Study on the Fan Layout Method of SF_6 Leakage in Confined Space

Fuhua Sun, Yue Zhao, Fengxiang Ma, Feng Zhu, Wangchao Dong, Xin Liu, Bo Li, and Ming Sun

Abstract When SF_6 gas insulation equipment is in operation, if there is a sudden leakage fault, especially SF_6 gas leakage in a closed space such as a transmission pipe gallery, underground substation, and indoor substation, The leaked SF_6 will endanger the life and health of operation and maintenance personnel and pollute the environment, and it will mix with the air in the environment, which increases the difficulty of recovery. In order to solve the problem of leaking gas in space, different arrangements of exhaust pipes and fans are tested. The results show that the SF_6 gas concentration in the confined space can be effectively reduced by using the arrangement of a small flow fan to supply air into the pipeline and large flow fan output in the front stage; At the same time, appropriate tee form and SF_6 concentration sensor layout are selected to optimize the test model further.

Keywords SF_6 gas · Gas leakage · Confined space · Fan layout

1 Introduction

Sulfur hexafluoride (SF_6) gas is widely used in the insulation of electrical equipment in the power industry due to its excellent insulation and arc extinguishing properties. However, as SF_6-insulated equipment is used for longer periods, aging and damage are inevitable, leading to the occurrence of leakage failures [1]. SF_6 gas has a density much higher than air under the same conditions. When it leaks into the environment, it accumulates in low-level spaces, causing local oxygen deficiency. Additionally, under the action of corona discharge, spark discharge, and high-temperature arcs, SF_6 gas reacts with impurities in the equipment to produce corrosive, irritating, and

F. Sun (✉) · B. Li · M. Sun
Henan Relations Co., Ltd., Zhengzhou 450001, China
e-mail: sunfuhua@relations.com.cn

Y. Zhao · F. Ma · F. Zhu · W. Dong · X. Liu
Electric Power Research Institute of State Grid Anhui Electric Power Co. Ltd., Hefei 230000, China

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toxic decomposition products, such as SO_2, SOF_2, and SO_2F_2, which pose a health risk to maintenance personnel and increase potential hazards. On the other hand, the Kyoto Protocol has listed six gases, including SF_6, as greenhouse gases. SF_6 gas has a GWP of approximately 23,500 times that of CO_2 and an atmospheric lifetime of 3200 years. Once it leaks, it will cause serious atmospheric pollution [2–4].

Enclosed spaces such as GIL, underground substations, and indoor substations have the characteristics of large space and a large number of equipment. When SF_6 gas leaks from the electrical equipment running in these spaces, the leaked SF_6 gas will mix with the ambient air, and the SF_6 concentration in the space will rapidly decrease while the volume rapidly increases, making the recovery of SF_6 gas difficult. If the leaked gas is not immediately discharged through the ventilation system, it will pose a risk to maintenance personnel and cause environmental pollution [5].

Therefore, when SF_6 leaks, the optimized design of exhaust pipes, fans, and ventilation systems is particularly important [6]. Xiao et al. [7] established 1D Flowmaster and 3D Fluent numerical analysis models to simulate SF_6 leakage in ultra-high voltage shield tunnels and optimized the ventilation system, finding that using a GIL tunnel with an upper and lower chamber structure can achieve rapid absorption and discharge of SF_6. Guo et al. [8] found that when the supply and exhaust ports are arranged in the center of the wall, it is more conducive to the uniform flow of ventilation. A symmetrical arrangement of exhaust ports is better than a single exhaust port for ensuring convection and exhaust diffusion of ventilation, and symmetrical supply and exhaust arrangements are conducive to forming controllable flow with the outside under micro-positive pressure conditions. Sui et al. [9] conducted a simulation study on SF_6 gas leakage in a comprehensive GIL tunnel and determined the most unfavorable leakage position and working condition based on GIL cabin exhaust ventilation data and SF_6 gas diffusion characteristics. They suggested placing SF_6 sensors in critical tunnel locations, such as sumps and low-lying areas, to ensure the safety of maintenance personnel. However, current studies have not provided specific recommendations for the layout of exhaust pipes and fans in the gas recovery system in enclosed spaces when SF_6 leaks.

