

SF₆ Byproducts in High-Humidity Environment: An Experimental Evaluation between 200°C and 500°C

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ABSTRACT

In the occurrence of arc discharges, spark discharges, corona discharges and overheated faults in electrical equipment, SF₆ would be decomposed to complicated byproducts, such as SO₂, H₂S and HF. Analyzing these byproducts is an effective method to judge the internal operation condition of electric equipment. In order to study characters of SF₆ byproducts at different temperature of overheated faults in the electric equipment, a series of overheated faults of electric equipment were simulated. SF₆ is very stable and not significantly decomposed at 200°C, 250°C and 300°C. SF₆ is significantly decomposed to SO₂, H₂S and HF at 350°C. The concentration of SO₂, H₂S and HF was 7.2, 1.6 and 1.9 μL/L after heating for 5 hours in environment of SF₆ with 3616 μL/L water, and it was increased to 23.0, 3.0 and 1.2 μL/L 3 hours later. SF₆ is more easily to be decomposed and decomposed more rapidly at higher temperature. The concentration of SO₂, H₂S and HF was 62.2, 15.6 and 3.6 μL/L after heating for 5 hours in environment of SF₆ with 4064 μL/L water, and it was increased to 91.4, 25.2 and 2.3 μL/L 3 hours later. SF₆ will be decomposed to format HF, which is strongly corrosive and whose concentration is likely to decrease when it is above a certain concentration.

Keywords: Sulfur Hexafluoride, Overheating Faults, Byproducts, Sulfur Dioxide, Sulfureted Hydrogen, Hydrofluoric Acid

1. Introduction

Sulfur hexafluoride (SF₆) is a colorless, orderless, non-toxic, and non-flammable gas. The gas is strongly electronegative and tends to attract free electrons. SF₆ is widely used as insulative gas in electric transmission and distribution equipment and its insulation property is about 2.5 times to those of air, which was traditionally used as isolative materials in electric equipment. The SF₆ electric equipment takes less area, has less operation noise and has no danger of fire, so SF₆ electric equipment elevates operation security.

In the occurrence of arc discharges, spark discharges and corona discharges, SF₆ would be reacted with little water, electrode and solid insulated material. SF₆ were decomposed to complicated gas and solid byproducts. Gas byproducts include carbon tetrafluoride (CF₄), thionyl sulfide (SOF₂), sulfuryl fluoride (SO₂F₂), and sulfur dioxide (SO₂), and solid byproducts include aluminum fluoride, tungsten fluoride, and so on [1-9].

It is difficult to judge the internal operation condition

of electric equipment, while analyzing the concentrations of SF₆ byproducts is an effective method to judge the internal operation condition of electric equipment. There are many cases these years about how to judge faults by analyzing SF₆ byproducts, such as CF₄ and SO₂, in Guangdong, and many similar examples were reported in the literature as well [10,11]. In past successful examples, we can only judge the faults of electric equipment and the position of the faults in the electric equipment by analyzing SF₆ byproducts. There is still little experience about characters of SF₆ byproducts in different condition of different types of faults in the electric equipment. A series of overheated faults about different temperature of electric equipment were simulated. The paper reports different types of SF₆ byproducts and their concentrations about different condition of overheated faults in electric equipment.

2. Method

The experiments were simulated in a section of bushing

of a breaker, which can be found in **Figure 1** in detail. The moisture of the SF₆ was between 3616 μL/L and 5189 μL/L, and the temperature was 200°C, 250°C, 300°C, 350°C, 400°C, 450°C and 500°C, respectively. The pressure of SF₆ in the simulator was 0.3 Mpa. There was a contact, which can simulate overheated faults through 900A current, but the heat was not enough for simulation requirements. There was a heating rod and a controller that was binding with the contact as well. The device can strictly control the temperature of simulation. In each simulated temperature, SF₆ was taken by a 1.25 L steel bottle from the simulator every hour to analyze SF₆ byproducts, such as fluoride 1 (probable SF₄), fluoride 2 (probable S₂F₁₀), SO₂, H₂S, HF and CO. The analysis method can refer to the literature [12-17]. The chromatograph used in the simulation was Agilent 7890 N with a flame photometric detector and a Gaspro capillary column (0.32 mm × 30 m) .

3. Results and Discussion

Table 1-7 show SF₆ byproducts and their concentrations of overheated faults simulation at 200, 250, 300, 350, 400, 450 and 500°C in high humidity. Moisture of the SF₆ was 4049, 4098, 4218, 3616, 3642, 5789 and 4064 μL/L respectively.

