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Study on Decomposition Gas Characteristics and Condition Diagnosis for Gas-Insulated Transformer by Chemical Analysis

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Abstract

Since SF_6 gas was discovered in the early 1900s, it has been widely used as an insulation material for electrical equipment. While various indicators have been developed to diagnose oil-immersed transformers, there are still insufficient indicators for the diagnosis of gas-insulated transformers. When necessary, chemical diagnostic methods can be used for gas-insulated transformers. However, the field suitability and accuracy of those methods for transformer diagnosis have not been verified. In addition, since various types of decomposition gases are generated therein, it is also necessary to establish appropriate analysis methods to cover the variety of gases. In this study, a gas-insulated transformer was diagnosed through the analysis of decomposition gases. Reliability assessments of both simple analysis methods suitable for on-site tests and precise analysis methods for laboratory level tests were performed. Using these methods, a gas analysis was performed for the internal decomposition gases of a 154 kV transformer in operation. In addition, simulated discharge and thermal fault experiments were demonstrated. Each major decomposition gas generation characteristics was identified. The results showed that an approximate diagnosis of the inside of a gas-insulated transformer is possible by analyzing SO_2, SOF_2, and CO using simple analysis methods on-site. In addition, since there are differences in the types of decomposition gas generation patterns with various solid materials of the internal transformer, a detailed examination should be performed by using precise analysis methods in the laboratory.

Keywords: *Gas-Insulated Transformer, SF_6, Decomposition Gas, Partial Discharge, Thermal Fault*

I. Introduction

If an abnormal phenomenon occurs continuously, SF_6 gas can be decomposed. Upon decomposition, it is generally recombined due to its natural characteristics. However, if internal insulation becomes defective due to discharge or overheating, the SF_6 gas decomposed into SFx first. Then, it continuously reacts with moisture, oxygen, and solid insulation. As a result, various kinds of decomposition gases such as HF, SOF_2, SO_2F_2, SO_2, CF_4 H_2S, CO, and CO_2 can be generated. The international standards for SF_6 gas are as follows; IEC 60376, 60480, and CIGRE SF_6 analysis guidelines [1]-[3]. These standards mainly provide brief guidelines of new (unused) SF_6 gas or reuse standard and major decomposition gas analysis methods. Moreover, the contents of these standards basically focus on switchgears and circuit breakers having a limited type of internal insulation material inside. Since the impact of the material inside a gas-insulated transformer on the major decomposition gases has not been sufficiently studied yet, the application of the existing standards to the diagnosis of gas-insulated transformers in operation in South Korea is very limited. Currently, in South Korea, UHF sensor-based partial discharge diagnosis is used to check the condition of a transformer, and in part, diagnosis of decomposition gas through a detection tube and portable analysis equipment is being performed. However, in the case of the UHF sensor, it is optimized for partial discharge diagnosis in GIS. For this reason, it is not appropriate to apply the UHF sensor method to gas-insulated transformers. Moreover, there are some differences in the type of internal insulation between the GIS (epoxy) and gas-insulated transformer (PET, Pressboard, Nomex paper). In addition, both the detection tube and portable analysis equipment that were previously in use at Korea Electric Power Corporation (KEPCO) have not been verified for the reliability for on-site diagnosis. In recent studies, decomposition gas generation characteristics due to high temperature overheating in the presence of SF_6 gas [4][5], the generation mechanism of SOF_2, SO_2F_2, SO_2, and HF in local overheating [6], decomposition gas generation characteristics due to discharge and decomposition mechanism under discharge condition [7][8], characteristics of generation of decomposition gas by discharge on the epoxy surface, the main insulator inside GIS [9], and the effect of moisture and oxygen as catalysts on the generation of internal decomposition gas before and after discharge [9][10] are mainly discussed. In Japan, studies on gas-insulated transformers have been actively conducted for a long time. In particular numerous studies on discharge and overheating in the presence of actual internal insulation have been reported [11]-[14]. However, internal insulation and other materials inside of Japanese gas-insulated transformer are different from domestic gas-insulated transformers. In addition, most studies have tried to explain the trend of decomposition gas generation through simulated experiments rather than analysis of actual facilities

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Fig. 1. Picture of on-site analytical equipment (from left, SF_6 Quality Analyzer [17], SF_6 DPD Analyzer [18], and Detection Tube [19]).

TABLE 1
Analytical Method by Decomposition Gas

	On-site analysis method		Laboratory analysis method
	Detection tube	Portable analysis equipment	GC
CO	○		○
CO_2	○		
SO_2F_2, CF_4			○
SO_2	○	○	○
SOF_2		○	○
Others			○

[15][16]. In response to these shortcomings, in this study, a total of 111 SF_6 gas samples from gas-insulated transformers currently installed and operated in some urban areas were analyzed by both on-site and laboratory analytical methods. Notably, a precise diagnosis (GC-PDHID, GC-MS) was performed to verify the accuracy and reliability of the on-site diagnostic method. In addition, the partial discharge and thermal fault that could occur inside an actual gas-insulated transformer were simulated, and the type of decomposition gas mainly generated when an internal abnormality occurred was investigated by using a precise analysis method. Finally, the possibility of using decomposition gas analysis data for diagnosis of a gas-insulated transformer during operation was discussed.