In this paper, three experimental models with different pipeline and fan layouts were established, and the influence of different experimental models on the discharge rate of SF_6 gas in enclosed spaces was determined through experiments. Based on the optimal experimental model, experimental verification was conducted, and reasonable optimization suggestions were proposed to provide reference for the installation optimization of fans in enclosed spaces.

2 Experimental Plan

According to the spatial diffusion model of SF_6 gas under ideal conditions, when SF_6 gas leaks, due to its density being greater than that of air, SF_6 gas will not only diffuse in the air, but also be affected by its own gravity, falling uniformly and steadily, and depositing near the ground [10–14]. Therefore, in this experiment, the exhaust duct will be arranged in different forms on the ground of the experimental chamber.

2.1 Experimental Methods

1. Before starting the experiment, multiple SF_6 concentration sensors are dispersedly arranged in the experimental chamber (with a volume of about 250 m^3) to detect the SF_6 gas concentration in different areas of the chamber.
2. According to the three different layout designs of the experiment, ventilation pipes and fans are set along the ground surrounding the experimental chamber, and the exhaust of the ventilation pipes is connected to the SF_6 recovery device.
3. The experimental chamber is sealed at all locations, filled with a certain volume of air, and the change in air pressure is observed to check the overall airtightness of the chamber.
4. A certain volume of SF_6 gas is introduced into the experimental chamber, and the SF6 concentration is monitored using SF_6 concentration sensors until the required concentration is achieved. Then, the fan and the recovery device are started to observe and record the changes in SF_6 gas concentration data in the experimental chamber.
5. The layout design is changed, and the above experimental procedures are repeated for the next group of experiments.

2.2 Different Pipeline and Fan Layout Effects

Recycling pipeline and fan layout method 1. As shown in Fig. 1, numbers 1, 2, and 3 represent three fans arranged in a “mouth” shape by being connected in series with the pipeline. The black arrows indicate the direction of gas flow in the pipeline, and the intake and exhaust ports are connected to the pipeline in this direction, with the outlet of fan 1 connected to the recycling device.

To increase the intake volume of the pipeline, it is proposed to drill holes at the position shown by the green arrow in Fig. 1, to increase the intake port of the recycling pipeline, and to use the pressure difference between the inlet and outlet of each fan to suck in as much leaked gas as possible.

Experimental results show that the layout of recycling pipelines and fans according to method 1 results in a slow decrease in SF_6 gas concentration in the experimental chamber. This is because the air flow sent out from the outlet of fan 3 will flow out of the air holes between fans 2 and 3 when flowing in the pipeline, and the intake air volume at the back end of the pipeline is small, leading to low recycling efficiency and slow decrease in SF_6 gas concentration. Therefore, layout method 1 is not feasible.

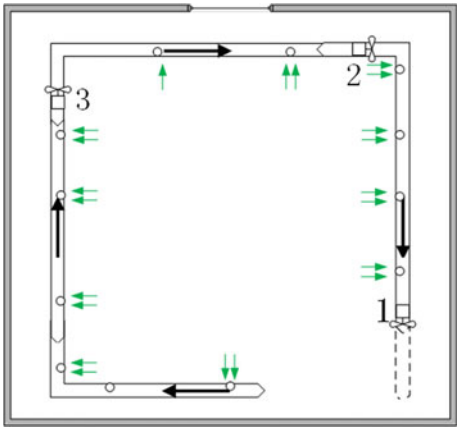

Fig. 1 Recycling pipeline and fan layout method 1

Recycling pipeline and fan layout method 2. As shown in Fig. 2, three fans are connected in series to the outlet, increasing the wind pressure, but the wind volume remains the same.

Experimental results show that the layout of recycling pipelines and fans according to method 2 also results in a slow decrease in SF_6 gas concentration in the experimental chamber. This is because of the wind pressure loss in the pipeline, and there is basically no gas entering the intake port at the back end, resulting in a significant decrease in the recycling speed when the SF_6 gas concentration in the experimental chamber drops to a certain value. Therefore, layout method 2 is not feasible.

Recycling pipeline and fan layout method 3. As shown in Fig. 3, small flow fans 1 and 2 are used to deliver gas to the pipeline, and large flow fan 3 is used to output gas.

