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# A Study on the Condition Diagnosis for A Gas-insulated Transformer using Decomposition Gas Analysis

## 가스분해 분석기법을 활용한 가스 전열 변압기의 상태 진단 연구

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Abstract

A growing number of gas-insulated transformers in underground power substations in urban areas are approaching 20 years of operation, the time when failures begin to occur. It is thus essential to prevent failure through accurate condition diagnosis of the given facility. Various solid insulation materials exist inside of the transformers, and the generated decomposition gas may differ for each gas-insulated equipment. In this study, a simulation system was designed to analyze the deterioration characteristics of $SF_6$ decomposition gas and insulation materials under the conditions of partial discharge and thermal fault for diagnosis of gas-insulated transformers. Degradation characteristics of the insulation materials was determined using an automatic viscometer and FT-IR. The analysis results showed that the pattern of decomposition gas generation under partial discharge and thermal fault was different. In particular, acetaldehyde was detected under a thermal fault in all types of insulation, but not under partial discharge or an arc condition. In addition, in the case of insulation materials, deterioration of the insulation itself rapidly progressed as the experimental temperature increased. It was confirmed that it was possible to diagnose the internal discharge or thermal fault occurrence of the transformer through the ratio and type of decomposition gas generated in the gas-insulated transformer.

*Keywords: Decomposition gas, Gas-Insulated Transformer, Overheat, Partial Discharge, $SF_6$*

## I. Introduction

In the case of $SF_6$ gas, its excellent insulation performance and non-inflammability have been recognized since the 1930s, and it has been applied to various types of $SF_6$ gas apparatuses, and these advantages are increasing the use of $SF_6$ gas insulated transformers in urban areas. In South Korea, about 50% of gas-insulated transformers have exceeded an age of 10 years since their first introduction in 2003, and more than half of them are expected in 20 years of operation soon.

Meanwhile, with our society's dependence on electric power, demand for high reliability of power supply, has increased these days. Accordingly, oil-immersed transformers have established gas analysis standards and diagnostic criteria for insulation materials since the 1980s, and have been performing transformer condition diagnosis through dissolved gas and furan analysis using both laboratory / field diagnostic methods. However, in the case of gas-insulated transformers, due to the complex material structure inside and unclear decomposition gas mechanism, there was not sufficient data available for diagnosis.

At present, the diagnosis of gas-insulated facilities including transformers based on a UHF sensor and the analysis of decomposition byproduct gases through detection tube are performed. However, the UHF sensor has not been perfectly optimized for gas-insulated transformer partial discharge diagnostics, because its structure and employed materials are quite different from other apparatuses such as GIS. In this situation, it is essential to develop a new approach for the predictive monitoring of gas-insulated transformers.

In recent years, research on the possibility of using diagnostics of gas insulated transformers using $SF_6$ decomposition gas analysis has been actively conducted[1]-[8]. Even if $SF_6$ is dissociated, it can be easily recombined due to its inherent properties. However, if discharged, overheat and other abnormal energy is continuously accumulated, which can cause defects in the internal materials and react with oxygen and moisture. Accordingly, various types of decomposition gases such as $SOF_2$, $SO_2F_2$, $SO_2$, HF, $CF_4$, CO, $CO_2$, and other intermediates can be generated. In other words, it is possible to diagnose the internal abnormality of the gas insulated transformer through the type and analysis of the generated decomposition gas, thereby improving the reliability of the equipment.

Existing studies have identified the $SF_6$ decomposition mechanism using quantum chemistry theory [9]-[10], decomposition gas analysis and its characteristics due to overheating or partial discharge [11]-[12], and moisture and oxygen impact on the $SF_6$ decomposition [13]-[14]. However, most of these studies show the results related to that in other $SF_6$ gas apparatuses, GIS, not in gas-insulated transformers. In addition, the results and data are not applicable to gas-insulated transformers.

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In this study, the formation patterns and the trend of major decomposition gases under a critical abnormal condition were investigated experimentally. Simplified systems were designed and used to simulate two common but important modes of gas-insulated transformer: partial discharge and overheat. Also, the study evaluated the effects of internal material differences – PET, NOMEX, pressboard, copper plate, and silicon steel plate, which are the key factors in distinguishing gas-insulated transformers from other gas-insulated apparatuses. In this regard, both quantitative and qualitative analyses were carried out on 5 major decomposition gases ($SOF_2$, $SO_2F_2$, $SO_2$, $CF_4$, and CO) using a gas chromatograph with two different kinds of detectors. In particular, in order to investigate the presence of other gases other than the five major components, MS was also applied for the qualitative analysis. In addition, the PET film and the pressboard, which account for more than 90% of the insulation materials in gas-insulated transformers, were analyzed to investigate structural changes under overheating through FT-IR and an automatic viscometer, respectively. Based on the results, the possibility and applicability of diagnosis using $SF_6$ decomposition gas generation characteristics were identified.

