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Dehumidifier Box Installation in Electro-Hydraulic Control Oil Tank System to Improve Asset Reliability Program*

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Abstrak

Ester fosfat adalah pelumas sintetis yang memiliki keunggulan sebagai fluida tahan panas dan tahan api. Oleh karena itu, minyak ester fosfat banyak digunakan dalam sistem *Electro-Hydraulic Control* (EHC) untuk mengatur pembukaan katup uap bersuhu tinggi, seperti yang digunakan pada Control Oil Steam 4.3 di PT PLN Indonesia Power Priok Blok 4. Meskipun memiliki berbagai keunggulan, minyak ester fosfat memiliki sifat higroskopis alami yang memungkinkannya menyerap uap air dari atmosfer. Hal ini dapat memicu proses hidrolisis yang menyebabkan penurunan kualitas minyak. Dalam penelitian ini, perilaku laju penyerapan air oleh ester fosfat diamati di bawah kondisi kelembapan lingkungan pada periode tahun 2020 hingga 2023. Selanjutnya, sebuah kotak dehumidifier inovatif dirancang berdasarkan gagasan pengendalian kelembapan di sekitar tangki control oil dan mulai diterapkan pada Oktober 2023. Pengamatan kembali dilakukan selama sembilan bulan untuk memantau perilaku laju penyerapan air oleh ester fosfat di bawah kondisi kelembapan yang terkendali. Hasil pengamatan terhadap laju penyerapan air oleh ester fosfat pada kelembapan lingkungan (50–80%) menunjukkan peningkatan yang tinggi, yakni sebesar 24 hingga 62 ppm per bulan, yang menyebabkan kandungan air melebihi batas peringatan (maks. 1000 ppm). Kondisi ini menimbulkan biaya perawatan yang tinggi, berkisar antara Rp 37.830.000 hingga Rp 363.584.000 atau lebih per tahun untuk menjaga kualitas pelumas. Sebaliknya, hasil pengamatan terhadap laju penyerapan air pada kondisi kelembapan terkendali (20%) menunjukkan laju yang jauh lebih rendah, yakni sebesar 19 ppm per bulan, tanpa melebihi batas peringatan. Berdasarkan temuan ini, dapat disimpulkan bahwa pengendalian kelembapan menggunakan kotak dehumidifier inovatif secara signifikan menurunkan laju penyerapan air oleh minyak ester fosfat, sehingga dapat meminimalkan degradasi minyak dan menghemat biaya perawatan.

Kata kunci: EHC, Ester Fosfat, Hidrolisis

Abstract

Phosphate ester is a synthetic lubricant with the advantage of being a fluid that has excellent heat resistance/ fire-resistant fluid. Therefore, phosphate ester oil is widely used in EHC (Electro-Hydraulic Control) systems to regulate the opening of high-temperature steam valves, such as those used in Control Oil Steam 4.3 at PT PLN Indonesia Power Priok Block 4. Despite its advantages, phosphate ester oil has a natural hygroscopic property that allows it to absorb water from the atmosphere. This can initiate the hydrolysis process, which can lead to oil deterioration. In this study, the behavior of the water absorption rate by phosphate ester was observed under ambient humidity conditions from year 2020 to 2023. Subsequently, an innovative dehumidifier box was designed based on the idea of controlling humidity around the control oil tank and was implemented in October 2023. Observations were conducted again for nine months to monitor the behavior of the water absorption rate by phosphate ester under controlled humidity conditions. The results of the observation of the water absorption rate by phosphate ester under ambient humidity (50- 80%) showed a high increase of 24 to 62 ppm per month, causing the water content to exceed the warning limit (max. 1000 ppm), necessitating high maintenance costs ranging from Rp 37,830,000 to Rp 363,584,000 or more annually to maintain the quality of the lubricant. In contrast, the results of the observation of the water absorption rate under controlled humidity conditions (20%) showed a much lower rate of 19 ppm per month, not exceeding the warning limit. Based on these findings, it can be concluded that humidity control using the innovative dehumidifier box significantly reduces the water absorption rate by phosphate ester oil, thereby minimizing oil deterioration and saving maintenance costs.

