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Enhancement of Thermal and Dielectric Characteristics of Transformer Oil Using Nanomaterials

A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

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بسم الله الرحمن الرحيم

﴿ قالوا سبحانك لا علم لنا الا ما علمتنا

إنك انت العليم الحكيم ﴾

صدق الله العظيم

الآيه(32) سوره البقره

Dedication

To my dear father who always keeps my head up to the sky

To the shining of light in our lives ……. dear mother

To the essence of my happiness ……. my brothers & sister

To all my friends

I dedicate my project

Ali Khairallah Ali

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COMMITTEE CERTIFICATION

We certify that we have read the thesis entitled "**Enhancement of Thermal and Dielectric Characteristics of Transformer Oil Using Nanomaterials"** and we have examined the student (**Ali Khairallah Ali**) in its content and what is related with it, and in our opinion, it is adequate as a thesis for **Degree of Master of Science in Mechanical Engineering**

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We certify that this thesis titled **“Enhancement of Thermal and Dielectric Characteristics of Transformer Oil Using Nanomaterials”** which is being submitted by **“Ali Khairullah Ali”** was prepared under our supervision at the Mechanical Engineering Department of the University of Diyla in a partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.

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Abstract

Among obstacles that effect on the operation transformer is a (high temperature, shortage insulation between the internal parts, exposure metal parts to corrosion), All these factors are controlled by transformer oil. Improving properties of transformer oil leads to increase efficiency of transformer, in addition extending life of transformer. In this study, will be highlighted by adding nanomaterials to transformer oil to increase efficiency of transformer. Two types of nanofluids will be produced the first one, adding one type of nanomaterials (Fe_3O_4 (20-30nm) to transformer oil and producing a nanofluid (Fe_3O_4 (20-30nm) +Oil) with different concentrations (0.2%,0.4%0.6% w/v). The second one, adding several nanomaterials (Al_2O_3(20nm), TiO_2(10-30nm), CuO(40nm)) and producing a hybrid nanofluid (CuO+ Al_2O_3+TiO_2+Oil) with concentrations (0.2%,0.4%0.6% w/v). The aim of this study is to produce a fluid have better properties than transformers oil, as well fast treatment of damaged or expired oil which will gain a lot of effort and time. The produced samples subjected to several tests included "Breakdown voltage test, Flash Point test, Pour Point test and Thermal Conductivity test" and then compared the results of nanofluid samples with the transformer oil. The results of tests showed that use of nanoparticles (Fe_3O_4) leads to enhance thermal conductivity about 12.9% at a concentration of 0.6% w/v, and thus lead more cooling of transformer. also increase dielectric (Breakdown voltage) about 24.2% at a concentration of 0.6% w/v. The results of the hybrid nanofluid tests showed, adding mixture of nanomaterials (CuO, Al_2O_3, TiO_2) leads to a further increase in the dielectric 54.4% at a concentration of 0.6% w/v. Thus, the produced nanofluids possess strong properties in terms of insulation and cooling, which is the most important characteristic that must be available in transformer oil. finally use these nanofluids instead of transformer oil leads to more efficiency and operating stability of transformer.

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Symbol Definition Table

Symbol	Definition
A	The surface area
m	mass
g	Gravitational constant
L	The characteristic dimension of length
W	The characteristic dimension of width
H	The characteristic dimension of Hight
K	Thermal conductivity of the material
∈	emissivity of the surface
β	Thermal expansion coefficient
ν	kinematic viscosity
μ	dynamic viscosity
Cp	Specific heat at constant pressure
ρ	Density
ϕ	volume fraction
g	acceleration due to gravity, (β) fluid
ΔT	Temperature difference
T_s	surface temperature
T_∞	fluid temperature
D	high of core in m
α	thermal diffusivity
h_c	heat convection coefficient
A_c	circumferential area
T_c	core temperature
T_o	oil temperature
m_n	mass of nano$particals$
ρ_n	density of nano$particals$
m_{bf}	mass of base fluid

ρ_{bf}	Density of base fluid
ρ_{nf}	density of nanofluid
$C_{p,nf}$	specific heat of nanofluid
$C_{p,bf}$	specific heat of base fluid
μ_{nf}	dynamic viscosity of nanofluid
μ_{bf}	dynamic viscosity of base fluid
d_p	nanoparticle diameter
M	Molecular weight
N	Avogadro's number
k_{nf}	Thermal conductivity of nanofluid
k_{bf}	Thermal conductivity of base fluid
k_{np}	Thermal conductivity of nanomaterials
V_{hp}	volume of hybrid nanofluid
$\rho_{hb,nf}$	Density of hybrid nanofluid
ρ_{np}	Density of nanomaterials
$\mu_{hb,nf}$	Dynamic viscosity of hybrid nano fluid
$Cp_{hb,nf}$	specific heat of hybrid nano fluid
$k_{hb,nf}$	thermal conductivity of hybrid nano fluid