## II. EXPERIMENTAL METHOD AND ANALYSIS CONDITION

### A. Partial Discharge Experiment

Based on IEC 60270, a partial discharge test was performed in the device shown in Fig. 1. A discharge cell having a gas volume of 2L was fabricated, and a surface discharge structure was applied to facilitate partial discharge size control. Pure $SF_6$ gas (99.999% of purity) was introduced into the cell (gas pressure was maintained about 1 bar) and four different magnitudes of partial discharge: 100, 1000, 3000, 10000pC, controlled by the applied voltage. First, in order to evaluate the characteristics of decomposition gas generation due to partial discharge of pure $SF_6$ gas, the surface discharge insulation was tested after placing glass (50x50mm, 5 sheets) composed of inorganic material between the electrode and the ground electrode. The total test time was 72 hours. From 2, 6, 24, 48, and 72 hours after the start of the experiment, 20cc of the gas inside the cell was collected using a gas syringe and analyzed for decomposition gases. In addition, to study the changes and trends of decomposition gas generation due to the influence of the internal insulation under partial discharge conditions, the samples of PET and pressboard were placed instead of existing glass between the electrode and the ground electrode. This test was performed for up to 48 hours in consideration of the breakdown point of each insulation material.

### B. Partial Overheat Experiment

The accelerated partial overheat test system (Fig. 2) consists of a stainless-steel chamber with a total volume of 10.3L (210×250mm) and a separate control box (automatic PID control function, 0~300℃ range adjustable) for temperature control. The main purpose of this test was to investigate the correlation between the thermal degradation characteristics of solid materials and the generation of decomposition gases. Therefore, after the solid materials were filled in a ceramic container (Fig. 3) in the same proportion as the material inside the gas-insulated transformer, 1 bar of 99.999% of $SF_6$ gas was filled together in the chamber. The test was performed at low temperature (140℃, 336h, gas sampling period 24, 48, 96, 168, 216, 336h-6 times / 160℃, 96h, gas sampling period 2, 6, 24, 48, 96h – 5 times / 180℃, 24h, gas sampling period 2, 4, 6, 24h – 4 times) and high temperature (260℃, 48h, gas sampling period 2, 4, 6, 24, 48h – 5 times). After the experiment, both gas and solid materials were collected for further analysis.

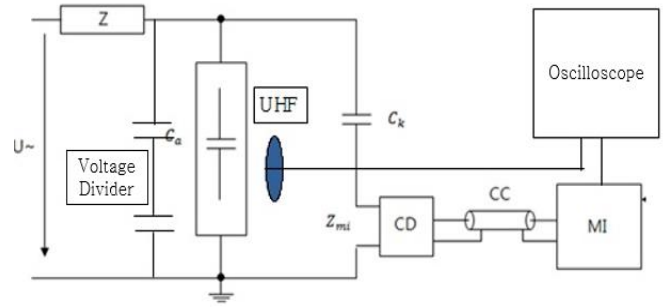



Fig. 1. Partial discharge test device configuration

Fig. 2. Fabricated Accelerated Degradation Test Chamber and Temperature Controller

Fig. 3. Inside deterioration test chamber (left) and Ceramic container for solid insulator (right)

### C. Decomposition Gas Analysis Method and Condition

The analysis of decomposition gases generated during both tests was first carried out through a gas chromatograph (Agilent, USA) equipped with a Pulsed Discharge Helium Ionization Detector (PDHID) and a Mass Spectrometer (MS). The five major gases were detected by PDHID, and other hydrocarbon gases such as CxHy, $C_2H_4O$, and $C_2H_6F_2Si$ were analyzed qualitatively by MS. In addition, for $CO_2$, the generation trend was examined using a portable detector tube (Gastech, Japan). In particular, we developed three analysis methods (for CO detection, $CF_4$ detection, $SO_2$, $SO_2F_2$, and $SOF_2$ detection) using PDHID to enhance the analysis accuracy of five major gases. VB-1 (60m×0.32mm×3μm), Molesieve 5A (30m×0.53mm× 20μm), and Gas-pro (60m×0.32mm) were used in connection. Various factors that could affect decomposition gas concentrations were removed by appropriate methods. For example, $SF_6$ background gas, which occupied most of the sample, as well as $O_2$

TABLE 1
Retention Time of Five Major Decomposition Gases Using PDHID

| Gas Component | Retention Time (min) |
|---|---|
| $SO_2F_2$ | 14.656 |
| $SOF_2$ | 15.110 |
| $SO_2$ | 17.163 |
| CO | 8.618 |
| $CF_4$ | 14.872 |

and $N_2$, which can be introduced during the gas sampling process, was removed using a valve switching system, and water was also removed using a Nafion dryer.

D. Solid Insulation Analysis Method and Condition

First, for the degree of polymerization of pressboard was carried out in accordance with IEC 60450. The principle of the analysis is to measure specific viscosity in cupriethylenediamine solution ($Cu(C_2H_8N_2)_2(OH)_2$), and infer the intrinsic viscosity through this result and finally to obtain the polymerization degree. The pressboard sample obtained after the overheat test was first impregnated with 100 mL of hexane and stirred (4 hours). It was then fluffed to separate the fibers and vacuum dried to remove moisture. The dried fluffed pressboard was dissolved in a mixture of 14 mL of 1 M cupriethylenediamine solution ($Cu(C_2H_8N_2)_2(OH)_2$) and 14 mL of DI water. The solution wherein the fluffed pressboard was completely dissolved was measured by a Ubbelohde viscometer and an automatic viscosity measuring device (AVS370, Germany) and finally the degree of polymerization was calculated.

