Study on critical characteristics of mineral insulating oil modified by nanomaterials and flame retardants

Jiaqiang Wei $^{1,*}$, Ying Huang $^2$ and Jianxing Yi $^3$

$^1$State Grid Hunan Electric Power Corporation Limited Research Institute, Changsha City, Hunan Province, China
$^2$State Grid Hunan Electric Power Company Limited, Changsha City, Hunan Province, 410004, China
$^3$State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei City, Anhui Province, 230026, China

*Corresponding author’s e-mail: weijq1@hn.sgcc.com.cn

Abstract. Insulating oil is a liquid insulating material which acts as an insulating medium and coolant. Mineral insulating oil is the most commonly used liquid insulating material in oil-immersed transformer. In this paper, the critical characteristics of mineral insulating oil modified by nanomaterials and flame retardants are studied. Modified mineral insulating oil prepared by mixing the nanoparticles (ferric oxide, copper, and magnesium hydrate) and tripropylphenyl phosphate (IPPP) for various volume concentrations with mineral insulating oil by ultrasonic process. Various critical parameters such as flash point, fire point, breakdown voltage, Kinematic viscosity are analyzed.

1. Introduction

Mineral insulating oil is widely used as insulating oil in immersed equipment due to good dielectric properties and low price, which act as coolant and provide electrical insulation. However, mineral insulating oil has poor fire-proof performance may lead to disastrous fire when transformer system fails. In order to overcome the shortcomings of mineral oil, many scholars have been studied on using flame retardant additives to improve the safety of materials. But flame retardant added in mineral insulating oil may changed other characteristics of mineral insulating oil such as breakdown voltage and Kinematic viscosity. In order to enhance mineral insulating oil thermal conductivity and electrical properties, some scholars have studied the characteristics of nanoparticles modified insulating oil [1-4]. R. Karthik et al. has studied Breakdown voltage, Kinematic viscosity, pH value, flash point, fire point of mineral insulating oil impact by different nanoparticles [5]. Z.J. Zhou et al. reported the characteristics of mineral insulating oil modified by silicon dioxide nanoparticles [6]. J. Ma et al. studied oxidation resistance of nanoparticles modified mineral insulating oil. Das et al. conducted experimental analysis of nanofluids with mineral insulating oil [7].

In this paper, mineral insulating oil first modified by nanoparticles and flame retardants studied. The critical characteristics, such as flash point, fire point, breakdown voltage, Kinematic viscosity, of different modified mineral insulating oil are analyzed.
2. Experimental

2.1. Experimental materials
In this paper, in order to enhance thermal conductivity and electrical properties of mineral insulating oil, nanometer ferric oxide, copper and magnesium hydrate selected as nanoparticles to modified mineral insulating oil. The sizes of ferric oxide, copper and magnesium hydrate are 100-300nm, 300-500nm and 10-20μm. Tripropylphenyl phosphate (IPPP) selected as flame retardant to enhance fire resistance of mineral insulating oil due to its low smoke, low toxicity and high efficiency.

2.2. modified mineral insulating oil
Modified mineral insulating oil are prepared by mixing nanometer ferric oxide or copper, nanometer magnesium hydrate and IPPP with mineral insulating oil by sanitation process. The mass fraction of nanometer ferric oxide and copper in modified mineral insulating oil is 0.1, 0.5, 1 and 2%. The mass fraction of magnesium hydrate in modified mineral insulating oil is 1 and 2%. The mass fraction of IPPP in modified mineral insulating oil is 5 and 10%.

2.3. Test method
The critical parameters of modified mineral insulating oil, such as flash point, fire point, breakdown voltage, Kinematic viscosity, analyzed in this paper. The flash point was measured refer to determination of flash point-Pensky-Martens closed cup method(GB/T 261-2008), fire point was measured refer to Petroleum products-Determination of flash and fire points-Cleveland open cup method(GB/T 3536-2008), breakdown voltage was measured refer to Insulating liquids-Determination of the breakdown voltage at power frequency(GB/T 507-2002), Kinematic viscosity was measured refer to petroleum products-Determination of kinematic viscosity and calculation of dynamic Kinematic viscosity(GB/T 265-1988).

3. Results and analysis
The results of pure mineral insulating oil and mineral insulating oil modified by nanomanterials and flame retardants are given in the table 1 and 2 respectively.