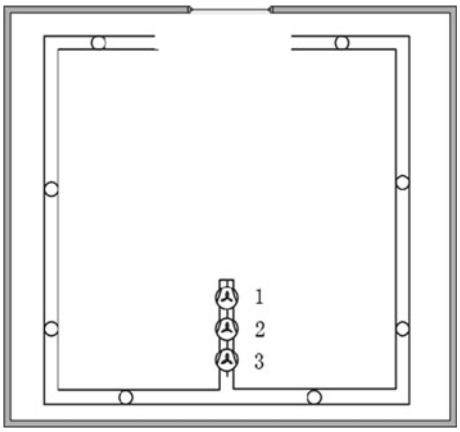

Fig. 2 Recycling pipeline and fan layout method 2

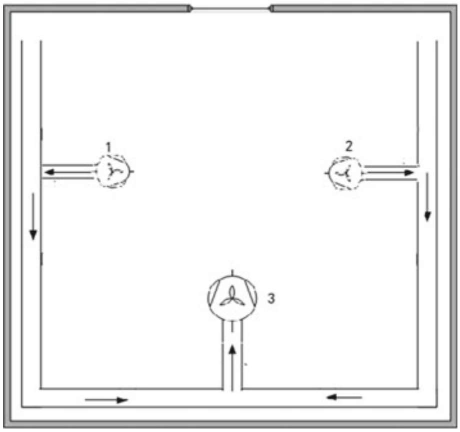

Fig. 3 Recycling pipeline and fan layout method 3

Experimental results show that the SF_6 gas concentration in the experimental chamber decreases significantly in the same period of time using layout method 3 compared to the first two methods. This is because no intake port is set up on the pipeline, and the gas is directly sucked into the pipeline through the fan's intake port, reducing the wind pressure loss in the pipeline and increasing the SF_6 recycling rate. Therefore, recycling pipeline and fan layout method 3 is adopted as the optimal experimental model.

3 Solution Optimization and Result Analysis

Based on the optimal recycling pipeline and fan layout method three, further optimization was carried out for this layout.

3.1 Solution Optimization

Pipeline Optimization. When using pipeline to transport gas, the flow resistance of gas in the duct is not only due to the viscosity of the air itself and the friction between the air and the duct wall, but also due to the local eddy currents caused by the change in flow velocity and direction when the air flows through fittings such as tees and elbows in the pipeline, which results in local resistance. In the case of constant frictional resistance, local resistance should be minimized as much as possible.

The size of the local resistance of the tee is related to the central angle of the branch pipe, the section shape of the tee, the area ratio of the branch pipe to the main pipe, and the flow rate. In order to reduce the local resistance of the tee, the central angle α of the branch pipe should be as small as possible. Compared with the

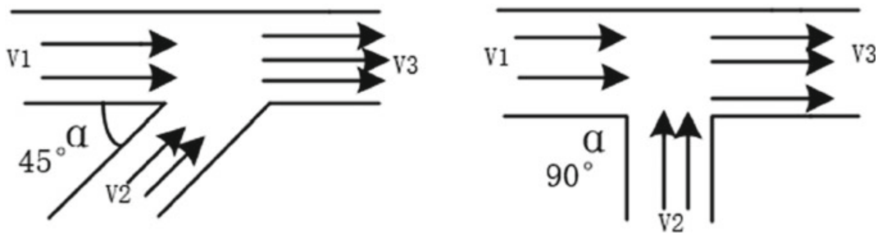

Fig. 4 Two common forms of tees

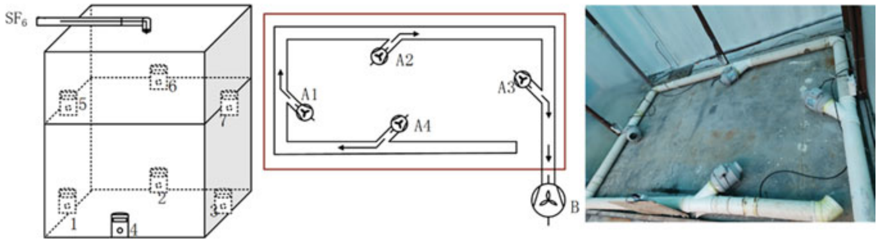

Fig. 5 Experimental Platform and Sensor Distribution

two common tee forms shown in Fig. 4, a 45° oblique tee is used at the connection between the duct and the fan, and an elbow is used at the bend of the duct.