In the case of PET, the sample collected after the overheat test was analyzed in the wavelength range of 4,000~400cm$^{-1}$ using Fourier Transform Infrared Spectroscopy (PerkinElmer, Germany). The absorbance of the carbonyl bond, at 1171cm-1, was examined.

## III. DECOMPOSITION GAS ANALYSIS RESULTS

A. Partial Discharge Experiment

First, in order to analyze the decomposition characteristics of $SF_6$ according to the increase of discharge amount in the presence of pure $SF_6$ gas without any solid insulation materials, the sample gas from each test was collected and detected using PHDID.

As seen in the results in Fig 4, $CF_4$ was not detected in any of the discharge magnitude tests. The highest concentration of CO was less than 10 ppm, which might be due to the gas sampling process. These results are reasonable given that since the test was performed under only a $SF_6$ gas atmosphere. Among all S included gases, $SOF_2$ was detected first, and then $SO_2F_2$ was detected as the discharge magnitude and time increased. In addition, much higher total amounts of $SOF_2$ and $SO_2F_2$ were detected compared to the concentration of $SO_2$.

In the case of the actual gas-insulated transformer, since its volume is at least 8,000 times larger than the cell used for the partial discharge experiment in this study, it was necessary to perform an additional experiment to discover the trend of decomposition gas generation by volume increase. For this reason, the same discharge test was performed in 10 and 50L cells under average discharge of 10,000pC.

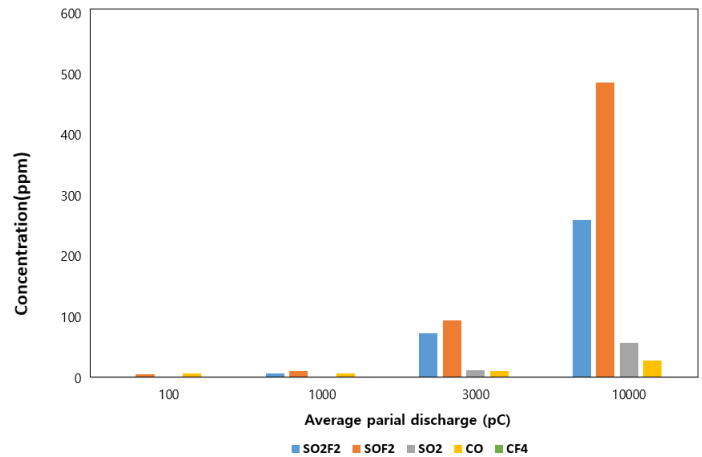
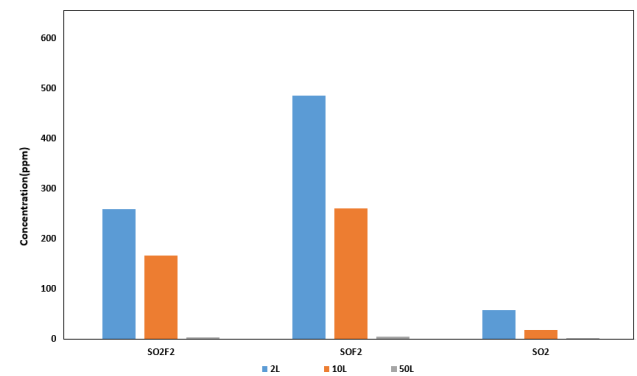
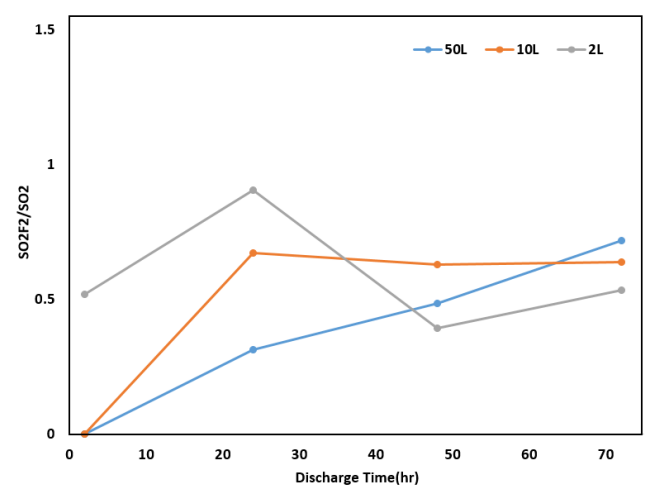



Fig. 4. Decomposition gas in the presence of $SF_6$ gas with increasing partial discharge




(a)




(b)

Fig. 5. Decomposition gas concentration of different discharge cell volume

Naturally, as the volume increased, the amount of decomposition gas generated decreased but it was not inversely proportional to the volume. However, when the ratio of $SO_2F_2/SOF_2$ was compared, as shown in Fig 5. (b), although this part needed further review and experiments, it was shown to converge to at about 0.6 over the discharge time.