II. Analytical Method

In this study, appropriate diagnostic methods for each decomposition gas (SOF_2, SO_2F_2, SO_2; directly generated due to decomposition of SF_6 gas / CO, CO_2, CF_4; produced due to solid insulation) were selected and applied for the analysis. (At the same time, to verify the reliability of portable analyzer, cross-validation was performed using Laboratory analysis (GC) for some decomposition gases: CO, SO_2).

A. On-site Analysis Method

Analysis of SOF_2, SO_2, CO, and CO_2 was performed using an on-site analysis method (detection tube, two types of portable analyzer). A GC-110S gas detection tube (Gastec, Japan) was used, and 1L, 2LC, and 5LC models were selected and applied to analyze CO, CO_2, and SO_2 respectively. SO_2 and SOF_2 were additionally analyzed using two types of portable analyzer (SF_6 Quality Analyzer, Germany, WIKA / SF_6 DPD Analyzer, Canada, Powertech). In addition, the reliability and field suitability were verified.

TABLE 2
Analysis Conditions of Five Major Decomposition Gases Using PDHID

Item	CF_4	SOF_2, SO_2F_2, SO_2	CO
Column	1. Pre-column: VB-1 (60 m × 0.32 mm) 2. Analytical column: Gas-pro (60 m × 0.32 mm)	1. Pre-column: VB-1 (60 m × 0.32 mm) 2. Analytical column: VB-1 (60 m × 0.32 mm)	1. Analytical column: Molesieve 5A (30 m × 0.53 mm)
Oven	40°C (Isothermal)	40°C (Isothermal)	40°C (Isothermal)
Column Pressure	18 psi, He	11.5 psi, He	10 psi, He

TABLE 3
Analysis Conditions of Five Major Decomposition Gases Using MS

Item	CF_4	SOF_2, SO_2F_2, SO_2, Others
Column	1. Pre-column: VB-1 (60 m × 0.32 mm) 2. Analytical column: Gas-pro (90 m × 0.32 mm)	1. Pre-column: VB-1 (60 m × 0.32 mm) 2. Analytical column: DB-1 (60 m × 0.32 mm)
Oven	40°C (Isothermal)	40°C (Isothermal)
Column Flow	1 ml/min, He	1 ml/min, He

TABLE 4
Retention Time (min) of Five Major Decomposition Gases Using PDHID, MS

Decomposition gas	PDHID	MS
SO_2F_2	14.656	11.10
SOF_2	15.110	11.39
SO_2	17.163	12.60
CO	8.618	-
CF_4	14.872	6.90

B. Laboratory Analysis Method

For precise analysis of decomposition gases (SO_2F_2, SO_2, SOF_2, CF_4, CO) and other SF_6 decomposition gases that may be generated inside, a GC (Agilent, USA) equipped with a PDHID (Pulsed Discharge Helium Ionization Detector) and MS (Mass Spectrometer) was used in laboratory. In particular, a separate valve system for sample injection was developed for the purpose of improving the analysis accuracy and separation of the five gases (SO_2, SO_2F_2, SOF_2, CO, CF_4). These gases were the main targets for laboratory analysis in this study. In addition, the following analysis conditions were applied to remove air, SF_6, and moisture that may be present in the gas sample to be analyzed. This prevented impurities affecting the decomposition gas concentration.

III. Decomposition Gas Analysis of Gas-Insulated Transformer

In South Korea, most of gas-insulated transformers have been installed in urban underground substations. In this section, a decomposition gas analysis was performed for 111 gas-insulated transformers (in 11 underground substations) installed in area A where the most gas-insulated transformers are installed among urban areas.