***Keywords**: EHC, Phosphate esters, Hydrolysis*

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1. INTRODUCTION

Hydraulic valves constitute essential elements in a multitude of hydraulic systems wherein the regulation of flow rate, pressure, or actuators is requisite. Numerous classifications of electro-hydraulic control valves exist, including proportional valves, flapper-nozzle valves, and various other valves equipped with electronic controllers. The advancement of materials, manufacturing processes, electronic technology, and computer technology has significantly augmented the capabilities of electro-hydraulic control valves, concomitantly introducing new requirements (Jin *et al.,* 2020).

The Electro Hydraulic Controller (EHC) unit constitutes a specialized hydraulic system designed for application in nuclear, thermal, or gas-turbine power generation facilities, serving the critical function of supplying stable hydraulic power to actuate various types of valves that regulate the flow of steam or gas directed towards the turbine (Xu *et al.,* 2020). Figure 1 shows a typical hydraulic system for an EHC control system in a power plant.

To enhance the hydraulic system's responsiveness, turbine manufacturers markedly elevated the fluid pressure. Nevertheless, this modification heightened the potential for fire hazards linked to the possible dispersion of hydraulic fluid should a leak occur onto a heated steam pipe. To mitigate this danger, fire-resistant fluids were utilized. Two distinct types of fluids were employed within the Electro-Hydraulic Control (EHC) systems: chlorinated aromatic hydrocarbons and triaryl phosphate esters (Xu *et al.,* 2020). Chlorinated hydrocarbons are banned due to their prolonged persistence, high toxicity, and carcinogenicity in animals and humans.

The Priok thermal power station (based on the gas-fired steam /combined cycle power plant) is in Jakarta, Indonesia. Currently, the plants are producing a total 2841 MW of power, making it the most significant power producer facility in the state. The present investigation exclusively focuses on Block 4, which generates 800 MW of electricity from the integrated facility. Priok Blok 4 uses Phosphate Ester oil for its steam turbine control oil for the EHC System.

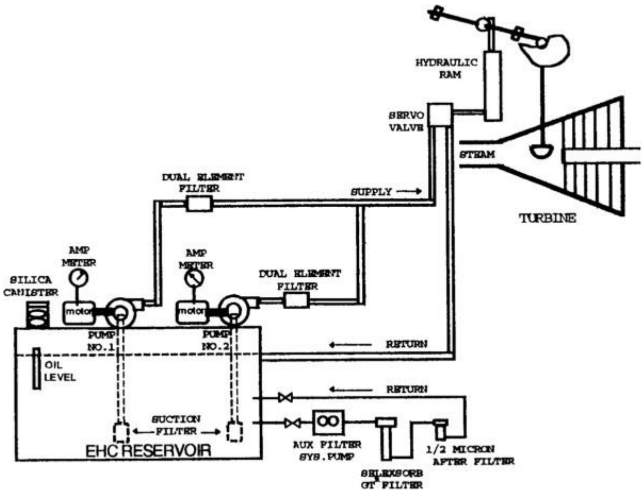

Figure. 1. Typical hydraulic System for EHC Control System

Mechanical equipment often functions under extreme conditions, including high speeds, heavy loads, and frequent start-stop operations, which results in elevated temperatures within the lubrication system (Y. Jin *et al.,* 2020). This inevitably generates adverse products, eventually resulting in performance deterioration and failure of the lubricants. Phosphate esters are widely utilized as lubricants, particularly in industrial settings where exceptional performance and fire resistance are critically significant. Besides its advantages, phosphate ester has disadvantages such as hygroscopic and oxidation.

Oxidation of phosphate ester is a free radical process that transpires when the fluid interacts with oxygen. Depending on the thermodynamic conditions, oxidation of phosphate esters transpires through three distinct mechanisms: 1. 'Low' temperature conditions (approximately <200 °C) lead to the formation of varnish precursors that ultimately precipitate. 2. 'Moderate-high' temperature conditions (ranging from ~300

°C to 1000 °C) result in oxidation or incomplete combustion due to micro-dieseling or energy losses manifested through internal valve leakage. 3. 'Extremely high' temperature conditions (exceeding >1000 °C) are associated with oxidation resulting from static discharge (ASTM D 8323-20). In addition to temperature, oxidation of phosphate esters is also accelerated through catalytic reactions on the surface. Varnish is a byproduct of the precipitation and deposition of degradation compounds (commonly referred to as varnish precursors) primarily resulting from the decomposition of hydrocarbons and phosphates.