For comparison with decomposition gas generation by partial discharge in the presence of insulation materials, PET and pressboard were

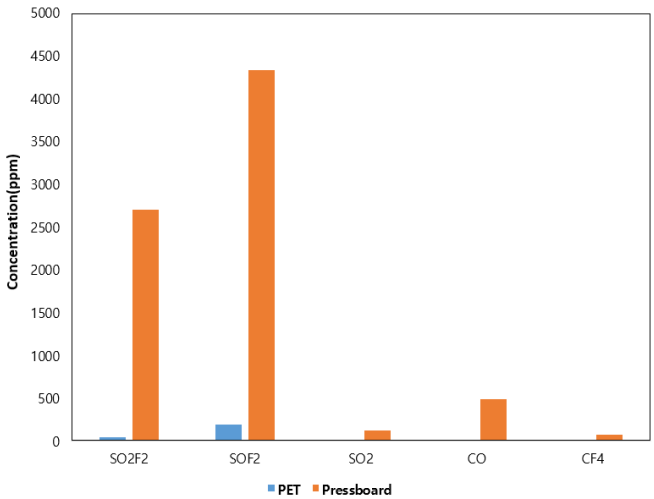



Fig. 7. PET, Pressboard Decomposition Gases

TABLE 2
Correlation coefficient in 100pC, 2L cell

| | $SO_2F_2$ | $SOF_2$ | $SO_2$ |
|---|---|---|---|
| $SO_2F_2$ | 1 | 0.95834 | - |
| $SOF_2$ | 0.95834 | 1 | - |
| $SO_2$ | -* | - | 1 |

* No detection

TABLE 3
Correlation coefficient in 1000pC, 2L cell

| | $SO_2F_2$ | $SOF_2$ | $SO_2$ |
|---|---|---|---|
| $SO_2F_2$ | 1 | 0.96658 | 0.80490 |
| $SOF_2$ | 0.96658 | 1 | 0.92205 |
| $SO_2$ | 0.80490 | 0.92205 | 1 |

TABLE 4
Correlation coefficient in 3000pC, 2L cell

| | $SO_2F_2$ | $SOF_2$ | $SO_2$ |
|---|---|---|---|
| $SO_2F_2$ | 1 | 0.99827 | 0.99000 |
| $SOF_2$ | 0.99827 | 1 | 0.99569 |
| $SO_2$ | 0.99000 | 0.99569 | 1 |

TABLE 5
Correlation coefficient in 10000pC, 2L cell

| | $SO_2F_2$ | $SOF_2$ | $SO_2$ |
|---|---|---|---|
| $SO_2F_2$ | 1 | 0.92191 | 0.80462 |
| $SOF_2$ | 0.92191 | 1 | 0.93370 |
| $SO_2$ | 0.80462 | 0.93370 | 1 |

TABLE 6
Correlation coefficient in 10000pC, 10L cell

| | $SO_2F_2$ | $SOF_2$ | $SO_2$ |
|---|---|---|---|
| $SO_2F_2$ | 1 | 0.99998 | 0.99857 |
| $SOF_2$ | 0.99998 | 1 | 0.99866 |
| $SO_2$ | 0.99857 | 0.99866 | 1 |

TABLE 7
Correlation coefficient in 10000pC, 50L cell

| | $SO_2F_2$ | $SOF_2$ | $SO_2$ |
|---|---|---|---|
| $SO_2F_2$ | 1 | 0.95873 | 0.36395 |
| $SOF_2$ | 0.95873 | 1 | 0.58672 |
| $SO_2$ | 0.36395 | 0.58672 | 1 |

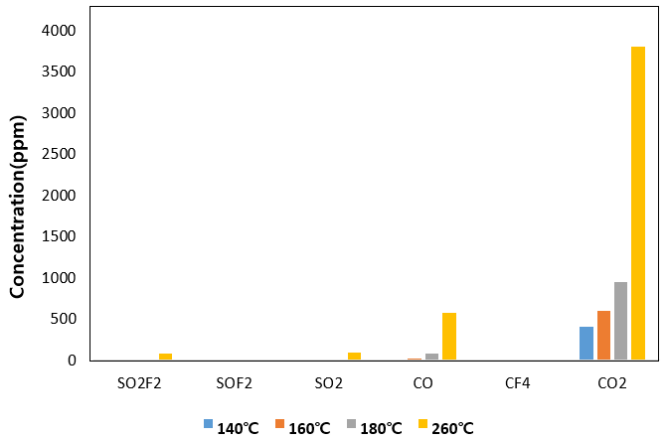
placed in the discharge cell, and the experiment was conducted under the same conditions. In general, however, it was confirmed that $CF_4$ was detected as a result of dielectric breakdown when a certain amount of discharge was applied for a predetermined time or more. In other words, when a sufficient amount of energy is applied to the insulation to break its insulation performance, $CF_4$ can be generated as a result.

In the case of PET, insulation was broken when discharge energy was continuously applied for about 3.5 hours at the average discharge amount of about 3000pC. However, in the case of pressboard, insulation was broken after 48 hours at 100pC, and the $CF_4$ concentration was about 70ppm, which was 10 times more than that of the PET case. Both PET and pressboard are mainly composed of C – C, C = O, C - H, and O = H bonds. Therefore, if the insulation deteriorates due to partial discharge, these bonds can be broken and dissociated into C, O, and H and react with F from $SF_6$.