At 200, 250 and 300°C, the concentrations of fluoride 1 and fluoride 2 (probable SF₄ and S₂F₁₀) were not increasing significantly. The concentrations of SO₂, H₂S, HF and CO were below detection limits. SF₆ is stable and not decomposed significantly at 200, 250 and 300°C. The concentrations of fluoride 1 (probable SF₄), fluoride 2 (probable S₂F₁₀) and SO₂ are not significantly increased with the time of heating.

Table 1. SF₆ byproducts of overheated faults simulation at 200°C (unit: μL/L).

	Fluoride 1 (probable SF ₄)	Fluoride 2 (probable S ₂ F ₁₀)
200°C brfore heating	3.4	9.0
200°C heating 1 hour	4.1	10.1
200°C heating 2 hours	3.3	8.3
200°C heating 3 hours	3.0	7.6
200°C heating 4 hours	2.9	7.3
200°C heating 5 hours	2.6	6.8
200°C heating 6 hours	2.7	6.9
200°C heating 7 hours	2.7	6.9
200°C heating 8 hours	2.7	7.0

Table 2. SF₆ byproducts of overheated faults simulation at 250°C (unit: μL/L).

	Fluoride 1 (probable SF ₄)	Fluoride 2 (probable S ₂ F ₁₀)
250°C brfore heating	3.1	7.9
250°C heating 1 hour	3.2	8.1
250°C heating 2 hours	3.4	8.4
250°C heating 3 hours	3.9	10.1
250°C heating 4 hours	4.5	10.6
250°C heating 5 hours	3.6	8.8
250°C heating 6 hours	3.3	8.0
250°C heating 7 hours	3.1	7.8
250°C heating 8 hour	3.0	7.6

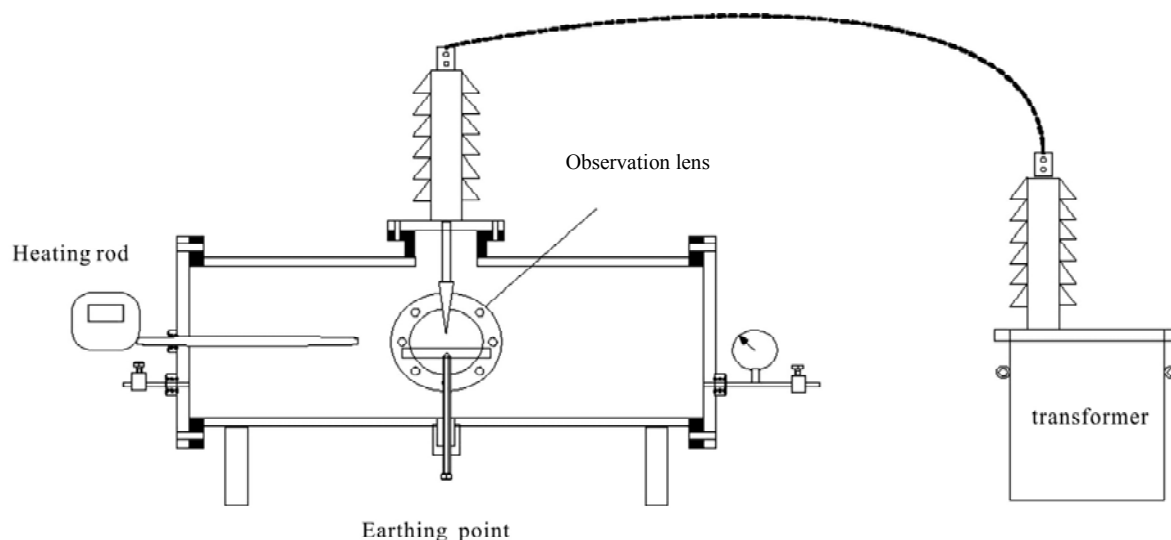


Figure 1. The experiment equipment.

Table 3. SF₆ byproducts of overheated faults simulation at 300°C (unit: µL/L).

	Fluoride 1 (probable SF ₄)	Fluoride 2 (probable S ₂ F ₁₀)
300°C brfore heating	2.8	7.2
300°C heating 1 hour	2.8	7.4
300°C heating 2 hours	2.8	7.3
300°C heating 3 hours	3.0	7.4
300°C heating 4 hours	4.5	10.7
300°C heating 5 hours	4.4	10.5
300°C heating 6 hours	3.5	8.8
300°C heating 7 hours	3.2	7.8

Table 4. SF₆ byproducts of overheated faults simulation at 350°C (unit: µL/L).