Hydrolysis represents a prevalent mode of phosphate ester degradation. In aqueous environments, phosphate esters typically decompose into their fundamental acids, specifically phosphoric acid derivatives and phenolic compounds. The hydrolysis reaction normally transpires at a relatively slow rate under standard ambient temperature conditions; however, its kinetics significantly accelerate with increasing temperature and are additionally enhanced by the presence of stronger acids and certain metallic ions (Phillips, 2021).

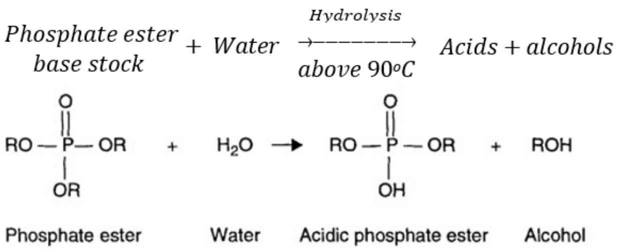

Figure. 2 Hydrolysis reaction of phosphate esters (W. D. Phillips, 2021)

The prevention of acid formation in phosphate ester fluids presents a significant challenge due to their inherently hygroscopic characteristics, which predispose them to moisture absorption from the surrounding environment. As long as there is moisture present, hydrolysis will persist unabated. The initial phase of oil degradation is marked by a notable increase in the total acid number (TAN), which subsequently enhances the oxidation and degradation mechanisms of the oil. The most severe documented lubricant degradation failure within the EHC system manifests when oxidation byproducts, primarily in the form of varnish with elevated adhesive properties, are produced, thereby disrupting hydraulic functionalities. The malfunction or adhesion of the hydraulic system during periods when the steam supply is expected to diminish, such as during a reduction in MW load, can lead to an excessive steam supply, culminating in turbine overspeed and potentially disastrous failure.

To achieve safe and reliable operation of EHC systems, the phosphate ester hydraulic fluid should be kept clean, with a low water content and acidity. To accomplish this, EHC systems generally have a fluid conditioning system with an acid scavenging filter, operating continually (W. D. Phillips, 2021). Condition Monitoring Program.

Table 1. Suggested Test of Routine Condition Monitoring Program for In-Service Phosphate Ester Fluids Used in EHC System

Property/Frequency	Test Method	Alternative Method
Appearance	See 12.1	ISO 2049
ASTM Color	D1500	
Acid Number	D664 or D974	ISO 6619 or ISO 6618
Water Content	D6304	ISO 760 ISO 20764
Volume Resistivity^B	D1169	IEC 60247
Fluid Cleanliness	ISO 11500 ISO 4406	ISO 4405 ISO 4407
Metal Content	D4898 D6595	D7596
Membrane Patch Colorimetry (MPC)	D7843	
Linear Sweep Voltammetry	D6971	
Viscosity	D445	ISO 3104 D7042
Chlorine Content^B	See 12.12	EN 14077 ISO 15597
Air Release	D3427	ISO 9120
Foaming	D892	ISO 6247
Mineral Oil Content	See 12.8	
Manifold Ignition Temperature^C	See 12.15	ISO 20823
Auto-Ignition Temperature^C	E659	DIN 51794

Attempting to reduce the fluid's degradation rate will be difficult if the system design, system operating conditions, and applied maintenance encourage oxidation to take place or allow moisture ingress. In such cases, the fluid may need to be replaced or subjected to bleed-and-feed more frequently. Alternatively, design changes can be made to increase fluid life. Auxiliary equipment can also be used to prevent oil degradation, for example

(V. Gryazin *et al.,* 2018) create a simple universal sensor for the quality control of lubricants and provide continuous monitoring of their state in terms of viscosity, temperature, moisture, and oxidation. With the help of the simple proposed devices, the concept of the most efficient use of lubricating fluids, as well as reduced operating costs is realized.

This paper will explore how simple modifications with additional equipment can enhance the reliability of lubricating oil. The research begins by collecting historical data on moisture from ambient air and design data from the EHC manual. This data will be used to create a model to determine the most effective design for the dehumidifier box. Next, observations are carried out to evaluate the impact of installing the box for further analysis and to assess the recommendations.