Abbreviation Definition Table

Abbreviation	Definition
ONAN	Oil Natural Air Natural
OFAF	Oil Forced Air Forced
OFWF	Oil Forced Water Forced
ONAF	Oil Natural Air Forced
ODAD	Oil Directed Air Directed
ODWD	Oil Directed Water Directed
MEMS	micro-electromechanical system
NEMS	nanoelectromechanical system
LEDS	Light-emitting diode system
MF	Magnetic Fluid
NF	Nanofluid
NFs	Nanofluids
Nps	nanoparticles
Nu	Nusselt Number
Gr	Grashof Number
Pr	Prandtl Number

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CHAPTER ONE

Introduction

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Introduction

1.1. Introduction

It is important to pay attention to the most important part of the electric power distribution and transmission networks, which is the electric transformer. During the quantitative conversion of electrical energy, many types of losses are arising. These losses usually take place at active parts (windings and core) of the transformer and then converted into heat. the accumulation for this heat without efficient dissipation will cause Negative effect on the operation and efficiency of the transformer [1]. Recently, after the arrival of nanotechnology and its entry into many fields, several investigations have been devoted for examining the effect of nanofluid on transformer [2]. Nanoparticles utilizing in nanofluid can be produced from various substances, such as nitride ceramics (AlN, SiN), oxide ceramic (CuO), carbide ceramics (Sic, Tic), semiconductors metal (Cu, Ag, Au), carbon nanotube [3]. The nanomaterial can be utilized for enhancing the properties of transformer oil, that leads to minimize transformer size and cost production and increase transformer life time [4].

1.2. Classification of Transformers in an Electrical System

Transformers are used in various places and fields, including in distribution networks, substation, power plant, and many applications and according to need. Because of the wide variety and different use, the classification of transformers represents a great challenge. Based on the size range, it will be categorized into major sectors [5]:

In general, most transformers are similar in electrophysical principle. Figure (1.1) three-dimensional model of an electrical power transformer. Table (1.1) Classification of transformers in terms of power and applied voltages.

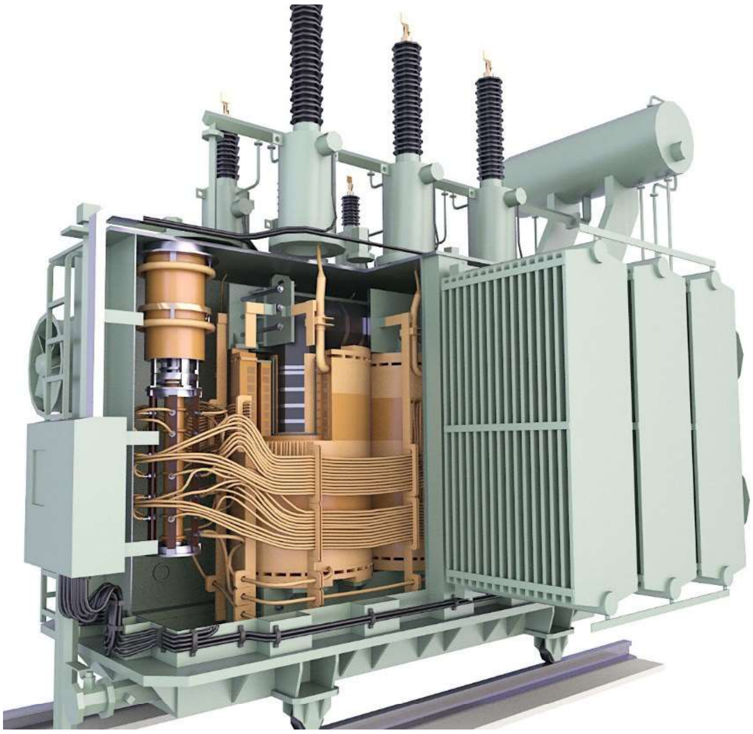

Figure (1.1) 3D Cut Diagram of power distribution transformer [6].

Table (1.1): Classification of power transformers [5].

Mini Transformers	Medium Transformers	Big Transformers
The maximum voltage of these transformers is less than 72.5 KV [5]. These transformers are usually used in the field of electric power distribution with rated less than 30 MVA.	In these transformers, the voltage is higher than (72.5 KV), the design used is single phase or three-phases, and the transformer rating 30- 250 MVA.	The rating voltage up to 145 KV and the range of power above 250 MVA.it can be designed as multi winding transformers or autotransformers in both single phase and three phase system.

