**	**X104 A1**	**X104 B1**
08.4.15	0.1	0.1
17.11.15	0.1	0.1
09.5.16	0.1	0.1
23.11.16	0.1	0.1
24.5.17	0.1	0.1
22.11.17	0.1	0.1
15.5.18	0.1	0.1
13.11.18	0.1	0.1
08.07.19	0.1	0.1
Reference Point	<0.2	

Figure 4.23 shows the data for acid number vs sampling date for X104 A1 and X104 B1. The blue bar graph represents for X104 A1 transformer while orange bar graph represents X104 B1 transformer. Other than that, the reference point for acid number for transformer oil is 0.2. Based on the value shows for all sampling oil it shows that the acid number for the transformer oil is still safe to use and not reduce its performance. The acid number need to be monitored such as by condition based maintenance or scheduling maintenance because to make sure the value below the maximum value for acid number. Moreover, by do the monitoring it will reduce the secondary damage towards the transformer oil and the transformer components.

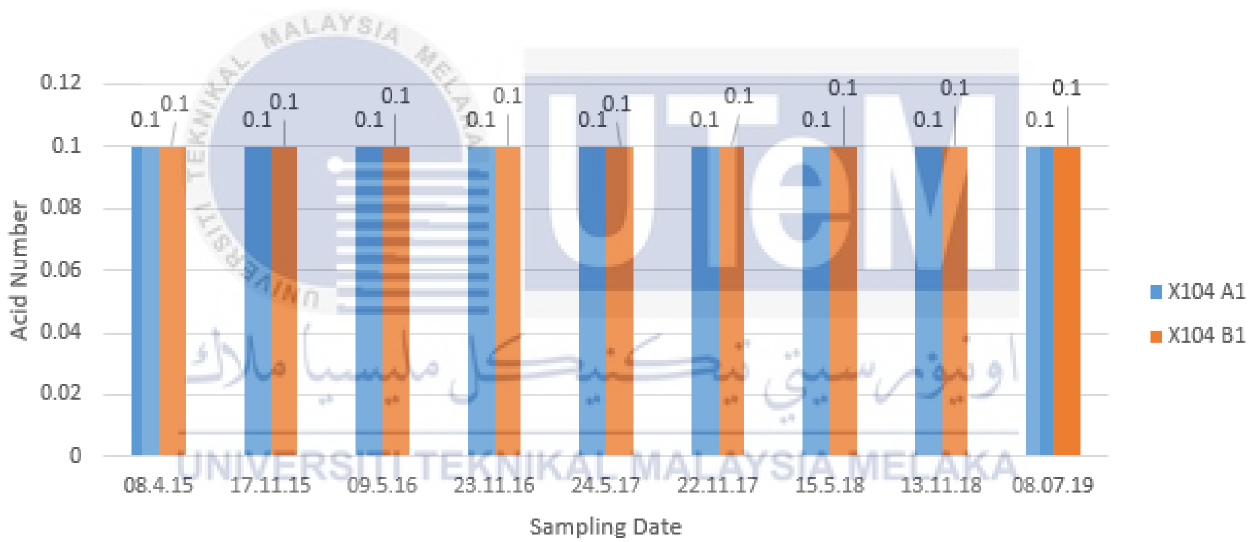

Figure 4.23: Acid Number for X104 A1 and X104 B1

Table 4.24 shows the interfacial tension for X104 A1 and X104 B1 transformers. The lower the interfacial tension value, lower the quality of the oil.

Table 4.24: Interfacial tension for express train X104 transformers

Interfacial Tension (mN/m)		
Sampling Date \ Type of Train Transformer	**X104 A1**	**X104 B1**
08.4.15	20.86	22.65
18.11.15	20.04	18.49
11.5.16	19.69	20.12
23.11.16	20.01	19.91
23.5.17	20.92	21.16
22.11.17	20.71	20.72
15.5.18	25.35	23.67
14.11.18	22.26	24.97
09.7.19	24.3	22.29
Reference Point	>20	

Figure 4.24 shows the interfacial tension vs sampling date for X104 A1 and X104 B1. The minimum reference point for interfacial tension is 20. The lowest value for X014 A1 is 19.69 mN/m while the highest is 25.35 mN/m. other than that, for the X104 B1 the highest value is 24.97 mN/m and the lowest value is 18.49 mN/m. The interfacial tension need to be monitored although it is not the priority because the reducing number for interfacial tension can make other particle easily to mix with the original particle, so it will reduce the transformer oil performance hence can cause secondary damage. Filtration process can be done to increase back the value beyond the reference point.

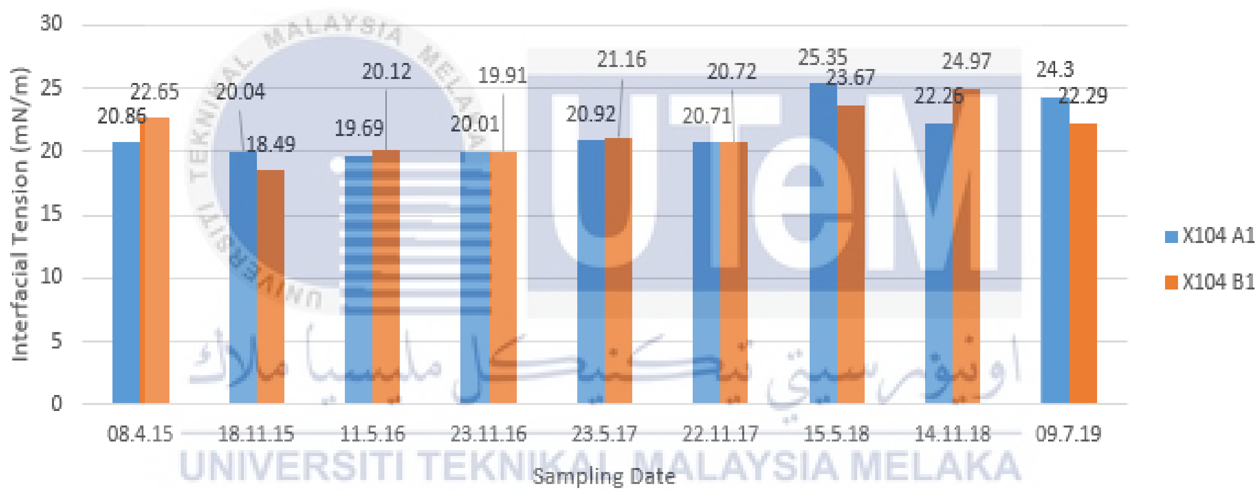

Figure 4.24: Interfacial Tension for X104 A1 and X104 B1

4.2.7 Express Train X108 A1 and X108 B1

This part will analyzed the tranformers for express train X108 form the result gain. Therefore,decision will be make towards the oil whether to reused, filter or change to new oil. **Table 4.25** shows the dielectric strength reading for express train transformers, X108.