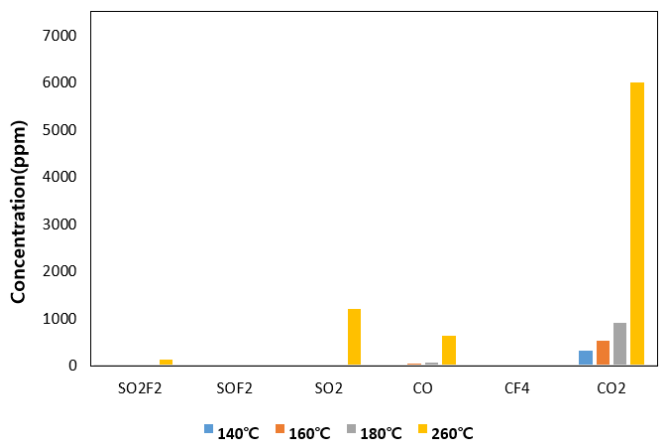
In the case of CO, even if dielectric breakdown does not occur, the insulation material itself can be deteriorated as discharge energy is applied. This leads to a decrease of the internal functional groups of the insulation material little by little. In addition, when comparing the concentration of decomposition gas at the average discharge amount of 100pC, although all five major decomposition gases differed according to their components, the amount of each gas in the case of pressboard was at least 20 times or maximum 70 times higher than in the case of PET, as shown in Fig.7.

In summary, compared to PET, pressboard is degraded by a relatively small amount of discharge energy, which combines SFx and C and O due to material degradation and dielectric breakdown, and produces $SO_2F_2$, $SOF_2$, $SO_2$, CO, and $CF_4$. Also, due to the decomposition and reaction of the insulation and the $SF_6$ gas, it was confirmed that a much larger amount of decomposition gas is generated when the effect of the insulation is present compared to the pure $SF_6$ gas.

In general, the amount of $SOF_2$ and $SO_2F_2$ that was detected at least three times higher than that of $SO_2$, which was confirmed to be a unique pattern that appeared even if the discharge amount was increased and regardless of the presence of internal insulation. With consideration of the $SF_6$ decomposition mechanism, $SOF_2$ is a reaction product generated in a short time through a relatively fast reaction that can be produced by the reaction of $SF_4$ and $H_2O$. However, in the case of $SO_2$, the rate constant of $SO_2$ formation reaction is lower than that of $SOF_2$, $SO_2F_2$ because it can be influenced by the amount of oxygen or moisture or applied energy for its formation. As a result of calculating the correlation of actual $SO_2F_2$, $SO_2$, and $SO_2$ using the Excel data analysis function, overall, the following order was found: $SOF_2$, $SO_2F_2$ > $SOF_2$, $SO_2$> $SO_2F_2$, $SO_2$. In the case of $SOF_2$, it was highly correlated with both $SO_2F_2$ and $SO_2$, which is consistent with the theoretical mechanism.




(a)




(b)

Fig. 8. (a) Decomposition gas concentration with temperature for Single sample,

(b) Decomposition gas concentration with temperature for Composite sample

In addition, MS identified various substances such as $F_2NOS$, $F_{12}N_2S_3$, $F_5NOS_2$, and $C_2H_6F_2Si$. However, no significant differences were found depending on the type of insulation.

Additionally, a basic experiment of arc discharge was performed on the actual GIS model for further comparison with the partial discharge. Unlike the partial discharge results, first, at least five times more $SO_2$ was detected than the amounts of $SOF_2$ and $SO_2F_2$. In particular, $CF_4$ and $SO_2$ were identified as the most generated decomposition products among the five major gases, which is considered to be influenced by the GIS internal nozzle material (PTFE, Polytetrafluoroethylene). Accordingly, this will be reviewed in further detail through further research.

B. Partial Overheat Experiment

In the accelerated overheat experiment, first, only pure SF6 gas was injected into the test chamber, and then the temperature at which $SF_6$ began to decompose was confirmed. When only $SF_6$ gas is present, it was confirmed that decomposition starts at 300℃ or higher. Based on this, overheat experiments in the presence of pure $SF_6$ gas were excluded, and the following two groups were prepared: 1) Composite sample (PET, pressboard, nomex paper + metal material) + $SF_6$ gas, 2) Single sample (PET, which accounts for the largest proportion among solid insulations in the actual transformer) + $SF_6$