Sensor Layout Optimization. In the layout of the SF_6 concentration detection sensors, optimization is carried out for layered placement, which is more conducive to detecting the difference in SF_6 gas concentration between the upper and lower spaces.

After optimization, the sensors are arranged in two layers. The SF_6 gas is filled from the top. The layout of the SF_6 concentration detection sensors and the pipeline fan layout inside the experimental platform are shown in Fig. 5:

The length of the experimental compartment is 3 m, the width is 2.1 m, and the height is 2.5 m, with a volume of about 15.8 m^3. Sensors 1–4 for SF_6 concentration detection are installed near the ground, and sensors 5–7 are installed at a position about 1.5 m above the ground. The flow rate of pipeline fans A1–A4 is 100 m^3/h, and the flow rate of pipeline fan B is 500 m^3/h. The outlet of pipeline fan B is connected to the SF_6 recovery device.

3.2 *Result Analysis*

After injecting a certain concentration of SF_6 gas and starting the fan, the changes in SF_6 gas concentration of each sensor are shown in Fig. 6. The data curve shows:

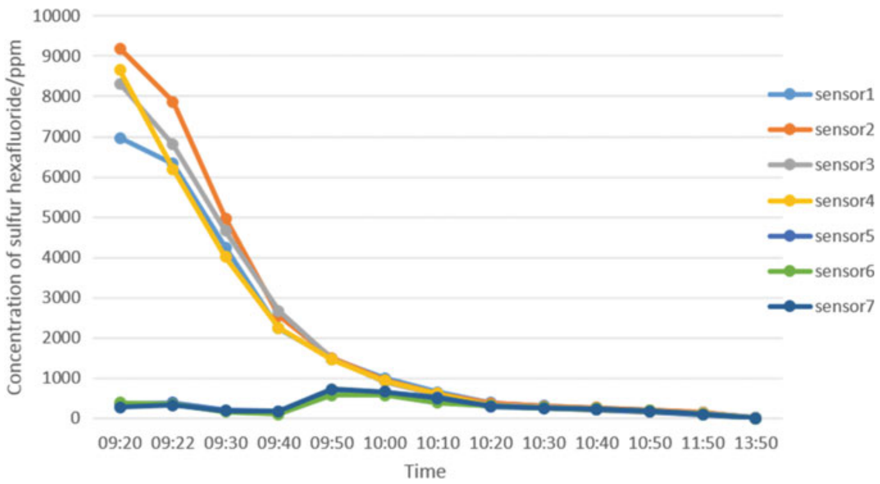

Fig. 6 SF_6 concentration change curve

1. After injecting SF_6 gas, the initial concentration of sensors 1, 2, 3, and 4 near the ground is much higher than that of sensors 5, 6 and 7 in the upper layer, indicating that SF6 gas is mainly concentrated near the ground.
2. At the end of the experiment, the SF_6 gas concentration of all sensors is close to 0, indicating that the method of using the fan and exhaust duct to discharge the leaked gas from the space can effectively reduce the SF_6 content in the space.
3. When the fan runs for about 40 min, the SF_6 content in the space can be reduced to 1000 ppm; with the increase of the running time of the fan, the SF_6 content in the space can be reduced to 0 ppm, which takes about 270 min.

4 Conclusion

This paper conducted experiments on the discharge of SF_6 leaks in enclosed spaces based on different layouts of exhaust ducts and fans, and optimized the layout. The following conclusions were drawn:

1. The layout of SF_6 recovery ducts and fans using method three, which involves small flow rate fans sending air into the ducts and large flow rate fans outputting, can effectively reduce the concentration of SF_6 gas leaked into enclosed spaces and has practical application significance.
2. By using a reasonable tee form and optimizing the layout of SF6 concentration sensors, the discharge and recovery efficiency of the model can be further improved, and the remaining SF_6 gas content can be measured more accurately.

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