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Methods for improving the workability of natural ester insulating oils in power transformer applications: A review

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ABSTRACT

Even though natural insulating oils (NEI) oils are environmentally friendly, these oils have not gained widespread use in high-voltage oil-immersed power transformers because of their unfavorable properties such as low pour point, low oxidation stability, low resistance to lightning impulse, and high kinematic viscosity. Hence, much effort has been made to overcome the disadvantages of NEI oils, including the addition of additives, modification of the chemical structure of oils and altering the transformer design to ensure compatibility with the oils. This review article is focused on the methods used to improve the workability of NEI oils in power transformers, namely, (1) depression of the pour point, (2) chemical modifications, (3) changes in the transformer design, (4) addition of nanoparticles, (5) addition of lightning resistance additives, and (6) addition of antioxidants. The benefits and challenges of each method are also discussed. It is believed that this review article offers new insight to scientists and researchers in this field.

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1. Introduction

It is known that natural ester insulating (NEI) oils are promising substitutes for mineral insulating (MI) oils because these oils reduce aging of insulating papers in high-voltage oil-immersed power transformers. In addition, NEI oils are environmentally safe because they are biodegradable and they are produced from renewable and sustainable resources. In addition, NEI oils are less flammable compared with MI oils and they do not contain corrosive sulfur. These oils also offer adequate dielectric strength, making them a feasible alternative for MI oils in power transformers [1–5].

The advantages of NEI oils have gained much attention from researchers worldwide. To date, NEI oils are used in several in-service power and distribution transformers in Australia, United Kingdom, Sri Lanka, and Germany [6–9] (Fig. 1). Meanwhile, *Companhia Paranaense de Energia* (COPEL), a power utility company in

Brazil, has been using NEI oils in their 13.8-kV recloser equipment for almost 5 years [10]. With the growing number of manufacturers and energy utilities developing and using NEI oils (especially in transformer applications), there is a need to establish international standards to facilitate and accommodate the usage of NEI oils in power transformers. At present, there are international standards available as a result of the growing number of transformer manufacturers and maintenance service providers involved in using NEI oils. These standards are:

1. IEC 62770:2013—Unused Natural Esters for Transformers and Similar Electrical equipment [11].
2. IEEE C57.147-2008—Guide for Acceptance and Maintenance of Natural Ester Fluids in Transformers [12].
3. ASTM D6871: 2008—Standard Specification for Natural (Vegetable Oil) Ester Fluids Used in Electrical Apparatus [13].
4. IEEE C57.155-2014—IEEE Guide for Interpretation of Gases Generated in Natural Ester and Synthetic Ester-Immersed Transformers [14].

Despite the advantages of NEI oils published in the literature, there are also a few disadvantages of NEI oils, which have led to

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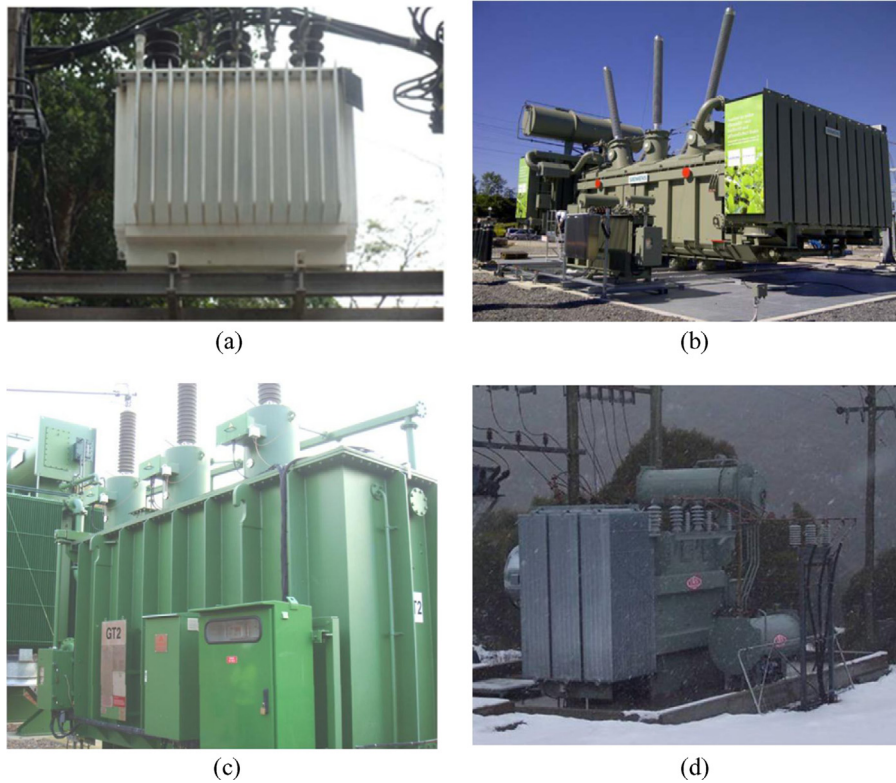