Table 4.25: Dielectric strength transformers for express train X108

Dielectric Strength (kV)		
Type of Train Transformer / Sampling Date	**X108 A1**	**X108 B1**
07.4.15	44	44
17.11.15	37	31
09.5.16	37	40
23.11.16	41	46
24.5.17	56	50
22.11.17	52	48
15.5.18	42	36
13.11.18	46	52
08.07.19	32	30
Reference Point	>30	

Dielectric strength need to be higher or equal to 30 kV because of the reference point. Therefore, if the sampling oil has value lower than 30 kV, the transformer oil need to be done to the process of cooking oil. The process is used to increase the dielectric strength beyond the minimum reference point. As show in **Figure 4.25** the lowest value for X108 A1 is 32 kV on 8th July 2019 while the highest is 56 kV on 24th May 2017. For X108 B1 transformer, the lowest value for dielectric strength is 30 kV and the highest value is 52 kV. Overall data for dielectric strength for both transformer shows that the dielectric strength is upper and equal the reference point. So, the transformer oil is still safe to use.

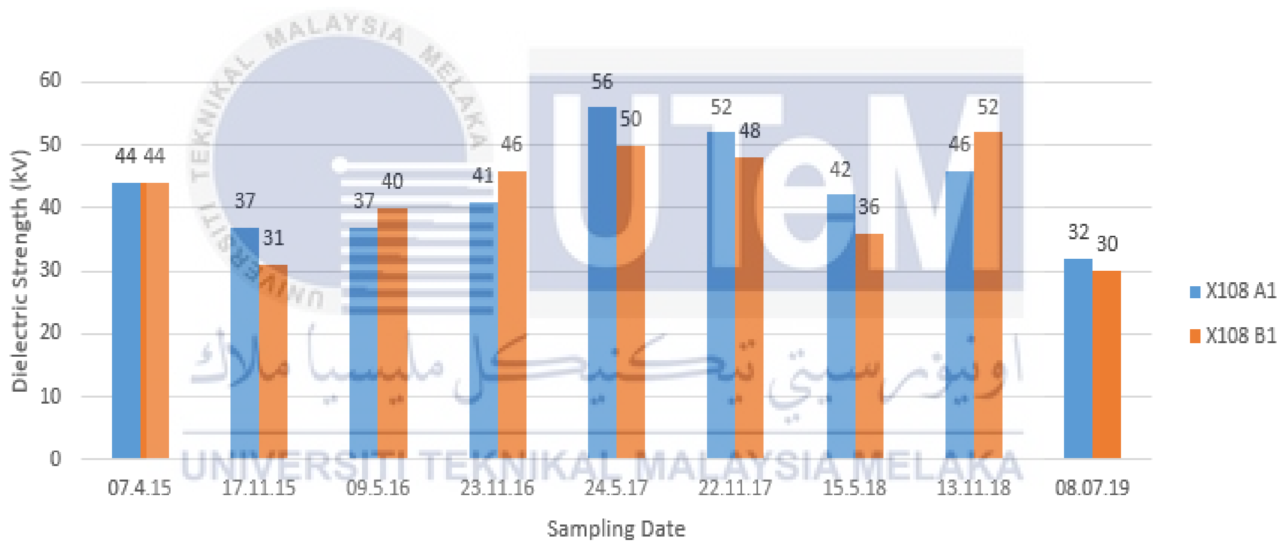

Figure 4.25: Dielectric Strength for X108 A1 and X108 B1

Table 4.26 shows the water content in express train X108 in both transformers, A1 and B1. The maximum water content can be hold the maximum is 50 ppm.

Table 4.26: Water content in both transformers for express train X108

Water Content (ppm)		
Type of Train Transformer / Sampling Date	**X108 A1**	**X108 B1**
07.4.15	23	24
17.11.15	34	42
09.5.16	28	38
23.11.16	32	34
24.5.17	17	19
22.11.17	30	34
15.5.18	28	32
13.11.18	23	26
08.07.19	34	28
Reference Point	<50	

Water content that exceed the reference point can occur the secondary damage towards the transformer oil. The maximum reference point for water content is 50 ppm. Therefore, the water content need to be lower than reference point to avoid any damage towards the oil and other transformer components such as winding and core. **Figure 4.26** shows overall value for water content for both transformer is under control and can be used. The higher value for X108 A1 is 34 ppm while the lowest is 17 ppm. Moreover, for X018 B1 transformer, the lowest value is 19 ppm while the highest value is 42 ppm. At 17th November 2015 and 8th July 2019 for X108 A1, the water content value is same which is 34 ppm. For the X108 B1 transformer, at 23rd November 2016 and 22nd November 2017 the water content also constant which is 34 ppm.

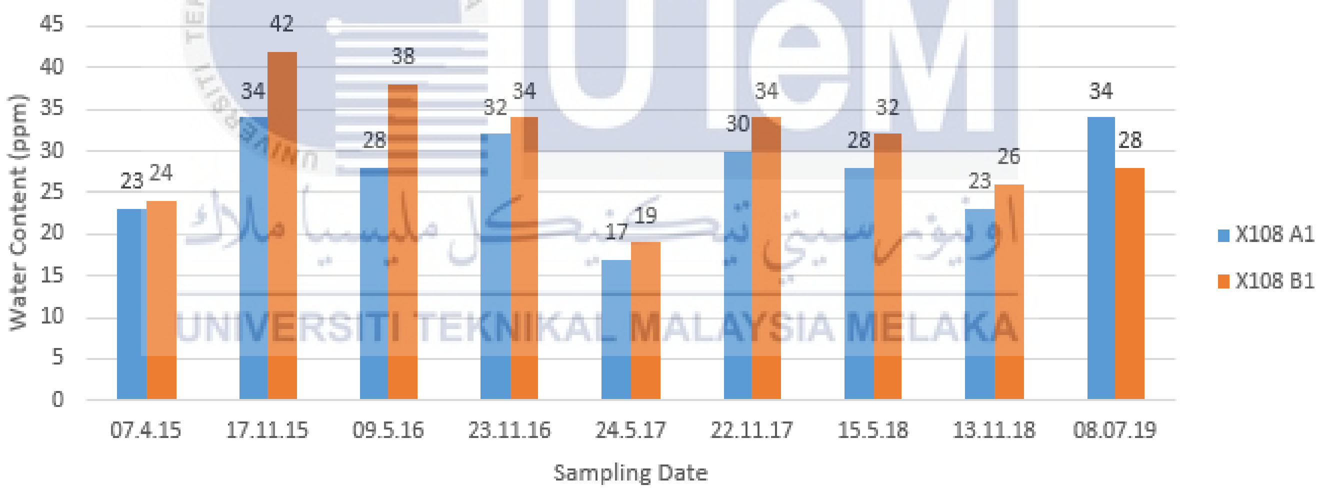

Figure 4.26: Water Content for X108 A1 and X108 B1

Table 4.27 shows the acid number content in express train X108 transformers. The acid number reading for the transformer oil cannot exceed the reference point which is 20.