2. METHODOLOGY

This project focuses on controlling the primary cause of oil degradation, specifically the absorption of water by oil, which can trigger the hydrolysis process in the oil. Based on field observations, the main source of water ingress into the oil originates from humidity around the EHC Control Oil Tank through the air breather.

The study will focus on the author's efforts to perform treatment on EHC lubricants with a phosphate ester type. The treatment included monitoring the water content of EHC oils through sampling and chemical analysis of the oils and giving action by installing a device that serves to condition EHC reservoir tanks.

2.1. Water Contamination Control

Water levels are the most critical factor in the surveillance of the phosphate ester lubricant's condition. When water contamination is present in the oil, it will initiate a hydrolysis reaction, producing an acidic product. When the acid is in direct contact with the mechanical system of the components, it can cause adverse effects. EHC control system degradation may result from corrosion and staining within the system.

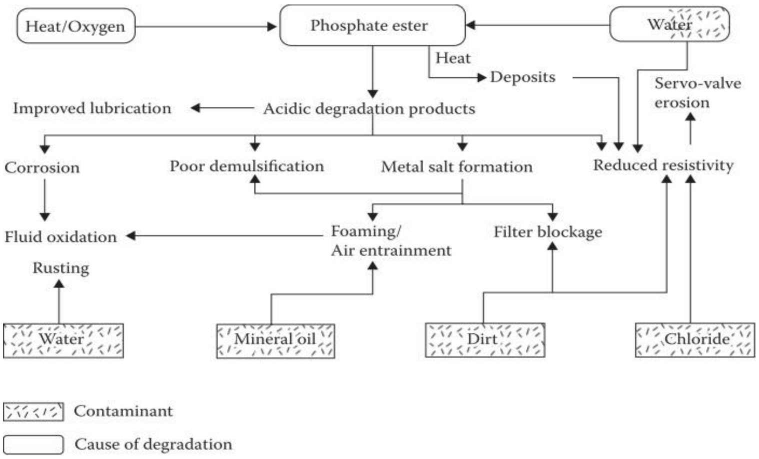

Figure. 3 Impact of contaminants and fluid degradation products on phosphate ester performance (W. D. Phillips, 2021).

Components that are potentially affected by hydrolysis products such as servo valves, switching vents, pumps, and other components. On the reservoir tank in the hydraulic system, PLTGU Block 4 is equipped with a section that serves as a breather where inside this tube there is a desiccant material that functions to absorb the moisture that may enter the tank so that it can damage the phosphate ester lubricant. On the design displayed in the manual book, this breather should be replaced periodically. The innovation in this journal is making simple equipment on a reservoir tank where this tool works to perform environmental conditioning on a breather which is called a dehumidifier box.

2.2. Dehumidifier Box

The main idea behind the creation of the dehumidifier box is to control the humidity around the breather of the Steam Turbine Control Oil Tank by using a box designed to fully cover the breather and direct the airflow through a moisture- absorbing material.

Dehumidifier Box Specifications:
Box Material : 0.8 cm Acrylic
Box Color : Colorless/ Transparent
Chemical Content : 16.8 liters of Silica Gel

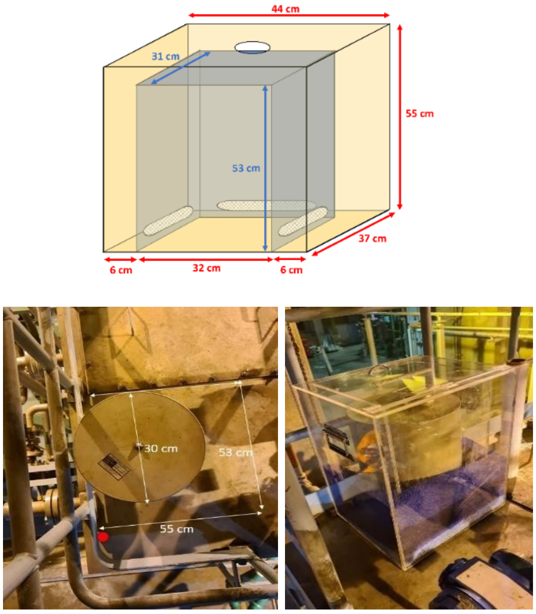

Figure. 4 Design of the dehumidifier box for controlling humidity in the reservoir tank.