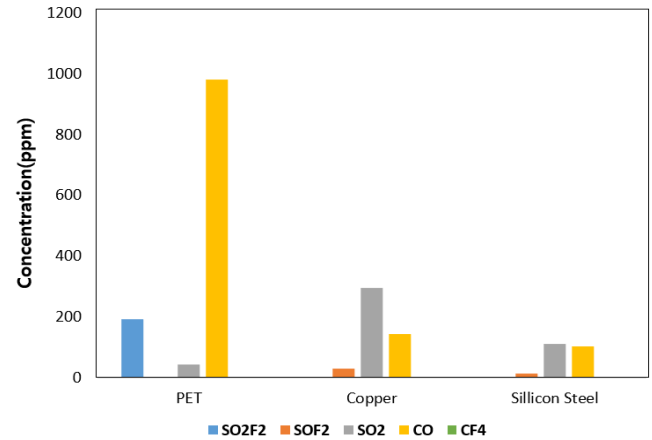
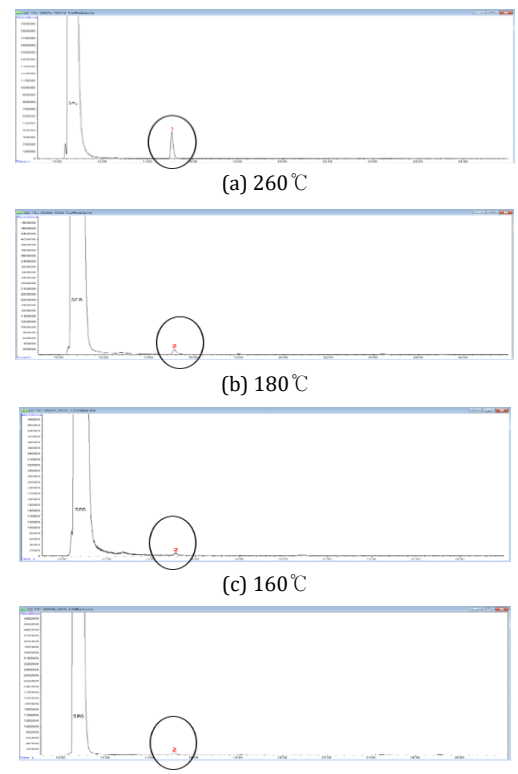



Fig. 9. $SO_2F_2$, $SOF_2$, $SO_2$, CO concentration by material



(a) 260℃

(b) 180℃

(c) 160℃

(d) 140℃

Fig. 10. Acetaldehyde MS chromatogram

gas. As a result of the accelerated overheat experiments at low temperature and high temperature, respectively, the decomposition gas trend was obtained as shown in Fig. 8.

After 24 hours of overheat experiment at each of the four different temperatures, with a total six gases (unlike the partial discharge experiment, $CO_2$ was additionally analyzed using a detection tube), $CF_4$ was not detected. During the test, on the basis of the absolute concentration value order, mostly $CO_2$ >> CO > $SO_2$ > $SO_2F_2$ > $SOF_2$ were identified. Similarly, it was confirmed that the relative order of generation of the six gases was $CO_2$ >> CO > $SO_2F_2$ ≥ $SOF_2$ > $SO_2$.

In particular, CO and $CO_2$ showed a tendency to increase linearly with temperature as the two gases were generated from deterioration of solid insulations. At low temperature, $SO_2F_2$, $SOF_2$, and $SO_2$ were rarely detected in either the composite or single sample, and O generated by the deterioration of the insulation at low

TABLE 8
Acetaldehyde concentration using detection tube

| Sample Name | Concentration(ppm) |
|---|---|
| 160℃, 2 hrs. | 10 |
| 160℃, 7 days | 250 |
| 180℃, 1 day | 150 |
| 180℃, 2 days | 425 |
| 180℃, 4 days | 500 |
| 180℃, 7 days | 625 |
| 260℃, 4 days | Over 750* |
| 260℃, 7 days | Over 750* |

* Over detection limitation(750ppm)

temperature was used as a source for generating CO and $CO_2$. Then, as the temperature increased, decomposition products such as $SO_2F_2$, $SOF_2$, and $SO_2$ were detected by reaction between O and SFx produced by the decomposition of $SF_6$.

In the case of the composite sample, the concentrations of CO and $CO_2$ were relatively higher because the Nomex and pressboard, which are the basic resources for generating C and O, were additionally included compared to the single sample. In addition, in the case of $SO_2$, due to the metal material (that has a catalytic effect for decomposition of $SF_6$ under an overheat condition), about 10 times more was generated compared to the single sample case. For further review of the effect of each metal material on decomposition gas generation, an overheat test was carried out for each PET, copper, and silicon steel sample alone at high temperature of 260℃ for two hours. As shown in Fig. 9, decomposition gases containing S were mainly detected in copper and silicon steel sheets, and CO was detected in PET.

A qualitative analysis of the presence of other decomposition gases in addition to the five major gases through MS showed that acetaldehyde was detected in all experiments regardless of temperature, and the peak of acetaldehyde also increased with increasing temperature (Fig 10).

To identify the actual value of acetaldehyde, a Gastec No.92 detection tube was used to analyze its concentration. The results are shown in Table 2 as below. As the temperature and degradation time increased, it was confirmed that the concentration of acetaldehyde increased. As can be seen in the MS chromatogram reviewed above, since the acetaldehyde peak was detected even at 140℃, it can be assumed that acetaldehyde will be present at several ppm or below level. Also, if overheating persists for a long time even at a temperature lower than 140℃, acetaldehyde might be detected. However, since acetaldehyde has not been detected in transformers that have been operating for more than 15 years (actual transformer operating temperature is 30-50℃), from a conservative point of view, acetaldehyde is a potential indicator for PET degradation due to overheating of abnormal operating temperature over 140℃.

In addition, at low temperatures(140, 160, 180℃), hydrocarbons such as $C_4H_8$, mercaptans such as $CH_4S$, ketones, and furan were detected, at high temperatures (260℃). Most of these gases were decomposed products due to thermal decomposition of pressboards. Based on the MS results, it is possible to make an approximate estimate of the thermal decomposition and decomposition temperature of a particular insulation.