	Fluoride 1 (robable SF ₄)	Fluoride 2 (robable S ₂ F ₁₀)	SO ₂	H ₂ S	HF
350°C brfore heating	7.0	18.9	N.D.	N.D.	N.D.
350°C heating 1 hour	6.9	19.2	N.D.	0.3	0.5
350°C heating 2 hours	5.6	15.4	N.D.	0.6	0.9
350°C heating 3 hours	5.8	16.1	N.D.	0.9	1.3
350°C heating 4 hours	5.7	16.0	N.D.	1.4	1.3
350°C heating 5 hours	5.7	15.9	7.2	1.6	1.9
350°C heating 6 hours	6.1	17.3	12.3	2.1	1.6
350°C heating 7 hours	5.8	16.3	18.6	2.4	1.6
350°C heating 8 hours	5.7	16.0	23.0	3.0	1.2

N.D.: not detected.

At 350°C, the concentrations of fluoride 1, and fluoride 2 (probable SF₄ and S₂F₁₀) were not increasing significantly. The concentration of SO₂, H₂S and HF was 7.2, 1.6 and 1.9 µL/L after heating for 5 hours, and it was increased to 23.0, 3.0 and 1.2 µL/L 3 hours later. The concentration of CO was below detection limits. SF₆ will decompose and produce 0.3 µL/L H₂S and 0.5 µL/L HF after heating for 1 hour, and will produce 7.2 µL/L SO₂, 1.6 µL/L H₂S and 1.9 µL/L HF after heating for 5 hours. The concentration of HF decreased when its concentration increases up to 1.9 µL/L. It may be because that HF was strongly corrosive and its corrosion to inner equipment made the concentration of HF decreasing. The

Table 5. SF₆ byproducts of overheated faults simulation at 400°C (unit: µL/L).

	Fluoride 1 (probable SF ₄)	Fluoride 2 (probable S ₂ F ₁₀)	SO ₂	H ₂ S	HF
400°C brfore heating	3.8	8.4	N.D.	N.D.	N.D.
400°C heating 1 hour	3.4	7.4	N.D.	0.6	0.9
400°C heating 2.5 hours	3.2	7.4	N.D.	1.6	2.0
400°C heating 5 hours	3.5	7.6	17.6	3.3	2.4
400°C heating 7 hours	3.2	7.0	29.5	4.7	2.2
400°C heating 8 hours	3.8	8.2	26.1	5.3	1.6

N.D.: not detected.

Table 6. SF₆ byproducts of overheated faults simulation at 450°C (unit: µL/L).

	Fluoride 1 (probable SF ₄)	Fluoride 2 (probable S ₂ F ₁₀)	SO ₂	H ₂ S	HF
450°C brfore heating	2.4	4.8	N.D.	N.D.	N.D.
450°C heating 1 hour	2.4	4.8	N.D.	0.8	1.0
450°C heating 2 hours	2.4	4.6	13.3	1.5	1.5
450°C heating 3 hours	2.5	4.7	19.3	3.1	2.4
450°C heating 5 hours	2.4	4.5	21.3	4.8	2.7
450°C heating 7 hours	2.5	4.7	36.4	7.1	2.5
450°C heating 8 hours	2.9	5.5	40.6	8.4	2.4

N.D.: not detected.

Table 7. SF₆ byproducts of overheated faults simulation at 500°C (unit: μL/L).

	Fluoride 1 (probable SF ₄)	Fluoride 2 (probable S ₂ F ₁₀)	SO ₂	H ₂ S	HF	CO
500°C before heating	5.9	15.6	N.D.	N.D.	N.D.	N.D.
500°C heating 1 hour	5.7	15.1	N.D.	4.6	3.4	N.D.
500°C heating 2 hours	5.5	14.7	33.4	7.0	3.7	N.D.
500°C heating 4 hours	6.0	15.7	50.8	12.6	3.5	N.D.
500°C heating 5 hours	5.8	15.2	62.2	15.6	3.6	N.D.
500°C heating 6 hours	5.7	15.0	68.3	18.4	3.3	0.2
500°C heating 7 hours	5.8	15.7	77.5	21.6	2.5	0.2
500°C heating 8 hours	15.1	35.7	91.4	25.2	2.3	0.9

N.D.: not detected.

concentrations of fluoride 1 (probable SF₄) and fluoride 2 (probable S₂F₁₀) are not significantly increased with the time of heating, while the concentration of SO₂ is significantly increased.