Table 1. Test results of mineral insulating oil.

| Parameters | Flash point(°C) | Fire point(°C) | Breakdown voltage(kv) | Kinematic viscosity (40°C,mm²/s) |
|------------|----------------|----------------|-----------------------|---------------------------------|
| Values     | 144            | 161            | 72.6                  | 9.67                            |
Table 2. Test results of modified mineral insulating oil.

| Number | Modified material | Flash point (°C) | Fire point (°C) | Breakdown voltage (kv) | Kinematic viscosity (40°C, mm²/s) |
|--------|------------------|------------------|----------------|------------------------|----------------------------------|
| 1      | 5%IPPP           | 161              | 179            | 62.3                   | 9.82                             |
| 2      | 10%IPPP          | 183              | 217            | 58.4                   | 9.86                             |
| 3      | 0.1%Fe₂O₃+5%IPPP | 163              | 183            | 65.3                   | 9.68                             |
| 4      | 0.5%Fe₂O₃+5%IPPP | 166              | 186            | 70.5                   | 9.46                             |
| 5      | 1%Fe₂O₃+5%IPPP   | 168              | 186            | 72.2                   | 9.10                             |
| 6      | 2%Fe₂O₃+5%IPPP   | 169              | 187            | 75.9                   | 8.87                             |
| 7      | 0.1%Fe₂O₃+10%IPPP| 181              | 215            | 60.7                   | 9.72                             |
| 8      | 0.5%Fe₂O₃+10%IPPP| 180              | 213            | 65.2                   | 9.64                             |
| 9      | 1%Fe₂O₃+10%IPPP  | 184              | 213            | 69.4                   | 9.59                             |
| 10     | 2%Fe₂O₃+10%IPPP  | 186              | 216            | 72.9                   | 9.08                             |
| 11     | 0.1%Cu+5%IPPP    | 167              | 188            | 63.3                   | 9.52                             |
| 12     | 0.5%Cu+5%IPPP    | 172              | 195            | 64.4                   | 9.28                             |
| 13     | 1%Cu+5%IPPP      | 174              | 202            | 62.4                   | 9.01                             |
| 14     | 2%Cu+5%IPPP      | 178              | 206            | 61.6                   | 8.68                             |
| 15     | 0.1%Cu+10%IPPP   | 182              | 215            | 59.3                   | 9.65                             |
| 16     | 0.5%Cu+10%IPPP   | 184              | 216            | 58.1                   | 9.32                             |
| 17     | 1%Cu+10%IPPP     | 186              | 214            | 54.7                   | 9.06                             |
| 18     | 2%Cu+10%IPPP     | 187              | 218            | 50.9                   | 8.76                             |
| 19     | 0.1%Mg(OH)₂+5%IPPP| 180              | 207            | 67.2                   | 9.72                             |
| 20     | 0.5%Mg(OH)₂+5%IPPP| 186              | 213            | 69.3                   | 9.61                             |
| 21     | 1%Mg(OH)₂+5%IPPP | 202              | 242            | 71.3                   | 9.62                             |
| 22     | 2%Mg(OH)₂+5%IPPP | 208              | 251            | 68.6                   | 9.68                             |
| 23     | 0.1%Mg(OH)₂+10%IPPP| 189             | 218            | 65.8                   | 9.76                             |
| 24     | 0.5%Mg(OH)₂+10%IPPP| 197             | 224            | 67.4                   | 9.59                             |
| 25     | 1%Mg(OH)₂+10%IPPP| 214              | 253            | 68.5                   | 9.67                             |
| 26     | 2%Mg(OH)₂+10%IPPP| 217              | 260            | 67.1                   | 9.62                             |

3.1. Flash point

As we can know form Table 2, the flash point of mineral insulating oil increased with mass fraction of IPPP in mineral insulating oil, the flash point of modified mineral insulating oil increased to 161°C, 173°C form 144°C in 5% IPPP and 10% IPPP modified mineral insulating oil respectively.

The flash point of mineral insulating oil modified by different mass fraction nanoparticle and 5% IPPP shown in figure 1. As we can see form figure 1, the flash point of modified mineral insulating oil increased with nanoparticle, nanometer magnesium hydrate enhancement the flash point of mineral insulating oil more than nanometer ferric oxide and copper. This indicate nanometer ferric oxide and copper enhancement the flash point of mineral insulating oil, but nanometer magnesium hydrate tremendous increase of flash point due to nanometer magnesium hydrate also as flame retardant.
Figure 1. The flash point of mineral insulating oil modified by different mass fraction nanoparticles and 5% IPPP.

The flash point of mineral insulating oil modified by different mass fraction nanoparticle and 10% IPPP shown in figure 2. As we can see from figure 2, the flash point of modified mineral insulating oil only increased nanometer magnesium hydrate, nanometer ferric oxide and copper can't enhancement with 10% IPPP, this due to flame retardant have more enhancement effect on flash point of mineral insulating oil.