Table 4.27: Acid number in express train, X018 for both transformers

Acid Number		
Type of Train Transformer / Sampling Date	**X108 A1**	**X108 B1**
07.4.15	0.1	0.1
17.11.15	0.1	0.1
09.5.16	0.1	0.1
23.11.16	0.1	0.1
24.5.17	0.1	0.1
22.11.17	0.1	0.1
15.5.18	0.1	0.1
13.11.18	0.1	0.1
08.07.19	0.1	0.1
Reference Point	<0.2	

Figure 4.27 shows the constant value from starting the sampling point is taken until the last sampling point. Moreover, the maximum acid number can content in the transformer oil is 0.2, the higher the value from this reference point need to filter back in order to get the optimum or normal value. Other than that, the acid number can cause corrosion towards the winding, core and surface of transformer hence it will increase the maintenance cost. The acidity also can cause deterioration of the insulation property of paper insulation of winding. Acid number also can be used in the process of neutralization towards the base or KOH.

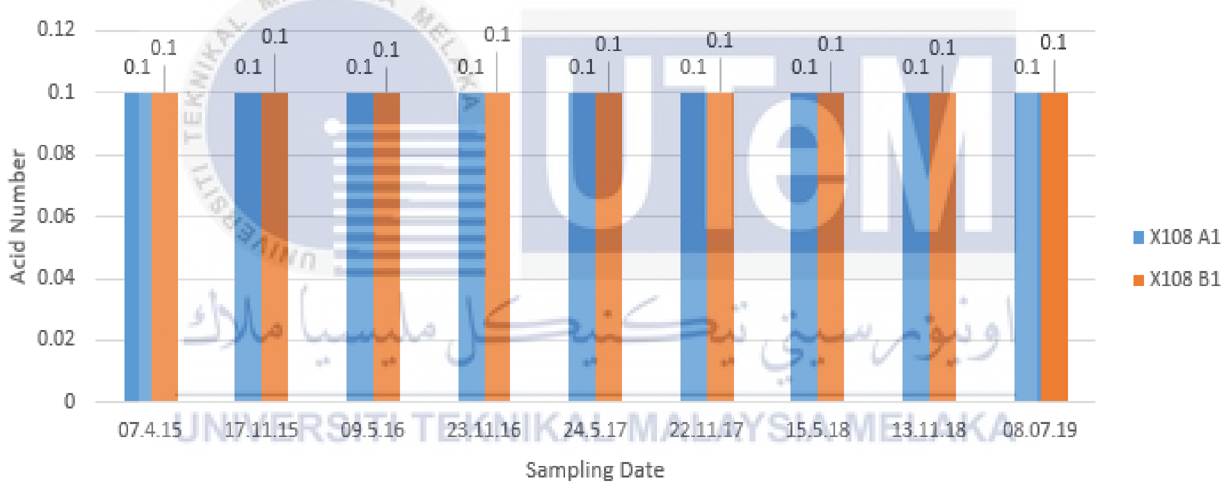

Figure 4.27: Acid Number for X108 A1 and X108 B1

Table 4.28 shows the interfacial tension in both transformers oil for express train X108. The interfacial minimum point or reference point is 20 mN/m.

Table 4.28: Interfacial tension data for express train X108

Interfacial Tension (mN/m)		
Type of Train Transformer / Sampling Date	**X108 A1**	**X108 B1**
07.4.15	24.03	23.34
17.11.15	23.45	22.99
09.5.16	23.78	23.45
23.11.16	24.37	24.83
24.5.17	23.77	24.00
22.11.17	23.21	23.81
15.5.18	22.80	23.40
13.11.18	20.68	21.04
08.07.19	21.91	21.25
Reference Point	>20	

Interfacial tension function needed to measure the attractive molecular force between water and oil. Other than that, it also used to determine the presence of polar contaminants and oil decay products. **Figure 4.28** shows the interfacial tension for both transformers, the highest value for X108 A1 is 24.37 mN/m and lowest value is 20.68 mN/m. For X108 B1 transformer, the highest value is 24.83 mN/m while the highest is 21.04 mN/m. The overall data is still under control because it is beyond the reference point which is 20 mN/m. If the value of interfacial tension is lower, it might cause other foreign particle to contaminated easily.

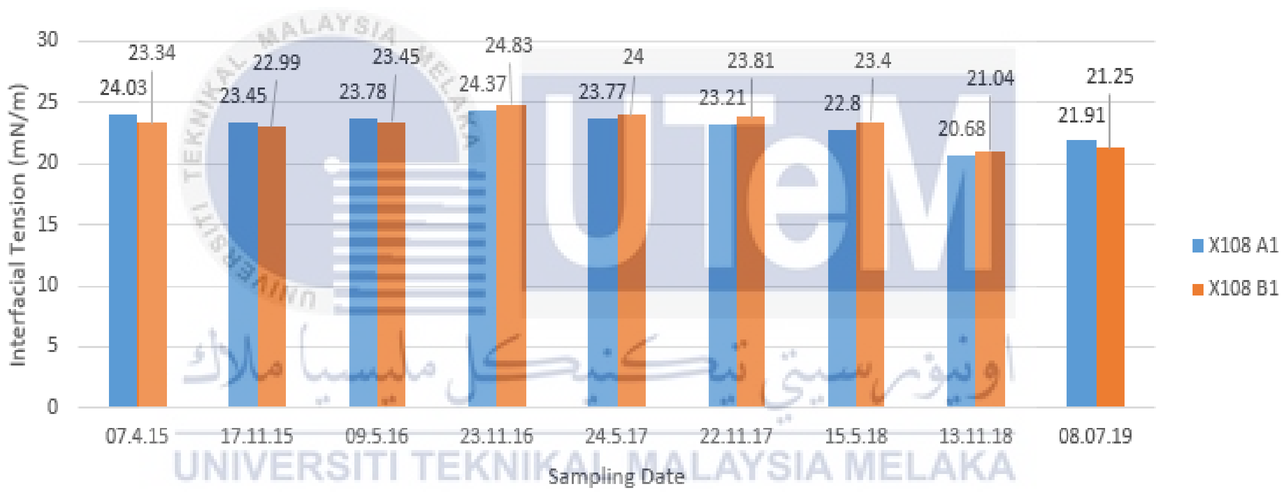

Figure 4.28: Interfacial Tension for X108 A1 and X108 B1

Figure 4.29 shows comparison between two transformers with different train which are express and transit train. The comparison is make on the dielectric strength result. For transit train T102, the highest value is 46 kV while the lowest value is 32 kv. For express train X102, the highest value is 46 kV and the lowest value is 29 kV.