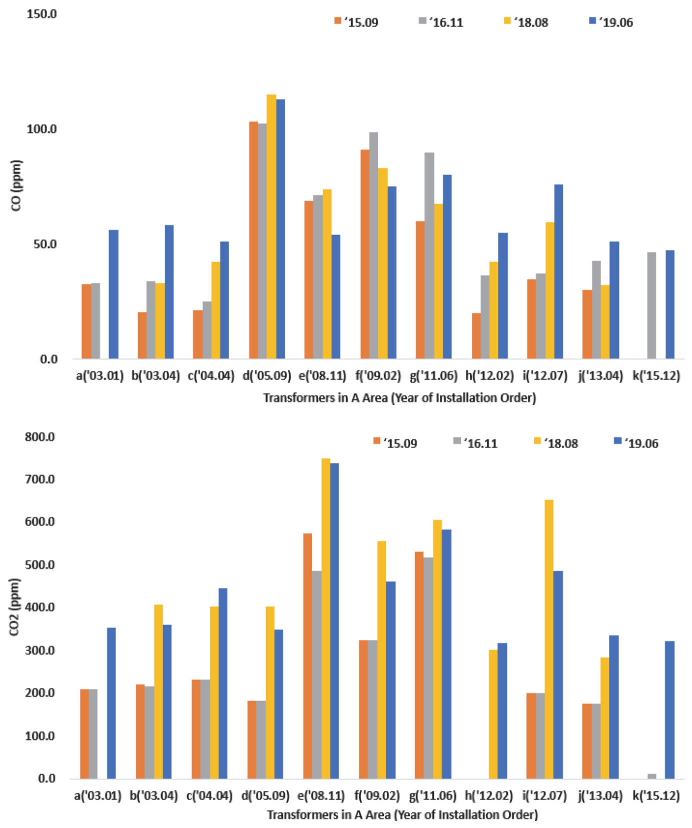

Fig. 2. CO, CO_2 trends using detection tube in 11 underground substations.

A. On-site Analysis Results

First, the results of analyzing CO, CO_2, and SO_2 using a detection tube are as follows. SO_2 was not detected at all. In the case of CO and CO_2, the trend increased over time as compared with the past analysis data. In particular, a transformer with a long operating time did not generate a lot of CO and CO_2 gas, contrary to the expectation. However, once it started to be generated inside the transformer, it was found that the gas concentration thereafter increased as the operation time elapsed (Fig. 2). Second, the results of analyzing O_2 and SOF_2 using portable analyzers as follows. Both SO_2 and SOF_2 were not detected from any portable analyzer.

However, in the case of the detection tube, the gas concentration is determined by visually checking the color change of the detection reagent present inside the detection tube. For this reason, the subjective judgment of the user may affect the result. In particular, in the case of CO and CO_2, there is no on-site diagnostic method other than the use of a detection tube. In this study, for CO, a cross-analysis using a laboratory analysis method was applied to verify the reliability of the detection tube.

B. Laboratory Analysis Results

First, SO_2, SOF_2, and SO_2F_2 were not detected in any of the transformers, which was consistent with the previous results obtained with portable analyzers. However, using MS, it was confirmed that complex decomposition gases including C, F, N, and S exist. Through this, SF_6 gas reacts with other insulation materials in the transformer and can be seen to generate complex and various intermediate decomposition products instead of immediately generating simple types of decomposition gases such as SO_2, SOF_2, and SO_2F_2 (TABLE 5).

TABLE 5

Decomposition Gas Analysis Results Using MS

Formula	Name
SF_6	Sulfur fluoride
C_6H_9NS	4-Ethyl-5-Methylthiazole
$C_6H_2F_8O_4$	Octafluorohexanedioic acid
C_5F_{10}	Decafluorocyclopentane
C_5H_5NOS	5-Formyl-4-methylthiazole
$C_3H_6F_5NO_2S$	Dimethoxymethylenimino
F_5NOS_2	N-(Pentafluorosulfanyl)sulfinylimine
C_6H_9NS	4-Ethyl-5-methylthiazole
C_7F_{14}	Perfluoromethylcyclohexane
C_6F_{12}	Dodecafluorocyclohexane
$C_2H_6F_2Si$	Difluorodimethylsilane
$C_7F_{12}O$	Ferfluoro(2-oxabicyclo[3.3.0]octane)
$C_4H_6O_2$	Cyclopanecaboxylic acid
C_4H_8	2-Methylpropene
C_3H_9FSi	Trimethylsilyl fluoride
$C_6H_9N_3S$	4-Pyrimidinamine

TABLE 6

Comparison of CO Concentration Between Detection Tube and GC (Example)

Sample	Analytical Method		Accuracy
	Detection tube	GC	
1	70	94.58	74.0
2	70	59.46	117.7
3	100	99.34	100.7
4	70	68.09	102.8
5	150	173.04	86.7
6	< 50	4.32	1157.4
7	< 50	26.37	189.6
8	< 50	22.06	226.7
9	< 50	24.79	201.7
10	60	58.87	101.9

Next, in the case of CF_4, it was detected not only in the existing transformer but also in some of the recently installed new transformers (the maximum value among the detected values was 54 ppm). However, according to the impurity requirements (permissible concentration) of the new SF_6 of IEC 60376, it is known that a transformer can be used with CF_4 up to 4,000 ppm concentration (in other words, the permissible concentration of CF_4 is less than 4,000 ppm). In addition, the concentration of CF_4 in the new SF_6 gas supplied to KEPCO for a transformer insulation is less than about 570 ppm. Based on this, it can be seen that there is no problem in use even when there is a significantly greater amount than the concentration of CF_4 detected in the actual transformer. For this reason, it is difficult to diagnose the transformer condition with the detection of CF_4. In other words, since new SF_6 gas would have a certain amount of CF_4, it is crucial to consider to adopt CF_4 as a diagnostic indicator gas to diagnose the transformer's internal condition. However, if an abnormality occurs in the actual transformer, the CF_4 concentration may change rapidly. This part will be continuously discussed through the evaluation of the characteristics of the decomposition gas for simulated partial discharge and a partial thermal fault in the later part of this paper.