1.3. Transformer Oil

Transformer oil (also referred to as insulating oil) This oil has certain properties, including dielectric at high temperatures.

Transformer oil is used in oil-filled electrical transformers to insulate, furnish up arcing and corona discharge, and to dissipate the warmness of the transformer (i.e., act as a coolant). In addition, transformer oil is used to preserve the transformer's core and windings. Another quintessential property of the insulating oil is its normal usual performance to stop oxidation of the cellulose-made paper insulation. The transformer oil acts as a barrier between the atmospheric oxygen and the cellulose – warding off direct contact and for this intent minimizing oxidation. The diploma of transformer oil is regularly measured the utilization of a MOG (Magnetic Oil diploma Gauge) [7].

1.4. Transformer Oil Properties

Most of the investigation results about damaged and destroyed transformers are due to the overload that results in a lot of residues such as insulator breakdown and overheating. Both insulation and high temperature are due to transformer oil, so oil checks must be repeated from time to another.

1.4.1. Breakdown Voltage

Oil transformer is an electrical insulator, but this insulator has a breakdown limit. At these limits, the insulator becomes an electrical conductor. This is one of the desirable properties of oil, as the higher ability to withstand high voltage it will be better in terms of use. In most cases, when testing this characteristic of breakdown voltage used (BD Breakdown voltage device) [8].

1.4.2. Viscosity

Viscosity is one of the most important properties of transformer oil due to its direct connection in the heat exchange process. High viscosity is a good characteristic of electrical properties, while low viscosity reduces the ability to cool. Therefore, a compromise is chosen to determine the best. It is necessary to take into account that the viscosity changes when the temperature changes. When the transformer is running, and because of the copper and iron losses of the transformer, the temperature will rise and therefore the viscosity of the oil will decrease [8].

1.4.3. Pour Point

Pour point is the lowest temperature at which it is difficult for the oil to flow. This impedes the cooling process of the transformer. It is necessary to test this property of the oil, especially in very cold regions. the type of oil used must be determined according to the surrounding conditions. Paraffin-based oil has a higher pour point value than naphtha-based oil, because paraffin oil contains a larger percentage of wax and therefore has a higher pour point [8].

1.4.4. Flash Point

Flash point is a chemical property of transformer oil. It is the temperature at which the oil begins to evaporate and form a combustible mixture. The higher the flash point, the better it is to avoid fires and explosions. When testing this property, the flash point must not be less than 140 °C [9].

1.4.5. Moisture Content

Moisture content is the amount of water present in transformer oil, which is an undesirable characteristic that has an effect on the oil's dielectric and boiling point. The higher the water content in the oil, the shorter the life of the oil, is in addition to the damage to the insulating paper and the oxidation of the rest of the transformer parts [9].

1.5. Improving Transformer Oil Properties Using Nanomaterials

After the discovery of nanoparticles, it became possible to use them in various fields, including the production of transformer oil nanofluids to improve some properties of the oil [9]. Many Lots experiments and investigations have been conducted on various types of nanoparticles and their effect on physical, chemical and electrical properties have been studied [10]. For the production of nanofluid. In the first step, prepare the used nanomaterials. Among these materials are metal oxides such as SnO_2, Fe_2O_3, ZnO, TiO_2, CuO, etc. There are several ways to prepare this material [11]. In the second step is the preparation of the nanofluid, where the basic things must be taken into account in selecting the nanoparticles, including thermal conductivity, dielectric and permittivity, each as needed, wherein nanomaterials are classified into conductor, semiconductor, and insulator are usually used to prepare Nanofluids using one of the two methods, which are either the one-step method or the two-step method [12].

In most cases, the two-step method is used, where the nanoparticles are mixed with the base liquid by one of the "high shear mixing, ball milling, ultrasonic or magnetic stirring" methods. In this way we avoid sedimentation or agglomeration [13].

1.5.1. Improvement of Insulation and Thermal Properties

Many studies and experiments that have been conducted have indicated that the use of some nanomaterials of certain shapes and sizes improves the properties of the oil in terms of electrical insulation and heat transfer [14]. Because of the high thermal coefficient of nanoparticles, it usually leads to an improvement in the thermal properties of metallic liquids.

Some nanomaterials when mixed with base fluids showed that they have the ability to absorb soluble gases as well as absorb water from oil, and this improves the properties and electrical insulation [15].

