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ANALYZING THE EVOLUTION OF TRANSFORMER OIL PURIFICATION METHODS

Abstract: Transformer oil plays a critical role in electrical transformers by providing insulation, cooling, and protection against oxidation. Over time, transformer oil degrades due to exposure to heat, moisture, and contaminants, leading to a loss in performance and potential hazards. This article examines the historical evolution of purification methods for transformer oil, from early filtration techniques to modern adsorption and renewable energy-powered systems. The strengths and limitations of various methods are analyzed, and statistical data are provided to showcase the comparative efficiency of these methods.

Key words: electrical transformers, transformer oil, various methods, and comparative analysis.

Language: English

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Introduction

Transformer oil is essential for the safe and effective operation of transformers. It provides electrical insulation, cools the transformer, and prevents oxidation of internal components. However, transformer oil deteriorates over time, accumulating moisture, gases, and particulate contaminants, which degrade its insulating and thermal properties. As the demand for improved operational efficiency and sustainability in the energy sector rises, the need for effective transformer oil purification has become increasingly important. This article aims to analyze the evolution of purification methods, from traditional

filtration to recent advances, such as solar-powered systems [2], [3].

Research Questions:

1. How have transformer oil purification methods evolved over time?
2. What are the comparative advantages and disadvantages of traditional versus modern purification techniques?
3. What role does renewable energy play in the advancement of these methods?

"Effective transformer oil purification is crucial for extending equipment lifespan, enhancing

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operational safety, and reducing environmental impact."

Dauletbay SARSENBAEV, 2024 year.

Main part

Historical Overview of Transformer Oil Purification Methods

Early Purification Methods

The earliest methods focused on mechanical filtration and centrifugation, which could remove solid particulates but had limited effectiveness against dissolved gases and moisture. These methods were widely adopted in the early 20th century due to their simplicity and low cost, though they were insufficient for comprehensive oil purification.

Mid-20th Century Developments

In the 1960s, vacuum dehydration and chemical treatment were introduced to address the limitations of

earlier methods. Vacuum dehydration became popular for its ability to remove moisture and dissolved gases effectively, though it required substantial energy. Chemical treatments helped neutralize acids formed from oil oxidation but introduced potential chemical waste.

Modern Techniques: 2000s to Present

Recent advancements have focused on adsorption-based technologies, utilizing materials like activated carbon and zeolites to remove impurities at a molecular level. High-vacuum technology and advanced filtration have further enhanced purification efficiency, while solar-powered systems have introduced sustainability to the field (Table 1). [4], [6], [13].

Table 1. Key Milestones in Transformer Oil Purification

Method	Era	Main Advantage	Key Limitation
Mechanical Filtration	1930s	Low cost, simple	Ineffective against moisture
Vacuum Dehydration	1960s	Moisture and gas removal	High energy consumption
Adsorption Technologies	1980s	Effective impurity removal	High initial cost
Solar-Powered Systems	2020s	Environmentally sustainable	Limited by sunlight availability

Current Transformer Oil Purification Technologies

Adsorption-Based Techniques

Modern adsorption techniques use materials like activated carbon, silica gel, and zeolites to capture impurities through physical or chemical bonding. These methods achieve high efficiency in removing acids and moisture, but adsorbents need periodic replacement, adding to operational costs.

High-Vacuum and Thermal Purification

High-vacuum systems are effective at degassing and dehumidifying transformer oil. Thermal methods can assist in removing dissolved gases, though they are energy-intensive and may contribute to carbon emissions.

Advanced Filtration Systems

Advanced filtration systems, including submicron filters, can remove smaller particulates more effectively than older methods. This type of filtration is typically used in combination with other methods to enhance overall purification quality.

Solar-Powered Purification Systems

The recent shift toward renewable energy has led to the development of solar-powered oil purification systems. These systems leverage photovoltaic cells to power filtration and vacuum equipment, minimizing the environmental impact and operational costs. Solar-powered systems are still emerging but represent a sustainable, eco-friendly alternative for transformer oil purification (Table 2) [7], [8], [9], [10], [15].

Comparative Analysis of Purification Methods

Efficiency and Cost Analysis

Each purification method is evaluated based on efficiency, cost, and operational requirements. Adsorption methods provide high efficiency but come at a high operational cost due to regular adsorbent replacement. Mechanical filtration is cost-effective but does not remove moisture as effectively as vacuum or adsorption methods.

Environmental Impact

While advanced filtration and vacuum methods are effective, they can have a significant environmental footprint due to their energy consumption and waste production. Solar-powered purification systems, by contrast, reduce greenhouse

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gas emissions, aligning with global environmental goals [11], [12], [14].

Table 2. Cost and Efficiency Comparison of Purification Methods

Method	Efficiency (%)	Average Cost (\$)	Environmental Impact
Mechanical Filtration	60	500	Low
High-Vacuum Dehydration	85	5,000	Moderate
Solar-Powered Adsorption	95	8,000	Low (Renewable energy use)

Future Directions in Transformer Oil Purification

As technology continues to advance, the field of transformer oil purification is expected to benefit from innovations like:

Eco-friendly Adsorbents: Development of biodegradable and reusable adsorbents.

AI and Machine Learning: Implementing intelligent control systems for optimizing purification processes.

Enhanced Renewable Energy Utilization: Expanding solar and possibly wind energy-powered systems to improve sustainability [1], [5].

Conclusion

This analysis highlights the evolution of transformer oil purification, demonstrating a shift from simple filtration methods to advanced, sustainable techniques. Solar-powered systems represent an environmentally friendly alternative, though they are still developing. As the energy sector progresses towards sustainability, ongoing research into more efficient, cost-effective, and eco-friendly purification methods will be crucial.

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