The humidifier box is made of sufficiently thick acrylic to support the weight of 16.8 liters of silica gel. Additionally, using colorless/transparent acrylic ensures that the physical changes in the silica gel, as it absorbs moisture, are visible, making it easy for operators to identify during patrol checks. Silica gel is a chemical substance that functions as a desiccant, characterized by a color change as its moisture content varies. Silica gel appears blue when it is dry or has not yet absorbed water, and it turns pink when it becomes saturated or has reached its maximum capacity for moisture absorption.

This equipment is placed on an existing breather that has already been installed in the tank reservoir. Subsequently, monitoring is carried out over a certain period to see the impact of installing the device on the water content of the phosphate ester lubricant.

2.3. Water Content Measurement And Monitoring

Phosphate ester oil in the control oil tank is routinely sampled, and water content is measured to monitor the rate of water content increase in the oil, which can lead to oil degradation. The measurement is conducted using the ASTM 6304 test method, utilizing a Coulometric Karl Fischer apparatus equipped with a diaphragm.

Summary of Test Method, an aliquot is injected into the titration vessel of a coulometric Karl Fischer apparatus in which iodine for the Karl Fisher reaction is generated coulometrically at the anode. When all of the water has been titrated, excess iodine is detected by an electrometric end point detector and the titration is terminated. Based on the stoichiometry of the reaction, 1 mol of iodine reacts with 1 mol of water; thus, the quantity of water is proportional to the total integrated current according to Faraday's Law. The sample injection can be done either by mass or volume. The viscous samples can be analyzed by using a water vaporizer accessory that heats the sample in the evaporation chamber, and the vaporized water is carried into the Karl Fischer titration cell by a dry inert carrier gas.

When measuring water content, the sample injected into the Karl Fischer chamber should be as proportional as possible according to the guidelines in the table below.

Table 2. Test Sample Size Based on Expected Water Content

Expected Water Concentration	Sample Size g or mL	μg Water Titrated
10 to 100 mg/kg or μg/mL	3.0	30 to 300
10 to 500 mg/kg or μg/mL	2.0	200 to 1000
0.02 to 0.1%	1.0	200 to 1000
0.1 to 0.5%	0.5	500 to 2500
0.5 to 2.5%	0.25	1250 to 6250

The results of the water content measurement are then compared to the limits established in the ASTM 8323 standard to determine the level of water contamination in the oil.

Table 3. Preferable Levels and Warning Limits for Properties of In- Service Phosphate Ester Fluid Used in EHC Systems based on ASTM 8323

Test	Preferable Level	Warning Limits	Interpretation	Action Steps
Water Content	300 mg/kg – 500 mg/kg	>1000 mg/kg	Wet phosphate esters are subject to accelerated breakdown. Common sources of water contamination include: atmosphere, wet solid adsorbent media and/or cooler leaks.	Investigate cause and correct. Consider installing a vacuum dehydration system, or reservoir dry gas purge. Consider bleed-and-feed or fluid replacement if contamination is severe

3. RESULT AND DISCUSSION

The scope of discussion in this paper concerns the influence of humidity and the rate of water absorption by hygroscopic Phosphate Ester Oil, which can lead to oil degradation. Based on the reaction on Figure 2, Preventing acid formation in phosphate ester fluids is not possible due to their highly hygroscopic properties, causing them to absorb moisture from the surrounding environment. If moisture is present, hydrolysis will persist.

In this paper, the water content parameter was observed in two conditions, ambient humidity and controlled humidity by using a dehumidifier box. Based on the humidity observations over the nine months (October 2023 – August 2024), a range of moisture values of 50-80% with an average of 60%. The water content is measured using the ASTM D 6304-07 method. The instrument used in the measurement was by using Karl Fischer titrators.

The basic principle of Karl Fischer's method is the chemical reaction between water and Karl Fisher's reagent (a mixture of iodine, sulphur dioxide, and solvents such as methanol). This reaction produces a colorless product, and the amount of reagent used in this reaction is proportional to the quantity of water in the sample.