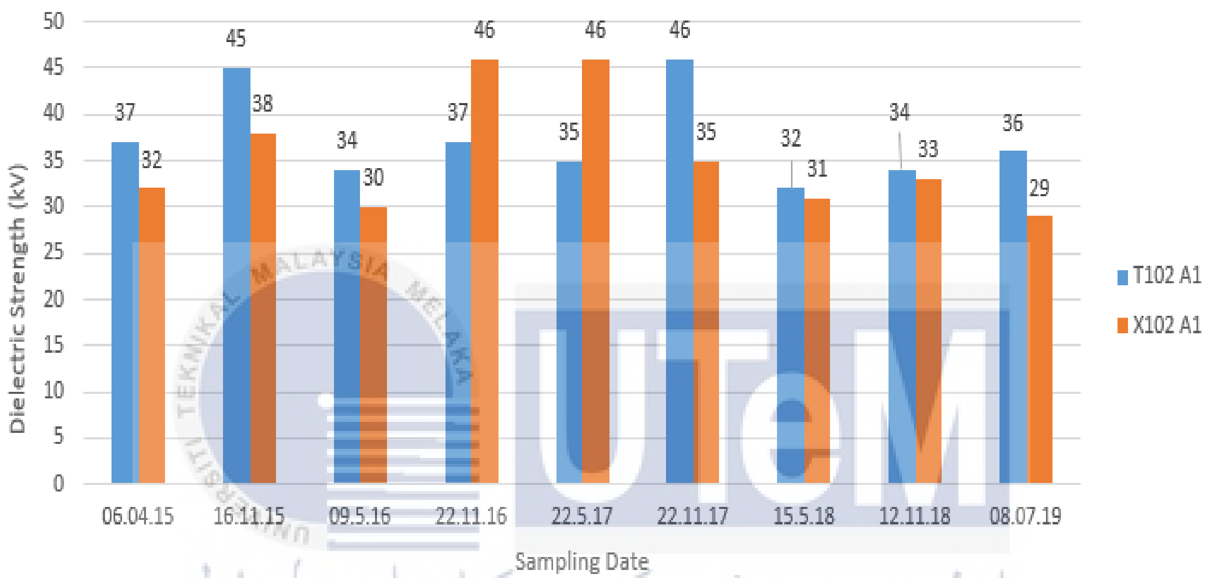

Figure 4.29: Comparison dielectric strength for T102 A1 and X102 A1

Figure 4.30 is compared between two different type of train, which are transit train T102 and express train X102. The comparison result also is made with same B1 transformers. For transit train T102, the highest value is 40 kV and the lowest value is 24 kV. For express train X102, the highest value is 49 kV and the lowest value is 20 kV.

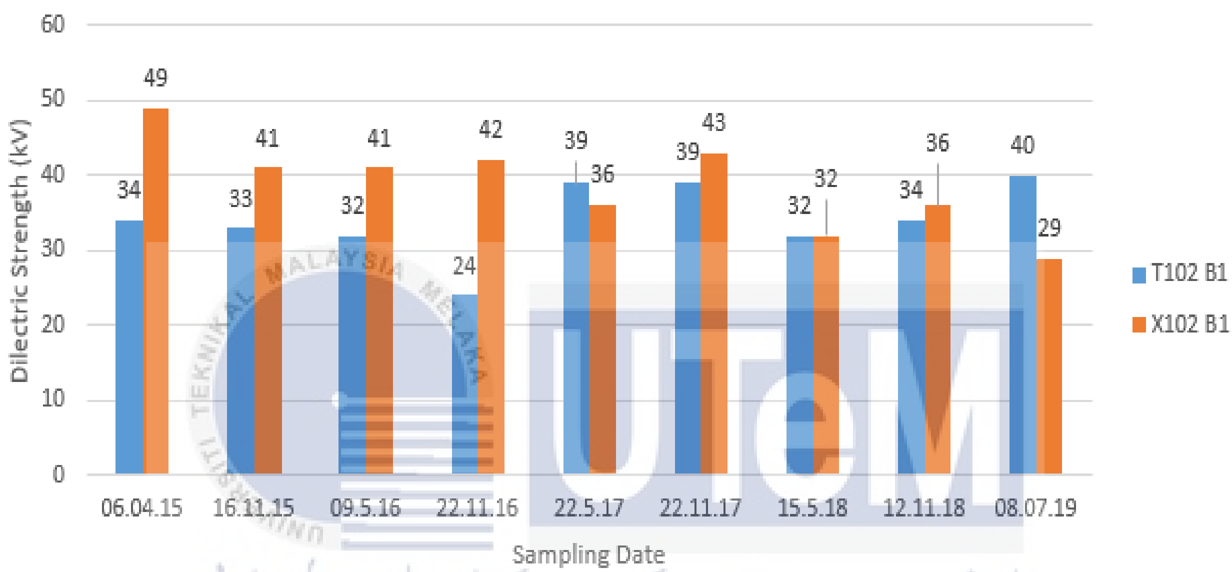

Figure 4.30: Dielectric strength comparison between T102 B1 and X102 B1

Figure 4.31 shows compariosn of water content between express train, X102 A1 and transit train, T102 A1. The highest water content value for transit train, T102 is 41 ppm and the lowest value is 25 ppm. Therefore, the higest water content value for express train, X102 us 43 ppm and the lowest value is 25 ppm.