1.5.2. Improvement of Physicochemical Properties

The addition of nanomaterials directly affects the physical and chemical properties. These properties are significantly related to the number of NPs scattered in the base fluid. Any characteristic of transformer oil can be improved by choosing the appropriate nanomaterial as well as the different physical parameters of the NPs (type, shape, size, concentration).

For example, the viscosity of NFs depends on the physical limitations of NPs but is also affected by the ionic strength of the base liquid, the pH value of the solution, Vander Walls, and the repulsive forces of NPs [16]. On the other hand, the density of NFs is affected by the concentration and type of NPs and temperature. In most cases, it was observed that the density increased with the enhancement of the NPs concentration and decreased with increasing temperature. An increase in temperature leads to an increase in the volume of the liquid and therefore a decrease in its density. The pour point is one of the required specifications when marketing transformer oil. The temperature that allows the oil to continue flowing must be very low. This property can be treated by adding some nanomaterials that have the ability to enhance this property. Beheshti and others [17,18]. evaluated the flash point with reference to the loading of the NPs. The flash point of NF showed a 4.6% improvement at NP loading (0.001 mass fraction %), although the flash point decreased with additional increase in NP loadings. Figure (1.2) general outline of thermophysical and electrical features of NFs.

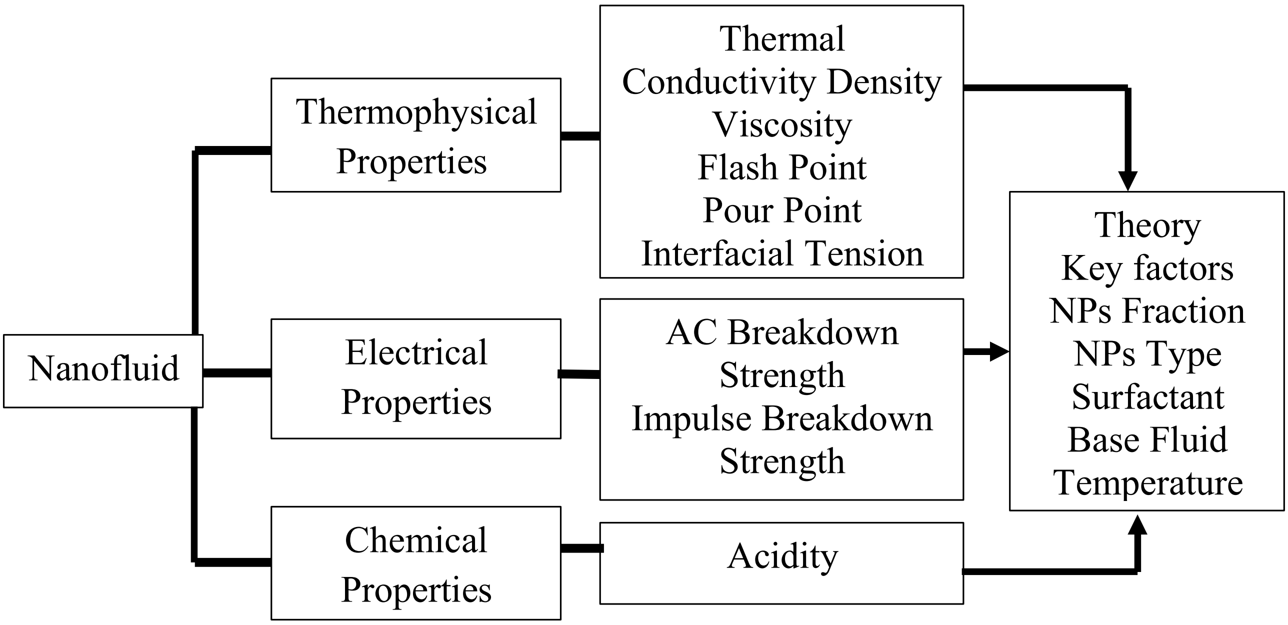

Figure (1.2) Graphic illustrations of general outline of thermophysical and electrical features of NFs [18].

1.6. Objectives of the Present Work

The current work aims to study enhancing the properties of power transformer oil by dispersing nanomaterials in transformer oil. This study includes experimental investigation of the volume fraction efficacy. Objective of the present study can be summarized as follows:

1- To study the effect of adding nano materials (Fe3O4) to enhance the transformer oil performance.
2- To study the effect of adding hybrid nanomaterials (Al2O3, TiO2, CuO) to enhance the transformer oil performance.
3- To study the effect of concentration of nanomaterials on transformer oil properties.
4- To investigate experimentally the effect of nanomaterials on thermophysical properties of transformer oil (Flash Point, Pour Point, Thermal Cond activity and breakdown voltage property.