Finally, from the results of the analysis on CO, which are shown in TABLE 6, the minimum value of the CO detection tube used in this study was 50 ppm. The CO value of the detection tube thus was about three times higher than the GC value. In other words, it was overestimated by about three times (average accuracy 336.4%, under 50 ppm) when it was below 50 ppm. In contrast, as a result of calculating the accuracy for those of 60 ppm or more, it was confirmed that there was no significant difference, with an average

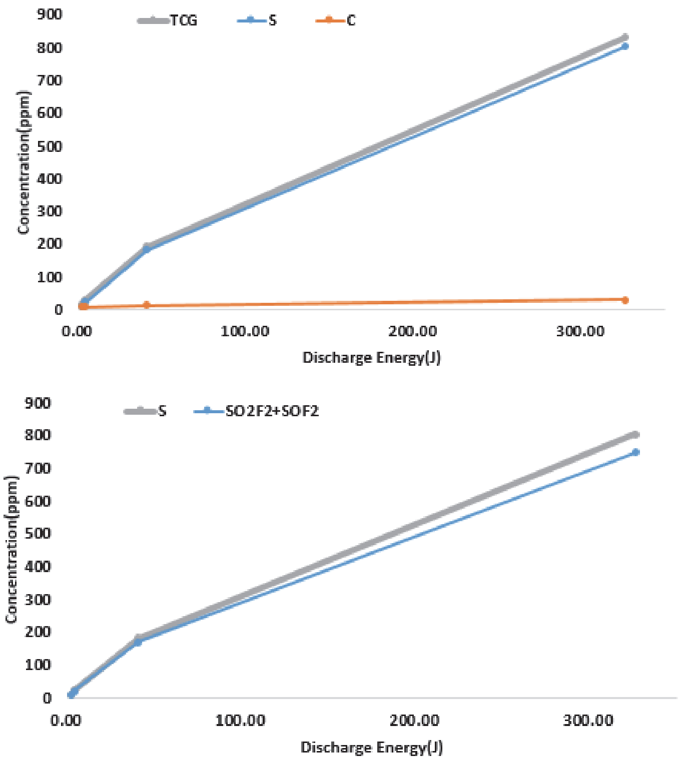

Fig. 3. Trend of decomposition gas generation according to discharge energy (SF_6 gas).

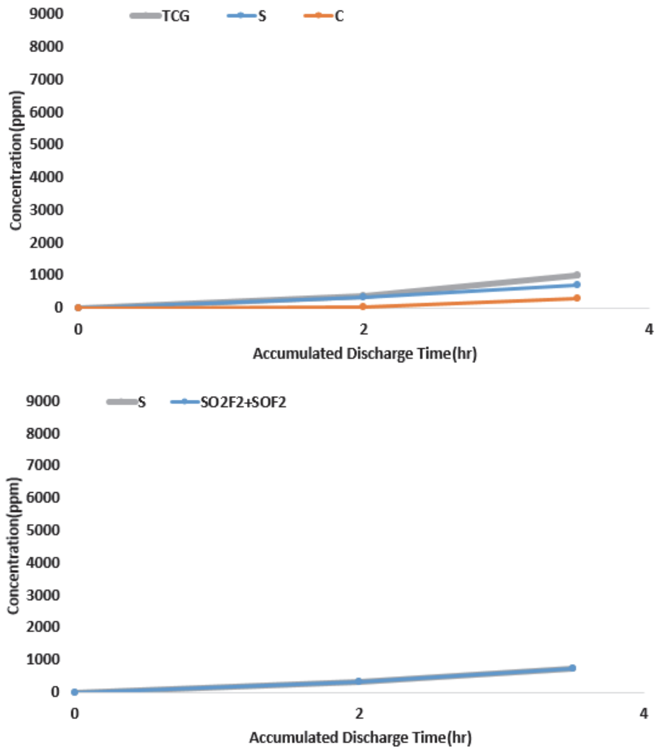

Fig. 4. Trend of decomposition gas generation according to accumulated discharge time (SF_6 gas + PET).

of 119.6% compared to the GC analysis value. The accuracy of the detection tube value compared to the GC value was calculated using the formula shown below. The analysis results and accuracy for some samples are shown in TABLE 6. It can thus be confirmed that the detection tube is an appropriate method to be used for the purpose of obtaining approximate concentration values and the overall trend.

$$\text{Accuracy} = 100 - \frac{\text{CO concentration from GC-CO concentration from detection tube}}{\text{CO concentration from GC}} \times 100$$

Overall, it was found that both the detection tube and portable analyzers having level of analysis reliability that are suitable for on-site diagnosis. However, CF_4, SO_2F_2, and other complex types of SF_6 decomposition gases can be analyzed only by a laboratory analysis method using GC. And CO_2 can be detected only by using a detection tube. Therefore, it is necessary to verify the possibility of condition diagnosis of the transformer by using the analysis data of the remaining decomposition gases (CO, SO_2, SOF_2) except CO_2, CF_4, and SO_2F_2. In other words, it is essential to examine whether these three gases can be used as indicator gases for the diagnosis of the condition of gas-insulated transformers. This was discussed through the analysis of the decomposition gas in a simulated partial discharge and thermal fault experiment described below.