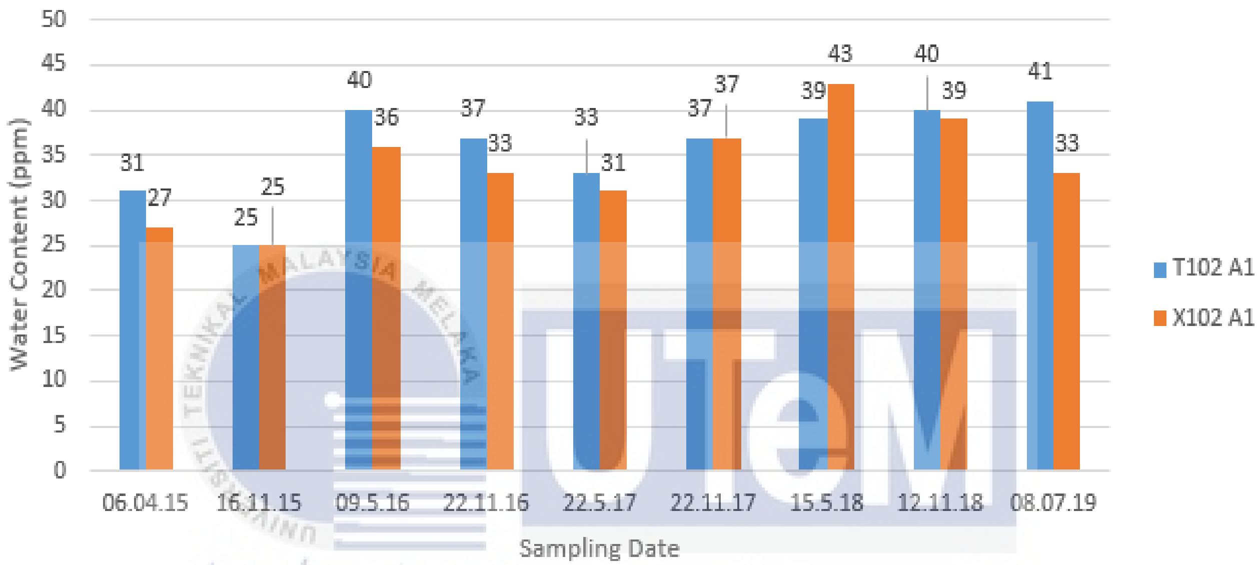

Figure 4.31: Comparison water content data for T102 A1 and X102 A1

Figure 4.32 shows the comparison water content data for express train X102 B1 and transit train T102 B1. From the graph shows that the highest value for water content for transit train is 46 ppm and the lowest is 21 ppm. For express train X102 B1, the highest value is 49 ppm and the lowest value is 14 ppm.

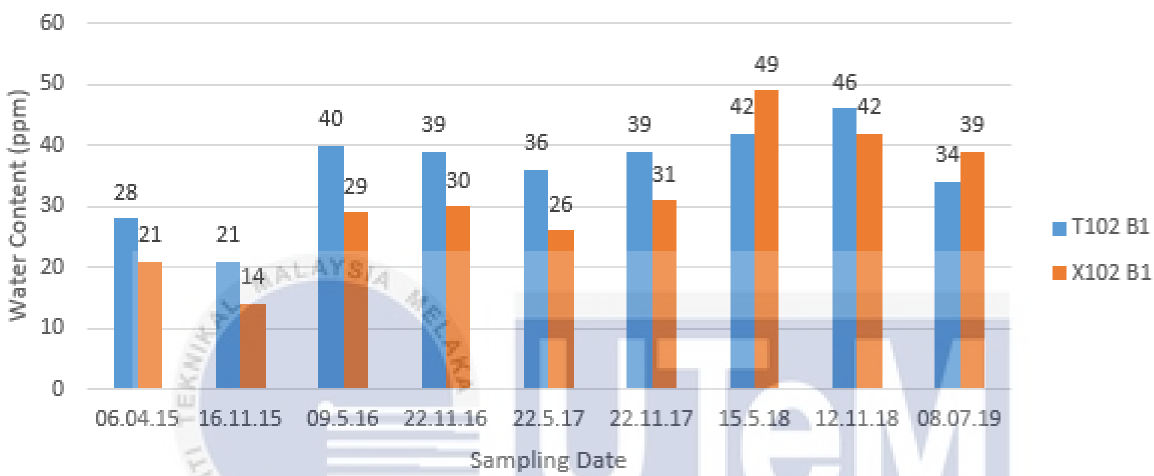

Figure 4.32: Comparison water content for X102 B1 and T102 B1

Figure 4.33 shows the comparison graph between express train X102 A1 and transit train T102 A1 for interfacial tension value. For transit train, T102 the highest value is 24.15 mN/m while the lowest reading is 19.5 mN/m. For express train X102, the highest value is 28.13 mN/m and the lowest value is 24.94 mN/m.

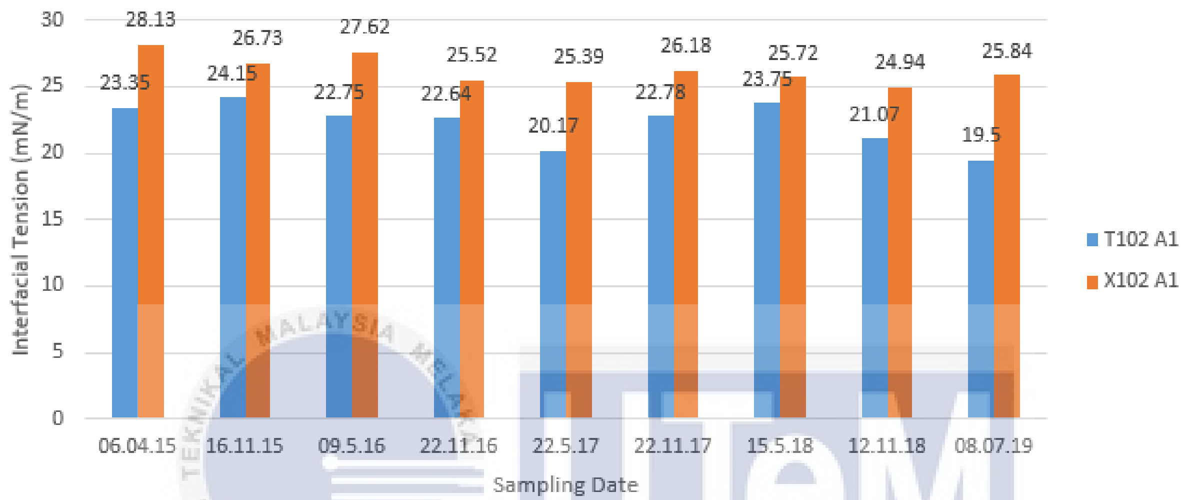

Figure 4.33: Comparison interfacial tension value for transit train T102 A1 and express train X102 A1

Figure 4.34 shows comparison between interfacial tension value for transit train T102 B1 and express train X102 B1. For transit train, T102 the highest value is 23.3 mN/m and the lowest value is 19.83 mN/m. While for express train, X102 B1 the highest value is 22.77 mN/m and the lowest value is 19.34 mN/m.