Figure 2. The flash point of mineral insulating oil modified by different mass fraction nanoparticles and 10% IPPP.

3.2. Fire point

As we can know from Table 2, the fire point of mineral insulating oil increased with mass fraction of IPPP in mineral insulating oil, the fire point of modified mineral insulating oil increased to 179, 197 form 161 in 5% IPPP and 10% IPPP modified mineral insulating oil respectively.

The fire point of mineral insulating oil modified by different mass fraction nanoparticle and 5% IPPP shown in figure 3. As we can see from figure 3, the fire point of modified mineral insulating oil increased with nanoparticle, nanometer magnesium hydrate enhancement the flash point of mineral insulating oil more than nanometer ferric oxide and copper. This indicate nanometer ferric oxide and copper enhancement the flash point of mineral insulating oil, but nanometer magnesium hydrate shows
tremendous increase of fire point due to nanometer magnesium hydrate also as flame retardant which similar to flash point.

**Figure 3.** The fire point of mineral insulating oil modified by different mass fraction nanoparticles and 5% IPPP.

The fire point of mineral insulating oil modified by different mass fraction nanoparticle and 10% IPPP shown in figure 4. As we can see form figure 4, the fire point of modified mineral insulating oil vary with modified material similar to flash point. Nanometer magnesium hydrate increase fire point of mineral insulating oil with 10% IPPP, nanometer ferrie oxide and copper can't enhancement which due to flame retardant have more effect on flash point of mineral insulating oil.

**Figure 4.** The fire point of mineral insulating oil modified by different mass fraction nanoparticles and 10% IPPP.
3.3. Breakdown voltage

As we can know from Table 2, the breakdown voltage of mineral insulating oil decreased with mass fraction of IPPP in mineral insulating oil, the breakdown voltage of modified mineral insulating oil decreased to 62.3kv, 58.4kv form 72.6kv in 5% IPPP and 10% IPPP modified mineral insulating oil respectively.

The breakdown voltage of mineral insulating oil modified by different mass fraction nanoparticle and 5% IPPP shown in figure 5. As we can see form figure 5, the breakdown voltage of modified mineral insulating oil increased with nanometer ferric oxide, decreased with nanometer copper. It increased with nanometer magnesium hydrate when the mass fraction of magnesium hydrate less than 1%, then decreased with nanometer magnesium hydrate reached 2%.

![Figure 5](image1.png)

**Figure 5.** The breakdown voltage of mineral insulating oil modified by different mass fraction nanoparticles and 5% IPPP.

The breakdown voltage of mineral insulating oil modified by different mass fraction nanoparticle and 10% IPPP shown in figure 6. As we can see form figure 6, the breakdown voltage of modified mineral insulating oil vary with mass fraction of nanoparticles with 10% IPPP is similar to with 5% IPPP.

![Figure 6](image2.png)

**Figure 6.** The breakdown voltage of mineral insulating oil modified by different mass fraction nanoparticles and 10% IPPP.
3.4. Kinematic viscosity
As we can know from Table 2, the kinematic viscosity of mineral insulating oil increased with mass fraction of IPPP in mineral insulating oil due to the kinematic viscosity of IPPP higher than mineral insulating oil, the kinematic viscosity of modified mineral insulating oil increased to 9.82 mm$^2$/s, 9.86 mm$^2$/s form 9.76 mm$^2$/s in 5% IPPP and 10% IPPP modified mineral insulating oil respectively.

The kinematic viscosity of mineral insulating oil modified by different mass fraction nanoparticle and 5% IPPP shown in figure 7. As we can see from figure 7, the kinematic viscosity of modified mineral insulating oil decreased with nanometer ferric oxide and copper, slight change with nanometer magnesium.

![Figure 7. The kinematic viscosity of mineral insulating oil modified by different mass fraction nanoparticles and 5% IPPP.](image)

The kinematic viscosity of mineral insulating oil modified by different mass fraction nanoparticle and 10% IPPP shown in figure 8. As we can see from figure 8, the breakdown voltage of modified mineral insulating oil vary with mass fraction of nanoparticles with 10% IPPP is similar to with 5% IPPP.

![Figure 8. The kinematic viscosity of mineral insulating oil modified by different mass fraction nanoparticles and 10% IPPP.](image)
4. Conclusion
IPPP shows tremendous improvement in flash point and fire point, nanometer ferric oxide shows tremendous improvement in breakdown voltage, nanometer magnesium shows improvement in flash point, fire point and breakdown voltage, nanometer copper shows improvement in flash point, fire point and kinematic viscosity. Therefore, critical characteristics of mineral insulating oil modified enhanced by nanomanterials and flame retardants.

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