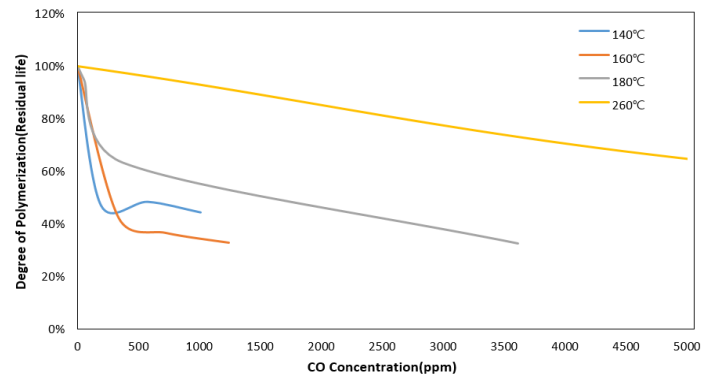



Fig. 11. Relationship between residual degree of polymerization and CO concentration of pressboard in the composite sample

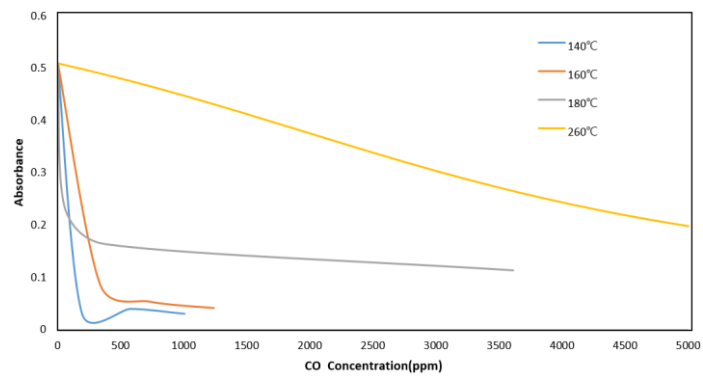



Fig. 12. Relationship between absorbance and CO concentration of PET in the composite sample

## IV. INSULATION DETERIORATION CHARACTERISTICS

### A. Pressboard

First, the degree of polymerization was calculated for the pressboard sample collected after the accelerated overheat experiment on the composite sample. As a result, as with the relationship between the insulating paper's residual rate based on the degree of polymerization and the generation of CO gas in oil-immersed transformers, the gas-insulated transformer also shows a positive correlation in which CO increases as the internal insulating material deteriorates.

### B. PET

Similarly, the PET sample collected after the accelerated overheat test for the composite sample at each temperature, as shown in the case of the pressboard, CO shows a positive correlation that increases as the PET thermal properties decrease. In other words, as temperature increases, the carbonyl group can be dissociated.

## V. GAS TRANSFORMER DIAGNOSIS ACCORDING TO DECOMPOSITION GAS ANALYSIS

Based on the decomposition gas analysis results discussed above, the applicability of gas-insulated transformer condition diagnosis

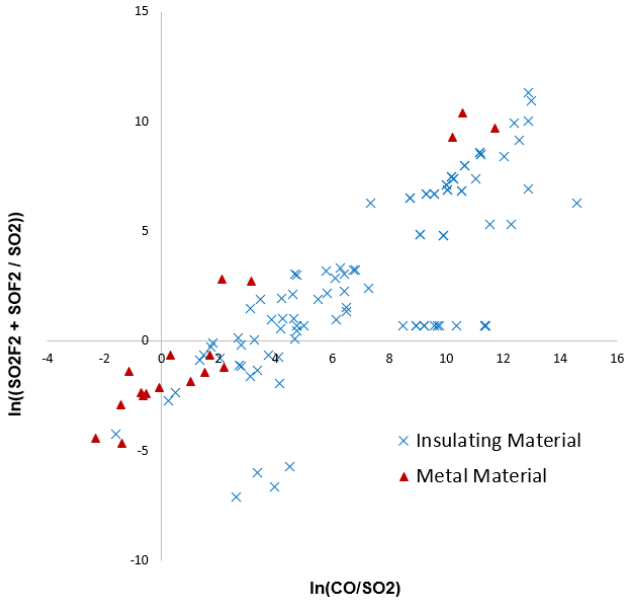



Fig. 13. Diagnosis of gas generation cause by internal material type I (Insulating Material: PET, nomex paper, Metal Material: Copper, silicon steel plate)