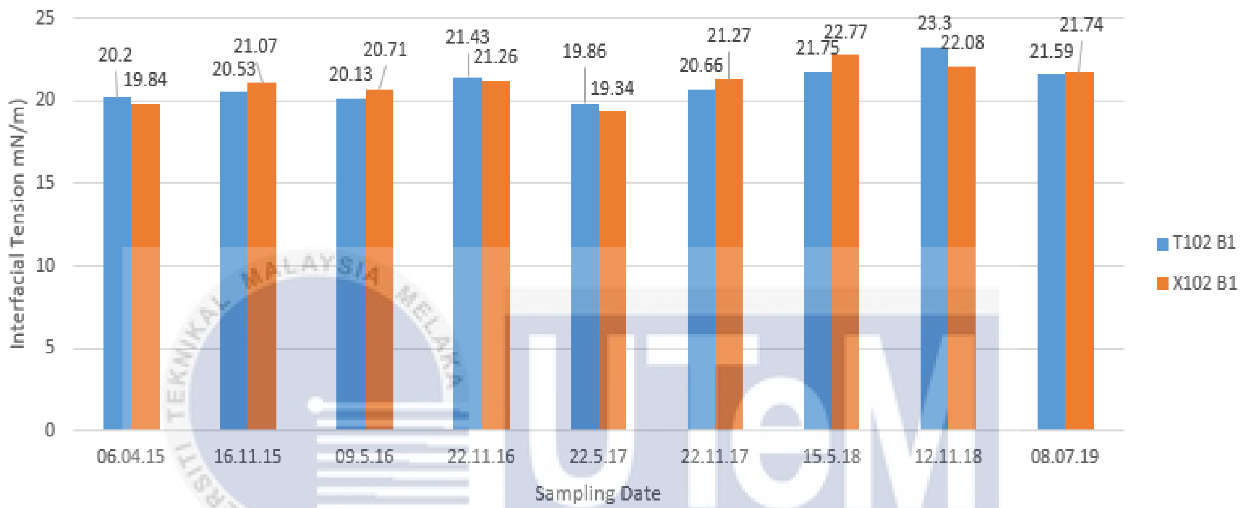

Figure 4.34: Interfacial tension data for transit train T102 B1 and express train X102 B1

4.3 Discussion

Detailed analysis has been analyzed based on the dielectric strength, water content, acid number and interfacial tension towards express and transit train which are T101 A1 and B1, T102 A1 and B1, T103 A1 and B1, T104 A1 and T104 B1, X102 A1 and B1, X104 A1 and B1 and X108 A1 and B1. Moreover, transformers are analyzed based on result gain from the ERL company. The maintenance towards the transformers are done by semiannually or each six months per year, this is because to prevent any damage that might be occurred towards the transformer oil and its components. The damage towards the transformer oil and the transformer components might increase the maintenance cost and shutdown time, so it will lower the production time.

Based on previous analysis, the dielectric strength is analyzed first because it plays an important role in transformer to function. Dielectric strength also called breakdown voltage for transformer oil. Breakdown voltage can be analyzed at which voltage between two electrodes immersed in the oil, separated by a particular distance. The lower the dielectric strength reduce the performance of transformer to step down the voltage for express and transit train, because the lower the breakdown voltage or dielectric strength shows the presence of moisture content and conducting substance in the oil. The reference point for dielectric strength safely to used is 30 kV, the lower the value will cause secondary damage towards the ability of transformer to perform its job.

Next, water content is an important to monitor because it will cause secondary damage towards the transformer oil and also transformer components such as winding, core and it surface. Water contamination can promote oxidation, lead to vapor cavitation and catalyze rust or other corrosion. Most of oil have additives in order to increase the extend the lifespan of lubricant hence can control the oxidation. Although the additive is function to prolong the lifetime of the transformer oil, it also depletes over time especially when combine with the higher moisture levels.

Other than that, acid number also need to monitored because it is harmful property. The water content in the oil might become soluble if the oil is acidic. Moreover, it is deteriorates the insulation property of paper insulation of winding and acidity also will accelerate the oxidation process in the oil. The constant number in the result for acid number due to dissolved gas analysis data such as hydrogen. The reference point for hydrogen gas is 100 while overall data for hydrogen gas still under the reference point, so it will not give effect towards acid number results. Higher number of acidity also can cause rusting of iron in the presence of moisture. The oxidation from the acid number can cause corrosion towards the transformer surface. its oil properties, winding and core. If the failure occurs, it will increase the secondary damage towards the transformer hence increase the maintenance cost. The increase number of acid will darken the oil and produce water and acids hence will culminate in producing the sludge.

Furthermore, dissolved gas analysis shows the result for gas content in the transformer oil such as hydrogen, oxygen, carbon dioxide and carbon monoxide. The result for overall gas shows that, the gas still under control and under reference point, so the gas content will not affect towards the transformer oils' properties. The higher number of gas content in the transformer oils' can cause failure towards the oils' properties such as corrosion, oil dilution and oxidation. The percentage of discounted cumulative gain for transformer oil also give the good result, which is lower than the reference point which is 720 ppm. So, the oil quality will remain good and safe to use.

Finally, based on the previous analysis the most part need to be monitored is interfacial tension because most of the value is near to reference point. Interfacial tension is function as to measure the attractive molecular mass between the water and oil. It is also used to determine the polar contaminants and decay product, so the good interfacial tension is the highest value. The lower value for interfacial tension might lower the force attraction between the particle, hence other foreign particle can easily mix with the current oil particle and cause damage towards the oil.

4.4 Preventive Maintenance Strategy

A transformer is typically a sturdy system with very good reliability which needs relatively low maintenance. When the transformer is applied towards the system, usually the user need to have a strategy for ensures an acceptable degree of efficiency and streamlined service life. An optimized maintenance strategy will ensure that required availability and reliability of transformer over its lifetime at low maintenance cost. The objectives or goal for good maintenance is to detect any early failure or abnormalities before it become worst. **Figure 4.35** shows a basic maintenance process.

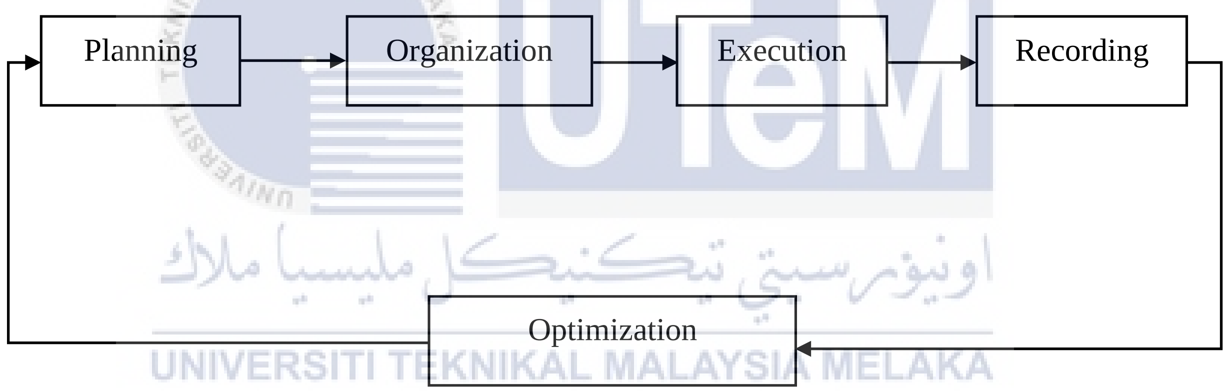

Figure 4.35 Maintenance Process

One of the important parts need to be monitored is transformer oil, because it plays an important role not only as coolant towards the transformer but as insulator. The lower the quality of the oil, it will affect the performance of transformer to reach its optimized performance. Therefore, preventive maintenance need to do in the transformer oil such as dielectric strength, water content, acid number and interfacial tension. **Table 4.29** shows the sampling oil need to be taken by following the maintenance duration.