IV. Decomposition Gas Analysis by Partial Discharge Experiment

To simulate the partial discharge inside a gas-insulated transformer, an experiment was performed by applying IEC 60270 [20]. First, within a 2L-sized partial discharge cell, 99.999% pure SF_6 gas was injected with the gauge pressure, one bar. The size of partial discharge amount was adjusted by the applied voltage. In addition, this experiment was performed in four ranges (100, 1,000, 3,000, and 10,000 pC). 20 cc of the gas inside the discharge cell was collected every 2, 6, 24, 48, and 72 hours for analysis of decomposition gases (CO, CF_4, SO_2, SOF_2, SO_2F_2). In addition, an arc discharge experiment using a circuit breaker model (GIS) was also performed to compare the generation of decomposition gases for each case: a transformer and a switchgear. Moreover, the surface discharge according to the type of metal material (Al, Cu) in contact with the surface of the epoxy insulation, which is the major insulation material of GIS, was simulated under a SF_6 gas atmosphere within the same 2L-sized partial discharge cell.

A. Decomposition Gas Analysis Results of Transformer Case

To examine the effect of the internal insulation material on decomposition gas generation, first, only SF_6 gas was injected into the discharge cell to conduct an experiment. Based on the applied voltage and discharge experiment data, the total amount of decomposition gas (hereinafter TCG), the amount of decomposition gases containing S (hereinafter S; SO_2F_2, SO_2, SOF_2), and the amount of decomposition gases containing C (hereinafter C; CO, CF_4) generated according to the discharge energy ($E = 1/2 \times Q \times V$) were expressed as follows. Fig. 3 shows that when partial discharge occurs in the presence of SF_6 gas, mainly SO_2, SOF_2, and SO_2F_2 are generated, and among them, SOF_2 and SO_2F_2 are the mainly detected gases. This indicates that a relatively large amount of energy is required to generate SO_2.

Next, PET and pressboard, which account for more than 90% of the solid insulation of the gas-insulated transformer, were placed

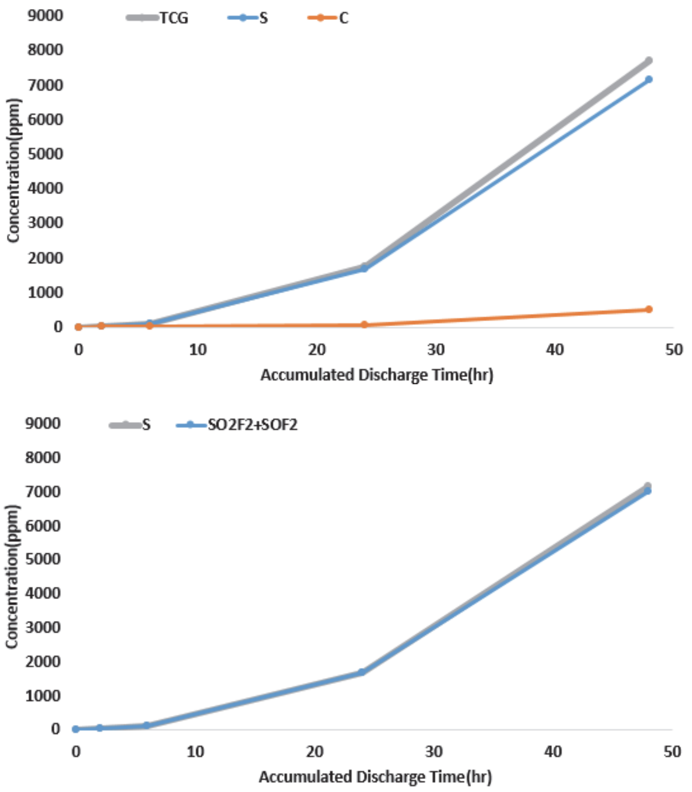

Fig. 5. Trend of decomposition gas generation according to accumulated discharge time (SF_6 gas + Pressboard).

inside the discharge cell together with SF_6 gas. The experiment was conducted up to 48 hours or at least until the time when dielectric breakdown occurred for each material. Even in the case of the presence of insulating material, the amounts of SO_2F_2, SOF_2, and SO_2 in the total amount of generated gas were large, but unlike the case of SF_6 alone, CO gradually increased over time due to the influence of insulating materials.