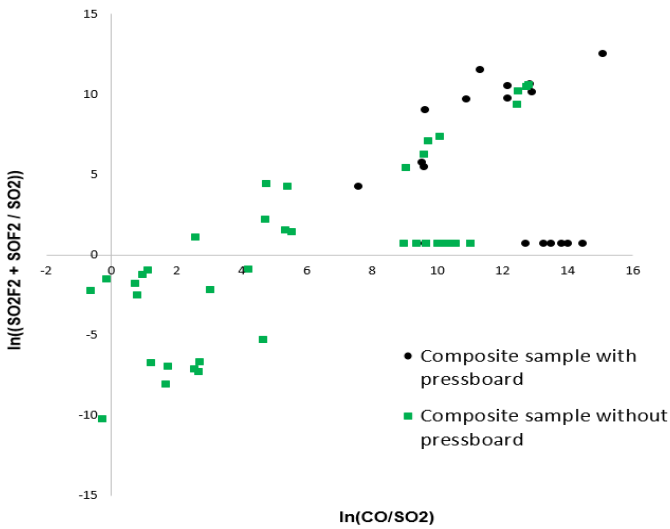



Fig. 14. Diagnosis of gas generation cause by internal material type II (with pressboard, without pressboard)

through the decomposition gas analysis was reviewed as follows. As a result of calculating the ratio value of $CO/SO_2$ and the ratio value of $(SOF_2+SO_2F_2)/SO_2$ to all the data analyzed during the partial discharge and overheat experiment were shown as follows, Fig. 13~15. Especially for overheat experiment data, the diagnostic possibility was reviewed using decomposition gas analysis results which was generated from different material. These results showed the possibility to identify a specific material degradation through the decomposition gas analysis.

In overall, the distinction between partial discharge and overheat was confirmed based on the decomposition gas analysis results.

If more detailed experiments (e.g., by discharge defects) are performed and applied to classify discharge defects according to the amount of gas generated even in partial discharges, it may be possible to diagnose the transformer more precisely through a decomposition gas analysis.

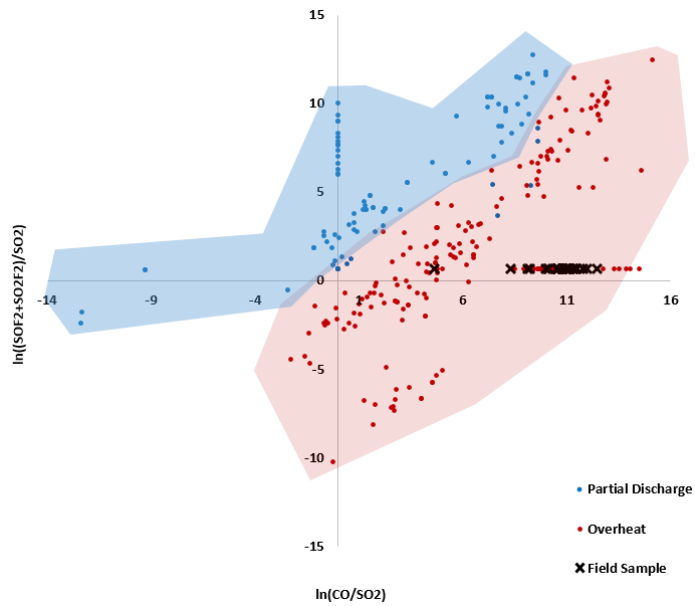



Fig. 15. Diagnosis of gas generation cause by analysis of major decomposition gases

## VI. CONCLUSION

The purpose of this study was to diagnose the internal state of a gas-insulated transformer through analysis of analysis of $SO_2F_2$, $SOF_2$, $SO_2$, CO, and $CF_4$, which can be detected in a $SF_6$ gas-insulated transformer. After the partial discharge and accelerated overheat experiments were conducted using the simplified simulation model, the gas and solid insulations were collected and their characteristics were evaluated. The following conclusions were drawn.

In case of partial discharge, the following is found. Mostly $SO_2F_2$, $SOF_2$, and $SO_2$ were detected, and in particular, $SO_2F_2$ and $SOF_2$ tended to be detected more than three-fold compared to $SO_2$. In particular, it was confirmed that $SO_2F_2$ and $SOF_2$ were generated before $SO_2$. ($SOF_2 > SO_2F_2 >> SO_2$)

$CF_4$ was only detected when discharge energy was continuously applied to the solid insulation over a certain level. (In the case of arc discharge, even if the insulation is not destroyed (no dielectric breakdown), the insulation is partially decomposed to generate $CF_4$.)

In summary, in the case of abnormality caused by discharge, $SOF_2$, $SO_2F_2$, and $SO_2$, which are decomposition products of $SF_6$, become the main gases when organic materials such as pressboard, PET, and PTFE are not involved. In addition, $CF_4$ can be added when organic materials are involved in discharge.

In the case of overheat, the following results were conducted.

At low temperatures, CO and $CO_2$ gases are mainly generated due to thermal deterioration of the insulation material itself, because not enough energy is transferred to cause decomposition of $SF_6$ gas. At high temperature, $SF_6$ gas is decomposed by the influence of internal metal material to produce gas such as $SO_2F_2$, $SOF_2$, and $SO_2$. In addition, CO and $CO_2$, which are the main gases in overheat tests, have a linear relationship with decomposition of solid insulation with increased temperature.

In particular, unlike the partial discharge case, $C_2H_4O$ is detected regardless of the temperature. By examining the correlation between the results of the characterization of solid insulations and the amount of CO gas generated, the degree of polymerization and absorbance in carbonyl group decreases as the amount of CO gas increases. In other

words, there is a significant correlation between these two variables.

In order to prevent failure of a gas-insulated transformer and secure reliable diagnosis technology, based on the results obtained in this study and combining additional experimental data (such as the characteristics of decomposition gas generation by discharge defects), the index gas selection and its concentration criteria under discharge and overheat occurrence will be established soon.

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