Table 4.29: Oil sampling duration

Test Description	Limit	Maintenance Duration
Dielectric Strength	Minimum to 30 kV	Each 6 month per year
Water Content	Maximum to 50 ppm	Each 6 month per year
Acid Number	Up to 0.2	Each 6 month per year
Interfacial Tension	Minimum to 20 mN/m	Each 6 month per year

Figure 4.36 shows the action need to be taken if the oil sampling data exceeds the reference value. The drastic action need to take to prevent any worst failure might occur towards the transformer oil and transformer parts which can cause higher maintenance cost. With the help of the above figure, it helps the users identify the source of problem easily and solve it effectively.

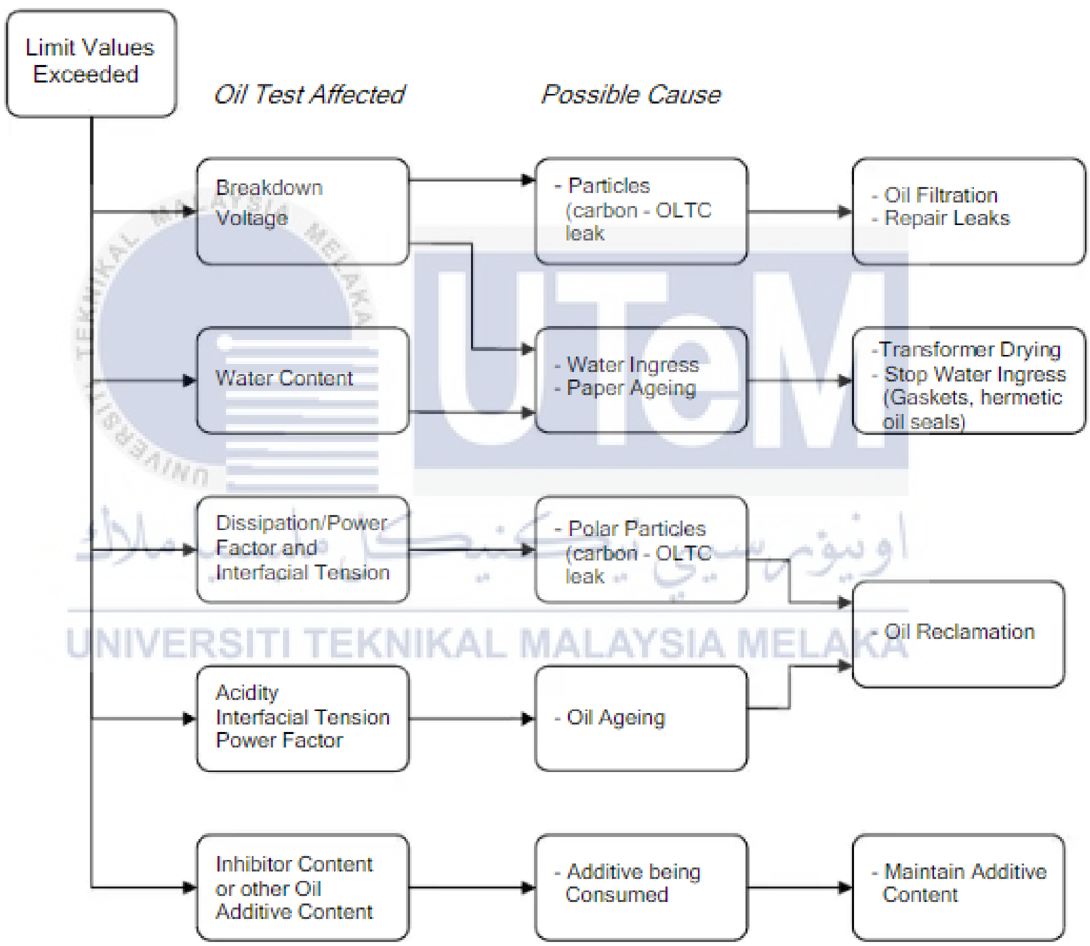

Figure 4.36: Decision Process in Cases of Oil Test Returning “Abnormal Values”

Furthermore, the transformer oil need to be tested in order to ensure it works for today's standards. Most of the standards are set by the ASTM which is international standards and oil testing is including the dielectric strength (ASTM D877), water content (ASTM D924-08), acid number (ASTM D664) and interfacial tension (ASTM D971). By doing the test, it will show the condition of the oils whether it is clean and create a baseline property that need to be tested periodically.

Some process can be done in order to achieve optimize performance for the transformer such as filtration process in order to reduce the contamination of particles or water. Moreover, to increase the dielectric strength, reduce the water content, reduce the acid number and increase the interfacial tension to optimize value, filtration process is needed by using VFDR 30 machine. This machine is online filtration process because to reduce the number of sludge in the oil rather than offline filtration.

The VFDR 30 machine process flow by transferring the oil from main transformer via VFDR 30 machine to external storage tank. Next, during the filtration or oil drying process the oil will circulate from the storage tank to the main transformer and return back to the storage tank. Time taken for the filtration process to occur is within 45 to 90 minutes. This process is repeated until all the value is in acceptable value and when required. Finally, transferring back the oil from the external storage tank to main transformer after the filtration process is complete.

Finally, by checking the component parts for transformer and environmental factors also are the factors the reliability of the transformer is decreasing. Therefore, action need to be taken in order to increase the reliability of the transformer oil to become good insulator and good coolant towards the transformer to achieve the optimized performance. Some of the components that can be monitored is silica gel, surface, winding and core while the environmental factors is temperatures and person in charge to do oil sampling.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The purpose of this study to analyze and study the maintenance practice on railway transformer oil. The objective of this study is to analyze railway vehicle transformer oil condition. Second, to compared the new and used transformer oil. Lastly, make recommendation to ERL Maintenance Support Sdn. Bhd. towards transformer oil whether for replacement, reused or filter the used oil. The issues for the transformer oil has been analyzed and identified from the data collection based on last 5 years' result which are from 2015 to 2019. Based on the result shown for express train X102 A1 and X102 B1 both transformer oil need to changed due to lower dielectric strength which is 29 kV at last sampling date. the lowest reading for dielectric strength can reduce the performance of transformers.

Next, for transit train T102 A1, the transformer oil need to filter first in order to increase back the value for interfacial tension. After filtration process have done, test the transformer oil back, if the interfacial tension value still below than reference point, change to new oil. This is accomplished the third objective which is make recommendations whether the used oil can be reused, replacement or filter the oil.

