Renewable and Sustainable Energy Reviews 52 (2015) 308–324

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Use of vegetable oils as transformer oils – a review

M. Rafiq [a,c,*], Y.Z. Lv [a,b], Y. Zhou [a,c], K.B. Ma [a,c], W. Wang [b], C.R. Li [a,c], Q. Wang [a,c]

[a] Beijing Key Laboratory of High Voltage and EMC, School of Electric and Electronic Engineering, North China Electric Power University, Beijing 102206, China
[b] School of Energy, Power and Mechanical Engineering, North China Electric Power University, Beijing 102206, China
[c] State key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University, Beijing 102206, China

ARTICLE INFO

Article history:
Received 29 January 2014
Received in revised form
17 May 2015
Accepted 8 July 2015
Available online 14 August 2015

Keywords:
Vegetable oil
Biodegradable oil
Renewable materials
Dielectric strength

ABSTRACT

The mineral or synthetic oil is mostly being used in conjunction with paper as the dielectric medium in most of the high voltage equipment. However, impact on environment, lack of petroleum oil reserves and disposal problems with used oils, have prompted researchers to direct their focus onto biodegradable and renewable insulating materials. The new insulating liquid materials development is guided by multiple factors such as environmental requirements and other safety and economic considerations. Therefore transformers manufacturer have to face new specifications related to these new requirements. The Vegetable-oil based transformer fluids increasingly replacing mineral oil-based products in the market place. They are successful because they perform better than mineral oil products and they provide definite environmental and safety gains. This paper reviews the current status of vegetable oils use as transformer oil, including their production, processing, and characterization. The vegetable oils most used as transformer oils are presented and their main advantages described in comparison with mineral oil. The various experimental work carried out in different countries is described, giving an overview of the current research carried out on the vegetable oils. In addition scope and challenges being faced in this area of research are clearly described.

Contents

* Corresponding author. Tel.: +8613641117142.

http://dx.doi.org/10.1016/j.rser.2015.07.032
1364-0321/

1. Introduction

The development of future low carbon network and smart grid has raised high demands on the reliability and performance of insulation materials used in electrical power system plants to cope with more dynamic and volatile operating conditions. A transformer, which transforms voltage and transfer energy, is one of the most vital components of a power network. Mineral oils have been used as coolant and insulator for over a century [1]. However, due to limitation of sources of mineral oils, sustainable production of transformer oil is being hotly debated worldwide since it is increasingly acknowledged that first generation mineral oil, primarily produced from petroleum products, are limited in reserves and have several other drawbacks such as, non-biodegradability (the level of biodegradability for mineral oil is not more than 30%), low flash point, non-renewable and could cause a serious problem if there is a spillage [2–4]. Also the enhanced industrialization and motorization of the society has led to a huge rise in demand of petroleum products. The above mentioned concerns have increased the attention to look for alternate, which can be produced from materials available abundant in nature and which potentially can offer greatest opportunities in the longer term.

Liquid filled transformers use billion of liters of insulating fluid. They come in various sizes: large, medium and small. Power as well as distribution transformers use oil for insulation and cooling purposes. The distribution smaller units are numerous than larger units because distribution is more widespread by definition and hence smaller units hold much more fluid in total as compared to larger units. Mineral oil is most commonly used transformer fluid and has been used for more than a century. Small units used in confined areas like shopping centers may use fire resistance fluids such as silicone, high temperature mineral oil and synthetic ester fluids. In the recent years, environmental concerns have been raised on the use of poorly biodegradable fluids in electrical apparatus in areas where spills from leaks and equipment failure could contaminate the surroundings. Contamination of the water supply is more serious as compared to the contamination of soil [5].

The vegetable oils are thought to be a suitable alternate of mineral oil in transformers. The vegetable oils are naturally obtained from seeds as well as form flowers. Many researchers and industries are performing investigations on vegetable oils for providing them as insulating oils in transformers and pollution free environment [6]. Vegetable oils have the properties like High biodegradable ($>95\%$), low toxicity, high flash points ($>300\ ^{\circ}C$), fire points ($>300\ ^{\circ}C$), provide lower flammability and it is considered more environmental friendly fluids [7–9]. In addition, these vegetable oils absorb more moisture compared to mineral oils [10,11]. However, high concentration of unsaturated fatty acid makes them unstable and prone to oxidation [12]. These fatty acid hydrocarbons chains and their degree of un-saturation affect the dielectric and physiochemical characteristics of vegetable oils. Vegetable oils have higher acidity than mineral oils [13] due to hydrolysis reaction which forms above mentioned acids (reaction that does not occur in mineral oils) and to the different chemical structure of the two oils. Also, the nature of the contained acids in both oils is different. Vegetable oils mainly contain highly molecular weight acids (HMA) like stearic and oleic acids whereas the mineral oil contains low molecular weight acids (LMA) like acetic, formic and levulinic acids [14–16].

Research efforts started in mid 1990s to develop a fully biodegradable liquid due to the utility interest. The R&D labs stated efforts in this direction and initiated oil development work. Vegetable oil was considered the most likely candidate for a fully biodegradable insulation liquid. Vegetable oil is available in plenty as a natural resource. It was considered a biodegradable and a good insulator [17]. Vegetable oils have emerged as an increasingly common mineral oil alternative. They offset all the main risks associated with common mineral oil, such as high flammability and environmental impact. They are made from renewable biological sources such as vegetables. It is biodegradable, non-toxic and possesses low emission profiles. Also, the use of vegetable oil liquids is environmentally beneficial.

Only recently transformer-grade vegetable oils become available. The first commercial product was BIOTEMP®, patented in September 1999 by ABB in US [18]. The base fluid was high oleic oil with 80% oleic content. These oils were produced from seeds which have been developed by selective breeding; recently gene manipulation techniques have also been used. Unstable tri-unsaturates were minimized by additional step of partial hydrogenation. The BIOTEMP® fluid is now in use in distribution transformers in some sensitive areas. Later in September 1999, another U.S patent was issued, for transformer oil obtained from regular soybean oil prepared by Waverly Light & Power in Iowa [19]. It is not high oleic oil. In March 2000, the Cooper industries, Inc in Milwaukee, WI under the trademark Envirotemp FR3® [20]. This fluid is being used in some commercial distribution transformers and is from standard grade oleic base oils. In August 2001, a second patent was issued to ABB inventors on BIOTEMP® [21]. Except BIOTEMP®, the fluid development details are not available, on which a dozen of technical papers have been published. For BIOTEMP®, the starting oil is high oleic oil, such as sunflower oil, containing 80% or more oleic content. Canola oil upgraded to this level of oleic content also been tested for use [22].

This paper gives a comprehensive review of the methods used for producing vegetable oil, experimental investigation on different oils, characterization, merits, demerits and challenges faced by vegetable oil are described.