At 400°C, the concentrations of fluoride 1, and fluoride 2 (probable SF₄ and S₂F₁₀) were not increasing significantly. The concentration of SO₂ was 17.6 μL/L after heating for 5 hours, and it was increased to 26.1 μL/L 3 hours later. The concentration of H₂S was 1.6 μL/L after heating for 2.5 hours, and it was increased to 5.3 μL/L 5.5 hours later. The concentration of HF was 2.4 μL/L after heating for 5 hours and it was decreased to 1.6 μL/L 3 hours later, the tendency of which was the same with that at 350°C. The concentration of CO was below detection limits. SF₆ will decompose and produce 0.6 μL/L H₂S and 0.9 μL/L HF after heating for 1 hour at 400°C, and will produce 17.6 μL/L SO₂, 3.3 μL/L H₂S and 2.4 μL/L HF after heating for 5 hours. The concentrations of fluoride 1 (probable SF₄) and fluoride 2 (probable S₂F₁₀) are not significantly increased with the time of heating, while the concentration of SO₂ is significantly increased.

At 450°C, the concentrations of fluoride 1 and fluoride 2 (probable SF₄ and S₂F₁₀) were not increasing signifi-

cantly. The concentration of SO₂ and H₂S was 13.3 and 1.5 μL/L after heating for 2 hours, and it was increased to 40.6 and 8.4 μL/L 6 hours later. The concentration of HF was 2.7 μL/L after heating for 5 hours, and it was decreased to 2.4 μL/L 3 hours later, the tendency of which was the same with that at 400°C. The concentration of CO was below detection limits. SF₆ will decompose and produce 0.8 μL/L H₂S and 1.0 μL/L HF after heating for 1 hour, and will produce 13.3 μL/L SO₂, 1.5 μL/L H₂S and 1.5 μL/L HF after heating for 2 hours. The concentrations of fluoride 1 (probable SF₄) and fluoride 2 (probable S₂F₁₀) are not significantly increased with the time of heating, while the concentration of SO₂ is significantly increased.

At 500°C, the concentrations of fluoride 1 and fluoride 2 (probable SF₄ and S₂F₁₀) were not increasing significantly. The concentration of SO₂ was 33.4 μL/L after heating for 2 hours, and it was increased rapidly to 91.4 μL/L 6 hours later. The concentration of H₂S was 4.6 μL/L after heating for 1 hour, and it was increased to 25.2 μL/L 7 hours later. The concentration of HF was 3.7 μL/L after heating for 2 hours and it was decreased to 2.3 μL/L 6 hours later, the tendency of which was the same with that at 400°C and 450°C. The concentration of CO was below detection limits. SF₆ will decompose and produce 4.6 μL/L H₂S and 3.4 μL/L HF significantly after heating for 1 hour, and will produce 33.4 μL/L SO₂ significantly after heating for 2 hours. The concentrations of fluoride 1 (probable SF₄) and fluoride 2 (probable S₂F₁₀) are not significantly increased with the time of heating, while the concentration of SO₂ is significantly increased.

4. Conclusions

SF₆ is very stable and not significantly decomposed at 200°C, 250°C and 300°C. SF₆ will decompose and produce 0.3 μL/L H₂S and 0.5 μL/L HF after heating for 1 hour at 350°C, and it will produce 7.2 μL/L SO₂, 1.6 μL/L H₂S and 1.9 μL/L HF after heating for 5 hours. At 400°C, SF₆ will decompose and produce 0.6 μL/L H₂S and 0.9 μL/L HF after heating for 1 hour, and it will produce 17.6 μL/L SO₂, 3.3 μL/L H₂S and 2.4 μL/L HF after heating for 5 hours. At 450°C, SF₆ will decompose and produce 0.8 μL/L H₂S and 1.0 μL/L HF after heating for 1 hour, and it will produce 13.3 μL/L SO₂, 1.5 μL/L H₂S and 1.5 μL/L HF after heating for 2 hours. At 500°C, SF₆ will decompose and produce 4.6 μL/L H₂S and 3.4 μL/L HF after heating for 1 hour, and it will produce 33.4 μL/L SO₂, 7.0 μL/L H₂S and 3.7 μL/L HF significantly after heating for 2 hours. According to above simulated experiments, SF₆ is beginning to form significant SF₆ byproducts at 350°C, and it is more easily to be decomposed at higher temperature. SF₆ will be decomposed to

format HF, which is strongly corrosive and whose concentration is likely to decrease when it is above a certain concentration.

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