The reducing number for all parts because the contamination occurred in the transformer oil itself such as moisture, particle and air contamination hence deplete the additives in the oil that function to prolong the oil life. Therefore, the transformer components also need to monitored to avoid any external contaminant such as air, dust or water that can affect the transformer oil. This result is gained based on the data that have being collected on the ERL Maintenance Support Sdn. Bhd.

This analysis cannot eliminate or shorten the duration for maintenance due to cost of oil sampling issues but can only propose the better way to manage the maintenance or doing the oil sampling. Hence, the second objective of this study has been accomplished which is analyzed the data whether beyond the reference point or not. Next, third objective also has been accomplished by make recommendations for transformer oil if any error occurred. The strategy is obtained by doing some research towards the transformer oil and its components. Lastly, all objective for this study is achieved.

5.2 Recommendations for future studies

This section offers some ideas for future research and further study. To further improve the maintenance and strategy of the transformer oil study. Here are the suggestions and potential works listed:

1. Determine the operation time, mileage covered and maintenance cost of repairs for each express and transit train that have been analyzed for meet the analysis requirements. So, it will make this analysis more accurate and efficient.
2. Analyze the maintenance critical issues that usually happen when the transformer got failure, so easy to determine the source of failure.
3. Furthermore, need to prolong the duration to collect the data, in order to gain the more details results and can shows the trend.
4. Based on the trend has been analyzed, the oil must be checked every six months and need to change if the reading of four main aspects such as dielectric strength, water content, acid number and interfacial tension is lower than the reference point.

REFERENCES

Agnihotri, S. (2019) What is a Transformer? Definition and Working Principle. Retrieved from https://www.electrical4u.com/what-is-transformer-definition-working-principle-of-transformer/.

Budai, G., Huisman, D., & Dekker, R. (2006). Scheduling preventive railway maintenance activities. *Journal of the Operational Research Society*, *57*(9), 1035–1044. doi: 10.1057/palgrave.jors.2602085

Cade, J. (2017, May 15). Role of Transformer Oil and types of Transformer Oil. Retrieved from https://medium.com/@jcade842/role-of-transformer-oil-and-types-of-transformer-oil-2f5f8cc10f8a.

Carey, A. A. (2019, June 27). Dielectric Constant and Oil Analysis. Retrieved from https://www.machinerylubrication.com/Read/226/dielectric-constant-oil-analysis.

D'Ariano, A., Meng, L., Centulio, G., & Corman, F. (2019). Integrated stochastic optimization approaches for tactical scheduling of trains and railway infrastructure maintenance. *Computers & Industrial Engineering*, *127*, 1315–1335. doi: 10.1016/j.cie.2017.12.010

Fitch, B. (2013, December 17). Oil Analysis Explained. Retrieved from https://www.machinerylubrication.com/Read/29598/oil-analysis-report.

Girdhar, P., & Scheffer, C. (2004). Oil and particle analysis. In *Practical Machinery Vibration Analysis and Predictive Maintenance* (pp. 168–220). Elsevier. https://doi.org/10.1016/b978-075066275-8/50007-2

Ho, T. K., Chi, Y. L., Ferreira, L., Leung, K. K., & Siu, L. K. (2006). Evaluation of Maintenance Schedules on Railway Traction Power Systems. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, *220*(2), 91–102. doi: 10.1243/09544097f02004

J. Wright, (n.d) A Simple Explanation of Viscosity Index Improvers. Retrieved from https://www.machinerylubrication.com/Read/1327/viscosity-index-improvers.

Lee, K. K. H., & Chau, D. K. W. (2012). Condition Based Monitoring in Railway. *Journal of International Council on Electrical Engineering*, *2*(1), 99–103. https://doi.org/10.5370/jicee.2012.2.1.099

Liang, Z., & Parlikad, A. (2018). A Markovian model for power transformer maintenance. *International Journal of Electrical Power and Energy Systems*. https://doi.org/10.1016/j.ijepes.2017.12.024

Mira, L., Andrade, A. R., & Gomes, M. C. (2020). Maintenance scheduling within rolling stock planning in railway operations under uncertain maintenance durations. *Journal of Rail Transport Planning and Management*. https://doi.org/10.1016/j.jrtpm.2020.100177

Murugan, R., & Ramasamy, R. (2019). Understanding the power transformer component failures for health index-based maintenance planning in electric utilities. *Engineering Failure Analysis*. https://doi.org/10.1016/j.engfailanal.2018.10.011

Rail transport: driving safely and saving power with dry transformers. (2019, July 1). Retrieved from https://researchmosaic.ch/rail-transport-driving-safely-and-saving-power-with-dry-transformers/.

Raposo, H., Farinha, J. T., Fonseca, I., & Galar, D. (2019). Predicting condition based on oil analysis – A case study. *Tribology International*, *135*, 65–74. https://doi.org/10.1016/j.triboint.2019.01.041

Santiyanon, D., Hongesombut, K., & Srisonphan, S. (2016). Simulation on Voltage Unbalance Reduction in Railway Electrification System by Different Special Transformers. *Procedia Computer Science*. https://doi.org/10.1016/j.procs.2016.05.104

Sen, R. N., & Ganguli, A. K. (1982). Preliminary investigations into the loco-man factor on the Indian railways. *Applied Ergonomics*, *13*(2), 107–117. https://doi.org/10.1016/0003-6870(82)90188-0

Senge, P. (2004). Maintenance Practices. *Making Common Sense Common Practice*, 219–264. https://doi.org/10.1016/b978-0-7506-7821-6.50012-8

Y. Zhao (2017). Spectro Scientific. Predictive *equipment maintenance oil analysis handbook third edition*. Retrieved from https://www.spectrosci.com/default/assets/File/SpectroSci_OilAnalysisHandbook_FINAL_2014-08.pdf

Zhong, Q., Lusby, R. M., Larsen, J., Zhang, Y., & Peng, Q. (2019). Rolling stock scheduling with maintenance requirements at the Chinese High-Speed Railway. *Transportation Research Part B: Methodological*. https://doi.org/10.1016/j.trb.2019.05.013

APPENDICES

Appendix A1: Gantt Chart for PSM 1

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Find Supervisor							**MID SEM BREAK**									
Project title confirmation																
Discussion with supervisor																
Research study																
Writing report																
Introduction																
Submission of progress report 1																
Literature review																
Methodology																
Slide presentation with supervisor																
Submission of final report																
PSM 1 presentation																

Appendix A2: Gantt Chart for PSM 2

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
PSM 2 working time	■	■	■	■	■	■		■	■	■	■	■	■	■	■
Site visit and Interview		■	■				**M I D S E M**								
Data Collection		■	■												
Analyze Data				■	■	■		■							
Submission of progress Report 2							**B R E A K**								
Report writing		■	■	■	■	■		■	■	■	■	■	■	■	
Submission of report														■	
PSM 2 presentation															■

Appendix B: Site visit to ERL Maintenance Support Sdn. Bhd., Sepang, Selangor