Research and Application of Standard Oil Dispensing System for Dissolved Gases in Transformer Oil

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Abstract. Measuring the content of dissolved gas components in transformer insulating oil by gas chromatography is an important means to judge the internal potential faults of oil filled electrical equipment in the process of operation supervision. The necessary work skills of power grid operators include the ability to detect the content of dissolved gas in transformer oil and judge the operation state of transformer. This paper introduces a preparation method and equipment of transformer standard oil. It can quickly prepare standard oils with various gas component contents. The standard oil quantity value is accurate, the data stability period is greater than 90 days, and the uncertainty is less than 5%. The equipment can be used for training and evaluation of transformer oil gas chromatographic analysis practitioners and calibration of transformer oil on-line gas chromatograph.

1. Introduction

Power transformer is one of the important operation equipment in power system. Its operation state has a great impact on the safe operation of the whole power grid system. With the larger power grid scale and higher equipment voltage level, there are higher requirements for the safe operation of transformers. In the preventive test, the content of dissolved gas in transformer insulating oil is determined by gas chromatography, which is an important means to judge the internal potential faults of oil filled electrical equipment in the process of operation supervision.[1]

This detection technology does not need to power off the equipment and is not disturbed by external factors. It can regularly monitor the internal insulation of oil filled equipment in operation to ensure the safe and reliable operation of the equipment. The necessary work skills of power grid operators include the ability to detect the content of dissolved gas in transformer oil and judge the operation state of transformer. The above skills training for these operators is an important way to improve the operation level of transformer. We need to prepare standard oil, which is transformer oil with different characteristic gas component content. It is necessary to use standard oil to simulate transformer oil under various transformer fault conditions for skill training and evaluation of operators.[2-4]

2. Establishment of standard oil preparation system

According to Henry’s Law: under the condition that the temperature and pressure remain constant, the solubility of a gas in the solution is directly proportional to the equilibrium pressure of the gas on the liquid surface, as shown in formula (1).[5]
The concentration of dissolved gas $i$ component in the liquid phase under equilibrium conditions, $\mu L$. 

$C_{il}$—Concentration of dissolved gas $i$ component in gas phase under equilibrium conditions, $\mu L/L$

$K_i$—Distribution coefficient of dissolved gas $I$ component after gas-liquid equilibrium at test temperature

Under the condition of constant temperature and pressure and sufficient time, the gas in the closed oil tank reaches the distribution balance between liquid and gas phases. Assuming that there is no dissolved gas component in the oil sample, we call it blank oil. At the beginning, add blank oil into the closed oil tank, and then fill a certain amount of standard gas (including target gas components). After the gas reaches equilibrium between liquid and gas, calculate the concentration of target gas components dissolved in oil phase. The calculation formulas are (2) and (3).

$$V_q C_{iq} = C'_l V'_l + C'_g V'_g$$ (2)

$$C'_l = V_q C_{iq} / (V_q / K_i + V'_g)$$ (3)

$C'_{iq}$—After the standard gas is filled into the closed system, the concentration of component $I$ dissolved in the liquid phase after the liquid and gas phases reach the distribution equilibrium, $\mu L/L$

$C'_{gq}$—After the standard gas is filled into the closed system and the liquid and gas phases reach equilibrium, the concentration of component $I$ in the gas phase, $\mu L/L$

$C_{iq}$—When the standard gas is filled into the closed system and the liquid-gas two-phase distribution is not started, the concentration of component $I$ in the gas phase, $\mu L/L$

$V_l$—Volume of liquid phase in closed system, L

$V_q$—Volume of gas phase in closed system, L

In a closed container, the transformer oil is heated to 80°C and vacuumized it to boiling point. Allow all dissolved gases in the oil to escape. In this way, a blank transformer oil containing almost no dissolved gas can be obtained. In a confined space with a certain temperature and pressure, a certain volume of blank transformer oil is fully mixed with an accurate quantitative volume of gas components to achieve dynamic balance between gas and liquid phases, that is, the standard oil containing gas components of preset concentration is obtained. The oil sample is detected by laboratory chromatograph, and the true value of gas component content in oil is obtained by various calculation methods.

The prepared standard oil contains 7 components: CH$_4$, C$_2$H$_4$, C$_3$H$_6$, C$_2$H$_2$, H$_2$, CO and CO$_2$.

3. Standard oil preparation device and its working principle

The standard oil preparation device consists of three parts: one is the preparation device providing quantitative gas components, the other is the vacuum oil filter device for preparing blank oil, and the third is the preparation oil tank with constant temperature and pressure function.[6] Its principle structure is shown in Figure 1, and the finished equipment structure is shown in Figure 2.

In order to reduce operating costs and avoid environmental pollution by waste oil, transformer oil is recycled. The used transformer oil is collected, purified into blank oil, and then prepared into standard oil. The specific working process includes blank oil preparation and standard oil preparation.[7-8]
3.1. Preparation of blank oil

The recovered transformer oil flows through the purification unit, which can remove most of the water and all particulate impurities in the oil.