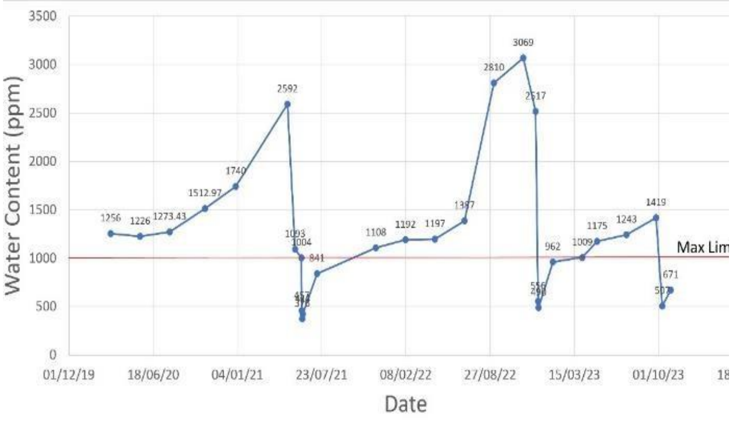

Figure. 5 Water Content (ppm) Trend in Ambient Humidity Without the Dehumidifier Box

The humidity level results in moisture absorption exceeding the water content limit, where the warning limit for water content is a maximum of 1000 ppm (W. D. Phillips, 2021). The trend of moisture absorption rate in ambient air can be seen in Figure.5. Compensation for this condition affects the treatment pattern that must be carried out as follows:

Table 4. List of Fluid Treatment Costs

No.	Description	Year	Cost
1	Oil purification	2021	Rp 37,830,000.
2	Oil purification	2022	Rp 39,255,900.
3	Oil purification	2023	Rp 67,593,450.
4	Total Oil Replacement	2023	Rp 363,584,000.

The environmental conditions during monitoring indicated that the average humidity around the EHC lubricant tank is about 61%. With this humidity level, the rate of increase in water content in the EHC lubricant after purification until it exceeds the required limit is around 5–6 months. Meanwhile, the manual's maintenance strategy mandates the replacement of the air breather component every six months. Therefore, every six months, purification of the EHC lubricant is necessary to reduce the water content in the lubricant, along with the replacement of the air breather.

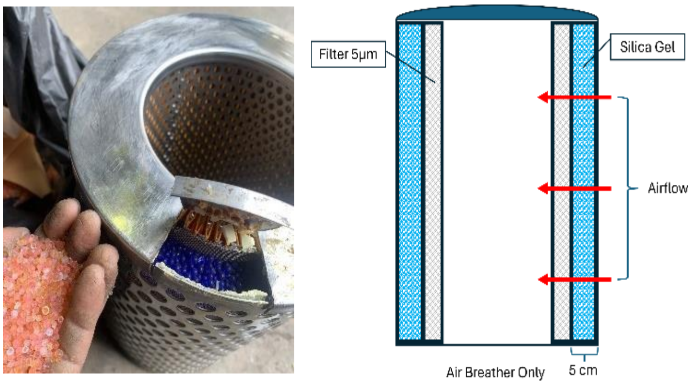

Figure. 6 Air Breather Component

The opaque metal cover of the air breather presents a challenge for monitoring its performance, making it difficult and impractical to observe the saturation level of the silica gel. At certain times, the potential for silica gel to become saturated before the scheduled replacement of the air breather is very likely to occur, as the thickness of the silica gel that the airflow passes through is only 5 cm, and the potential for uneven airflow across various surfaces may happen. Furthermore, diagnosing the saturation of silica gel can lead to errors, as we can only observe the outer layer of the silica gel, leaving the deeper layers unobservable for determining its saturation.

In 2023, the innovation of the Dehumidifier Box was designed based on the idea of controlling humidity in the control oil tank area of Steam 4.3. Then, on October 18, 2023, the equipment was installed in the system, followed by observations of the moisture absorption rate by the phosphate ester oil. Based on observations over nine months, the moisture absorption rate by the phosphate ester oil was found to be much slower compared to ambient humidity conditions. As a result, it is expected that the maintenance costs previously incurred during 2021-2023 can be minimized, leading to savings in maintenance budgets.