For each case, the decomposition gas generation pattern is shown in Fig. 6. Commonly, in the case of CF_4, it was confirmed that it was detected only when dielectric breakdown of the insulating materials occurred. However, even at this time, much larger amounts of SO_2F_2, SOF_2, and SO_2 were produced than CF_4. As a result, it is appropriate to diagnose by using SO_2F_2, SOF_2, and SO_2 rather than through CF_4 when an abnormality occurs due to partial discharge inside the gas-insulated transformer.

SO_2F_2, SOF_2, and SO_2 are the main gases that can be generated in the gas-insulated transformer due to partial discharge. However, since it is impossible to analyze SO_2F_2 using an on-site analysis method, the correlation between these three gases was examined through calculation of the correlation coefficient (Pearson-R). As a result, the following three tables show that all three gases generated by partial discharge have a high correlation with each other; that is, when one increases, the other also increases. In other words, for on-site diagnosis of the gas-insulated transformer, it may be efficient to confirm whether the two decomposition gases, SOF_2 and SO_2, are detected through an on-site analysis method.

B. Decomposition Gas Analysis Results of GIS Case

The decomposition gas pattern for this experiment is shown in Fig. 7. Although there are small differences depending on each case, the proportion of SOF_2 and CF_4 in the total decomposition gas is high in common.

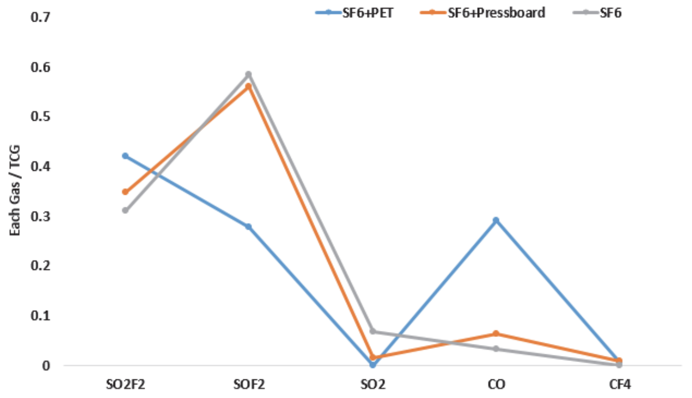

Fig. 6. Trend of decomposition gas generation according to accumulated discharge time (SF6 gas + Pressboard).

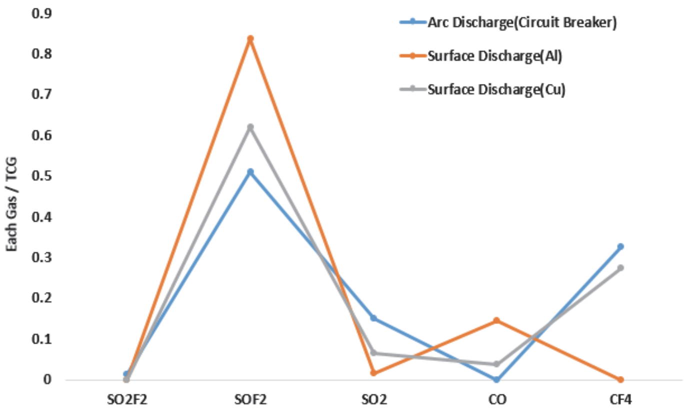

Fig. 7. Decomposition gas pattern of each case.

C. MS Comparison Between Gas-Insulated Transformer and GIS

A SF_6 decomposition gas analysis using MS was also conducted for the purpose of additionally examining the differences according to internal solid materials. As a result, in the case of PET and pressboard (gas-insulated transformer), all the same substances were detected except for $C_7H_3D_3S$. In the case of F_5NOS_2 or $C_2H_6F_2Si$, since they were also detected in actual transformers installed in the field, these materials are generally considered to be substances that can be generated by decomposition and interaction when internal insulation and SF_6 gas are present. In the case of the decomposition gas of the discharge experiment according to the type of metal material that comes into contact with the surface of the epoxy insulator, it can be assumed that the gases are basically generated due to the influence of the epoxy material.

V. Decomposition Gas Analysis by Thermal Fault Experiment

The temperature group for thermal fault experiments was designed as high temperature (260°C) and low temperature (140,

TABLE 7
Correlation Coefficient Between Decomposition Gases During Partial Discharge of SF_6 Gas

	SO_2F_2	SOF_2	SO_2
SO_2F_2	1		
SOF_2	0.995	1	
SO_2	0.998	0.999	1

TABLE 8
Correlation Coefficient Between Decomposition Gases During Partial Discharge of SF_6 Gas + PET

	SO_2F_2	SOF_2	SO_2
SO_2F_2	1		
SOF_2	0.991	1	
SO_2	0.896	0.902	1

TABLE 9
Correlation Coefficient Between Decomposition Gases During Partial Discharge of SF_6 Gas + Pressboard