The above oil is injected into the auxiliary oil tank, and then start the circulating pump, vacuum pump, two-way pump and constant temperature heating device to heat the transformer oil to 80 °C.

The atomizer set at the top of the auxiliary oil tank atomizes the transformer oil into tiny oil droplets. All dissolved gases and moisture in the oil escape from the oil and are discharged from the auxiliary oil tank with the vacuum pump. This step lasts for 90 min−120 min, which can purify the recovered transformer oil into blank oil.
3.2. Preparation of standard oil

The empty transformer oil in the auxiliary oil tank is transferred to the main oil tank, maintain the conditions of 50℃ and 20kPa~50kPa, inject the accurately quantified standard gas into the main oil tank, set the 50% saturation of equilibrium gas, maintain circulation, and fully mix the oil with the gas to be dissolved.

Inflate and pressurize the balloon and keep the constant pressure to 130kPa. Open the transformer oil sampling valve to collect the operating transformer oil sample.

4. Accuracy and stability test of standard oil

4.1. Quality inspection of blank oil

The residual impurities in the blank oil will affect the quality of the standard oil and must be removed as much as possible. Test the gas content of various characteristic components in the blank oil to investigate the oil purification treatment effect. The results are shown in Table 1.

| Residual rate % | 3.2 | 4.1 | 0.6 | 3.9 | 4.1 | 4.7 | 3.9 |
|-----------------|-----|-----|-----|-----|-----|-----|-----|
| Recovered oil   | μL/L| 9.4 | 21.7| 375.1|10.2 |12.2 |12.9 |
| Blank oil       | μL/L| 0.3 | 0.9 | 2.1 | 0.4 | 0.5 | 0.6 | 0.2 |

It can be seen from the experimental results that the residual rate of dissolved gas after purification is less than 5%, and the quality of blank oil is good.

4.2. Accuracy test of standard oil

Use the chromatograph that has passed metrological verification to detect the concentration of dissolved gas in transformer oil as the standard value. Compare the preset values and investigate the coincidence between them. The test results are shown in Table 2.

| Deviation % | -1.9 | 3.6 | 2.0 | 1.7 | 0.2 | -3.4 | -3.8 |
|-------------|------|-----|-----|-----|-----|------|------|
| Preset concentration | μL/L | 78.8 | 122.6 | 544.0 | 40.2 | 47.5 | 49.7 | 23.5 |
| Measured concentration | μL/L | 77.3 | 126.6 | 554.7 | 40.9 | 47.6 | 48.0 | 22.6 |

It can be seen from the experimental results that the deviation between the preset concentration and the measured concentration is less than 4%, the consistency between the prepared concentration and the actual concentration is good, and the accuracy of the prepared standard oil is high.

4.3. Stability test of standard oil

The balloon is inflated after being filled with nitrogen, and the prepared constant value oil sample is discharged under positive pressure. The volume of discharged oil is expanded and filled by the balloon. Therefore, during operation, the standard oil is in a strictly sealed state, which is a single liquid phase, no gas cavity is generated, and the amount of dissolved gas in the oil is stable. The gas concentrations of each characteristic component of the standard oil in the unit were detected respectively for storage for 0d (initial content), 7d, 31d and 90d, and the stability of each dissolved gas component was investigated. The test results are shown in Table 3.
Table 3. Stability test of standard oil sample in main oil tank

| Test date  | Gas content of characteristic components in oil μL/L | H₂ | CO | CO₂ | CH₄ | C₂H₄ | C₂H₆ | C₂H₂ |
|-----------|---------------------------------------------------|----|----|-----|-----|------|------|------|
| 2020-03-06| 45.5 73.0 362.7 26.9 29.8 32.1 13.8              |    |    |     |     |      |      |      |
| 2020-03-13| 44.2 72.5 357.9 26.3 29.6 31.4 13.6              |    |    |     |     |      |      |      |
| 2020-04-06| 43.8 71.4 357.2 26.1 29.1 31.1 13.3              |    |    |     |     |      |      |      |
| 2020-05-07| 44.0 71.3 357.5 26.5 28.0 30.5 13.4              |    |    |     |     |      |      |      |

5. Conclusion
Using the standard oil preparation system of dissolved gas in transformer oil, the accurate preparation of target components and target concentration of standard oil can be realized. The prepared standard oil can be used for the calibration of laboratory chromatographic analysis system, the calibration of on-line chromatography of transformer oil and the training of employees in electrical test posts in power industry. It can be stored stably for 90 days, can meet various work needs and has high practical application value.

After the research and development of the device, it has been used for the calibration of transformer oil online chromatography and the training of employees for electrical test posts in the power industry. It has been running for 24 months, and 9036 employees have been trained, a total of $1.2 \times 10^5$ class hours.

Full reuse of transformer oil with zero discharge. The cost of operating consumables (electricity and gas) is about 9960 yuan, with an average of ¥0.083/class hour. The training and teaching effect is remarkable, and the economic and social benefits are remarkable.

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