Fig. 1. NEI oil-immersed transformers: (a) coconut oil-immersed distribution transformer (160 kVA, 33/0.4 kV) installed at Wathara, Kesbewa, Sri Lanka, in 2001 [7]; (b) siemens 420 kV extra-high voltage transformer filled with Envirotemp™ FR3™ fluid installed at Bruchsal-Kändelweg substation near Karlsruhe, Germany, in 2014 [8]; (c) UK Power Networks 90 MVA 132 kV transformer installed at Luton, UK, since 2009 [6]; (d) 10–16 MVA transformer installed at Thredbo, New South Wales, Australia, and has been in operation since 2005 [6].

reluctance in using NEI oils in power transformers by energy utilities. These disadvantages are:

1. Low pour point [2,15].
2. Low oxidation stability [16,17].
3. Low resistance to lightning impulse [18–20].
4. High kinematic viscosity [21,22].

Pour point is one of the critical properties of NEI oils especially if these oils are to be used in countries with cold climates. Resistance to lightning impulse and kinematic viscosity are important properties of insulating oils especially for power transformers with high voltage and power ratings. Oxidation stability is an essential property of insulating oils owing to the fact that ~90% of distribution transformers worldwide are free-breathing transformers [23]. The low pour point, low oxidation stability, low resistance to lightning impulse, and high kinematic viscosity of NEI oils have led to reluctance by energy utilities to use NEI oils in oil-immersed power transformers.

For this reason, it is a challenge to promote the use of NEI oils in power or distribution transformers. One of the strategies that can be implemented to overcome this barrier is to enhance the properties of NEI oils so that the properties are superior or at least comparable with MI oils. This is due to the fact that MI oils have been used in all of types of transformers for almost a century [2,24]. Extensive research and development of MI oils is one of the factors that lead energy utilities to remain complacent in using these oils in power transformers even though MI oils are detrimental to the environment. Based on historical records, research and development on NEI oils began in the 1990s because of environmental and health issues, which have become a major public concern because of oil spillage and leakage incidents. In addition, there is growing con-

cern on the carcinogenic effect of polychlorinated biphenyls (PCB) present in MI oils [25].

2. Methods to improve the workability of natural ester insulating oils in power transformers

There are a few methods used to overcome the disadvantages of NEI oils and improve the workability of these oils in power transformers. These methods are listed as follows:

1. Depression of the pour point,
2. Chemical modifications,
3. Changes in the transformer design,
4. Addition of nanoparticles,
5. Addition of lightning impulse resistance additives,
6. Addition of antioxidants.

Each method is discussed in this following section, which will provide the reader with valuable insight on the key methods used to improve the properties of NEI oils. These methods are developed to gain attention from the key players of energy utilities for selecting NEI oil as one of the alternative insulating oil besides mineral insulating (MI) oil. In this article, all of six methods will be discussed to discover the reliability of NEI oil in the power utilities market.

2.1. Depression of the pour point

According to the ASTM D97 standard test method [26], pour point is defined as the temperature at which a liquid begins to lose its flow characteristics due to transition of the liquid–solid states. The pour point is a critical parameter for transformer insulating oils, specifically those that are intended for use in cold climates.

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