	SO_2F_2	SOF_2	SO_2
SO_2F_2	1		
SOF_2	0.999	1	
SO_2	0.996	0.996	1

TABLE 10
Decomposition Gas Analysis Results Using MS

Item		Name
PET + SF_6 (Gas-Insulated Transformer)	$C_2H_6F_2Si$	Difluorodimethylsilane
	F_7NOS	Pentafluoro sulfur
	$F_{12}N_2S_3$	Sulfur fluoride nitride
	F_5NOS_2	N-(Pentafluorosulfanyl)sulfinylimine
Pressboard + SF_6 (Gas-Insulated Transformer)	$C_2H_6F_2Si$	Difluorodimethylsilane
	$F_{12}N_2S_3$	Sulfur fluoride nitride
	$C_7H_5D_3S$	Methyl D3 thioanisole
Al + SF_6 (GIS)	C_6H_8O	2, 5 Dimethylfuran
Cu + SF_6 (GIS)	C_5H_8O	Methyl isopropenyl ketone

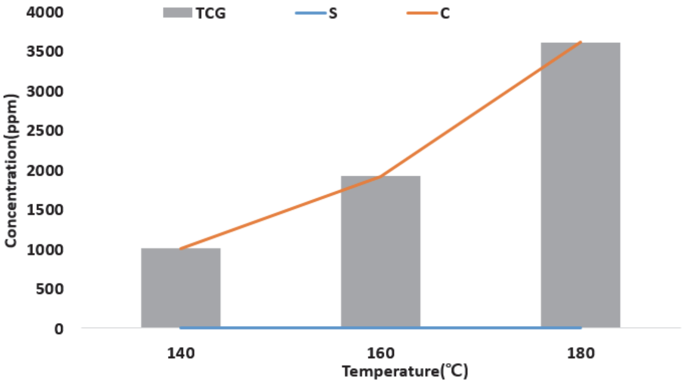

Fig. 8. Trend of decomposition gas generation according to temperature.

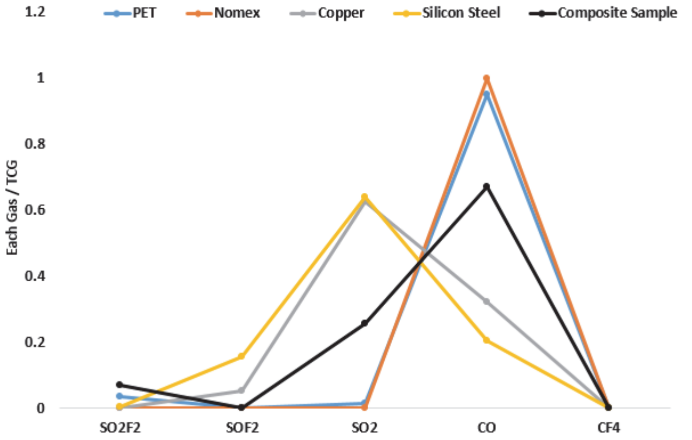

Fig. 9. Trend of decomposition gas generation according to material (at 260°C).

160, 180°C) by considering the melting point of the material and the existing literature including IEC 60172 [21]. A stainless-steel chamber with a total volume of 10.3 L (210×250 mm) was manufactured, and SF_6 gas, metal material (silicon steel plate, copper), and solid insulation (PET, pressboard, NOMEX) were located inside the chamber. Since each impact of insulation materials on gas generation is a critical point, in contrast with the discharge case, NOMEX was also tested and analyzed under the thermal fault experiment to understand the decomposition gas generation pattern depending on each internal material. At this time, the decomposition gas generation trend was observed by varying the gas sampling time according to each experimental temperature (140°C, 336 h, gas sampling 24, 48, 96, 168, 216, 336 h / 160°C, 96 h, gas sampling 2, 6, 24, 48, 96 h / 180°C, 24 h, gas sampling 2, 4, 6, 24 h, / 260°C, 48 h, gas sampling 2, 4, 6, 24, 48 h).

A. Decomposition Gas Analysis Result (at Low Temperature)

At low temperature, since the proportion of PET and pressboard among the insulation materials is more than 90%, most of the gas generated by decomposition inside was CO (no detection of CF_4, SO_2F_2, SOF_2, very low detection of SO_2). In other words, due to the chemical structure of the insulation materials, each material (PET- polyethyl benzene-1, 4-dicarboxylate, Pressboard- 90% cellulose and 10% hemicellulose, lignin, NOMEX- phenylene isophthalamide) could partially degrade into CO under the thermal fault condition.

B. Decomposition Gas Analysis Results (at High Temperature)

At high temperature, the decomposition gas generation pattern for each material could be more clearly detected. CF_4 was not detected in all cases, and SO_2, SO_2F_2, and SOF_2 were detected regardless of the type of material at this temperature. The pressboard was excluded at this temperature, because the decomposed gas such as CO was excessively generated even in the early stage of high temperature, and the chamber pressure rapidly increased.