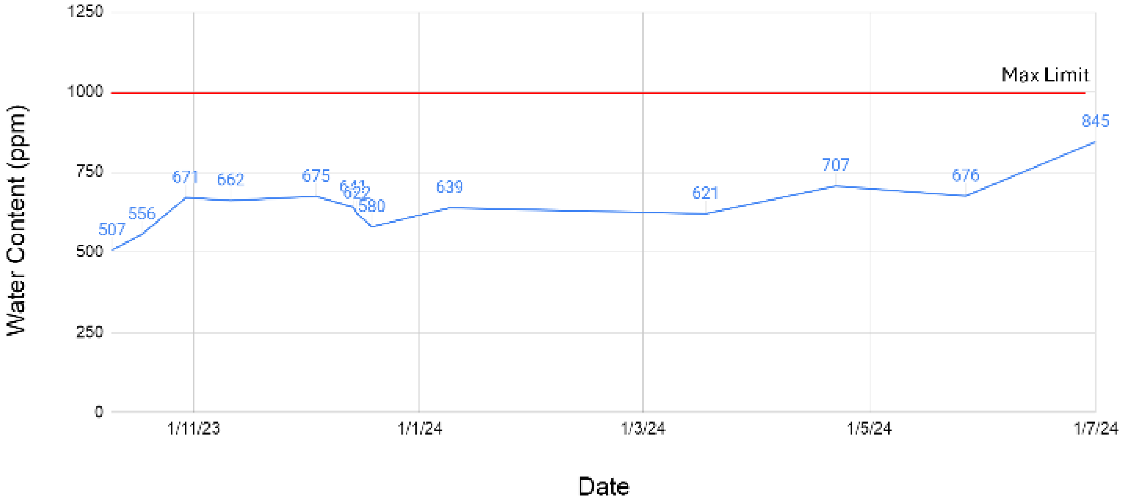

Figure. 8 Water Content (ppm) Trend in Controlled Humidity by Using Dehumidifier Box

After the installation of the dehumidifier box, the humidity can be controlled at around 19%, resulting in a decrease in the rate of water content increase in the lubricant, which extends the purification frequency to nine months.

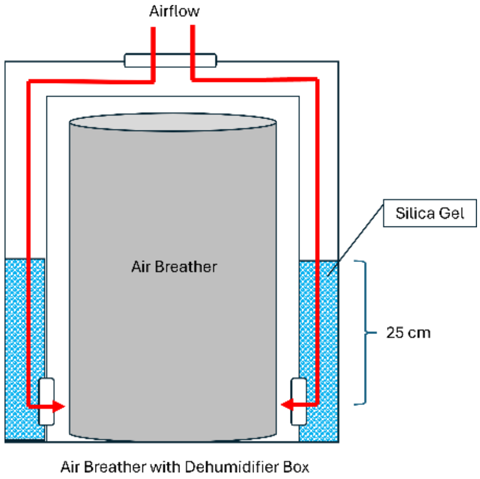

Figure. 9 Airflow direction in Dehumidifier Box

The box's design allows air to flow through a 25-cm-thick silica gel, which is five times thicker than the air breather. As a result, the silica gel in the dehumidifier box largely replaces the function of desiccant in the air breather, negating the need for an air breather replacement.

When the water supply is limited, the hydrolysis reaction will persist until all the water within the fluid is fully depleted. Once this occurs, the rate of acid formation will significantly decline. The principle of controlling hydrolysis is a primary concern in preventing future issues. This principle is not only applied in the context of EHC oil in power plants but is also implemented in the aviation industry.

4. CONCLUSION

To sum up, The experiments conducted in this study demonstrate that the dehumidifier box effectively lowers the humidity surrounding the EHC oil tank. Specifically, it reduces the average humidity level from 60% to 19%. As a result, the pace at which water content increases is significantly reduced, decreasing from an average of roughly 43 ppm per month to 19 ppm per month. The dehumidifier box has also been proven to decrease the fixed maintenance costs associated with EHC oil and tank management. This includes reducing the number of annual purifications from two to one, eliminating the need for an air breather replacement, and resulting in a significant cost reduction. The total expenses have been reduced from Rp 102,085,900 to Rp 41,105,900 per year. This reduction is achieved through a one-time oil purification process and the purchase of 25 kg of silica gel, without the necessity of air breather replacement.

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