As a result, under the high temperature condition, 260°C, even if a metallic material is present together with an insulating material therein, it is likely that an excessive amount of CO gas will be detected due to the influence of the insulating material, thereby enabling diagnosis. In addition, while still less than CO, SO_2 may be used as a secondary indicator because it is excessively produced at a high temperature compared to a low temperature due to the influence of the internal metal material. It is known that metal materials such as Si steel plate sometime plays a role as a catalyst to decompose SF_6 into SO_2 and other SOxFy gases. From the results of the MS analysis according to the internal material, it was difficult to clearly distinguish the difference between the metal materials.

However, in the case of the insulating materials, the gas generation difference by material was clearly seen (CH_3CHO for PET, C_4H_4O for pressboard).

VI. Diagnosis of Gas-Insulated Transformer Using SO_2, SOF_2, CO

In summary, in the case of discharge, SOF_2, SO_2, can be key element gas. For the case of a thermal fault, it was confirmed that a transformer diagnosis through CO is possible because of the large influence of internal insulation. Accordingly, for the final verification, the decomposition gas ln (CO) value generated and the decomposition gas ln (SOF_2 + SO_2) containing S were calculated and shown in Fig. 10, respectively. As it can be seen in Fig. 10, condition diagnosis (examination of partial discharge or thermal fault occurrence) can be possible based on the concentration of three decomposition gases. These gases were selected because of the following reasons: CO is the major decomposition gas indicating both normal and abnormal degradation of the insulating material. Moreover, CO can be detected by an on-site analysis such as use of a detection tube. Regarding SOF_2 and SO_2, as already outlined in TABLES 7-9, both gases can be detected by on-site analytical methods. In addition, the correlation coefficient among three gases (SOF_2, SO_2F_2, SO_2) are positively very high, which means either one gas increases, the other gas can increase. As a result, it was suggested that the transformer diagnosis can be performed by using the amounts of the three kinds of generated decomposition gases. Moreover, since all of these decomposition gases can be analyzed using an on-site analysis method, it can be used as a reference for roughly verifying the cause of gas generation before a precise diagnosis using GC.

VII. Conclusion

In this study, the current condition of gas-insulated transformers installed in an urban area was reviewed using a simple analysis and a precise analysis method. Also, main decomposition gases due to discharge and thermal fault were examined through simulated experiments. The results are as follows.

1) It was found that the detection tube and portable analysis equipment were excellent for on-site analysis with proper levels of accuracy, and thus would be efficient for primary diagnosis in the field.
2) In the case of partial discharge, SO_2F_2, SOF_2, and SO_2 are the mainly produced gases. In particular, since there is a highly positive correlation among these decomposition gases, the analysis of SO_2 and SOF_2 can be used to determine the condition of a transformer by using an on-site analysis method.
3) In the case of decomposition gas generation under a thermal fault, the influence of insulation materials (PET, Pressboard, NOMEX) was the greatest. Thus, a large amount of CO gas was generated, followed by SO_2 gas due to the influence of metal material. Therefore, similarly, the condition of the transformer can be diagnosed in the field by analyzing CO and SO_2 using a detection tube.
4) In addition, there was no significant difference in decomposition gas results based on the types of metal materials, but between insulating materials, differences were detected (CH_3CHO for PET and C_4H_4O for pressboard), showing a marked difference.
5) In the case of CF_4, it was not detected at all under a thermal fault experiment, but it was detected when insulation material breakdown occurred under a partial discharge condition. However, at this time, SO_2F_2 and SOF_2 were still detected more than 10 times as compared to the CF_4 concentration. For this reason, rather than analyzing CF_4, it is efficient to analyze decomposition gas containing S, and then make a comprehensive judgment on the overall gas generation pattern through analysis of CF_4, if necessary.

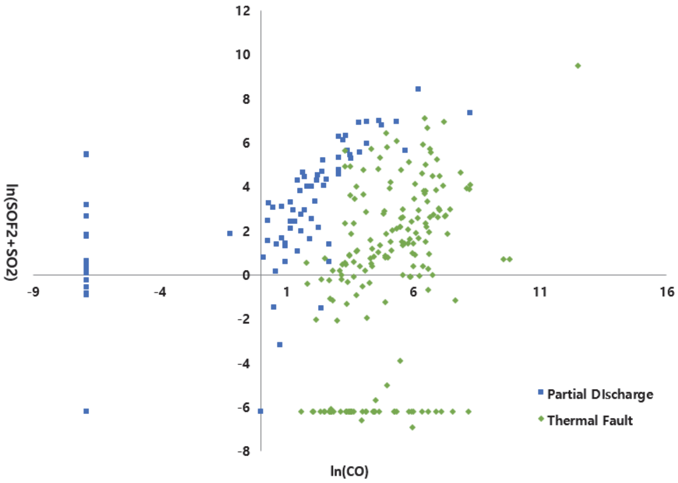

Fig. 10. Transformer diagnosis by CO, SO_2, and SOF_2 analysis data.

Based on the results discussed in this study, it is expected that the suggested approach will contribute to a stable power supply by preventing and diagnosing sudden failures in advance of gas-insulated transformers installed in major urban underground substations.

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