ABSTRACT
Joint study for technical standards for recycling and handling of SF₆ was conducted from 1996 to 1998 by the representatives of Academy, Utilities, Equipment Manufacturers and Gas Producers in Japan under the coordination of Electric Technology Research Association Japan (ETRA: Chair: Professor Takuma, Kyoto University), and the voluntary actions for SF₆ emission reduction from electrical equipment are being taken since 1998 in accordance with the criteria and agreement of the joint study. This paper describes the follow-up activities after the joint study and the voluntary action plans and presents the perspective of SF₆ emission for the future.

1. BACKGROUND OF SF₆ USAGE IN JAPAN

In recent years, since there has been a significant increase in electricity demand, substation equipment is required to be more reliable and compact, coping with higher voltage and larger capacity ratings. By application of sulfur hexafluoride (SF₆) to substation equipment like circuit breaker and switchgear, downsizing and less maintenance cost can be achieved to greater degrees than conventional air-insulated substation in virtue of its excellent performance of SF₆. Therefore, Gas insulated equipment like gas circuit breaker (GCB), gas insulated switchgear (GIS) and gas insulated transformer (GIT) are being widely and commonly applied. Particularly in Japan where the land acquisition is extremely difficult, there is a large demand for gas insulated equipment as above.

On the other hand, since SF₆ was identified as a greenhouse gas in recent years, electric power companies and equipment manufacturers in Japan have been studying on countermeasures for limiting the release into atmosphere. Since the economical solution with alternative measure has not been found yet in spite of great efforts in the concerned fields, we have to continue to use the SF₆ with special attention. Therefore, consideration and practical actions should be taken to keep the SF₆ emission to a minimum so that we can make the best use of gas-insulated equipment.

2. SF₆ HOLDINGS AND EMISSIONS IN JAPAN (Obtained by Joint Study)

The world's production of SF₆ in 1995 was estimated approximately 8,500 tons. Of the total, some 30% were produced in Japan. SF₆ is mainly used for electric insulation. From the results of surveys in Japan on the amounts of SF₆ handled by gas producers and gas-insulated equipment manufacturers, conducted by the joint study, the amount of SF₆ and the quantity of emissions from 1990 to 1995 are estimated as shown in Fig. 2-1.

Generally, since SF₆ for electric insulation purposes is used in enclosed vessels, the amount of SF₆ holding increases in proportion to the amount of facilities. According to the survey, the amount of SF₆ possessed by the electric power companies had increased by 400 tons to 500 tons per year while the amount by the other industries had grown by 100 tons to 150 tons per annum. Emissions from the gas producers are taking place from their production processes and in course of disposing of residual gas, which remained inside of returned SF₆ cylinders. Emissions at the equipment manufacturers occur in testing stage both during development and production in their factory as well as during the installation work at site. Emissions at the electric power companies correspond to the emission at maintenance stage and removal stage as well as natural leakage from equipment.
3. VOLUNTARY ACTION PLANS

In April 1998, Federation of Electric Power Companies (FEPC) and Japan Electric Manufacturers’ Association (JEMA) announced the voluntary action plan for the reduction of SF₆ emission from electric equipment, respectively. Voluntary action plan was issued based on the results of joint study and the understanding that electric power companies and electric equipment manufacturers must make every effort to keep the SF₆ emission to minimum in order to make use of gas insulated equipment, since the economical alternative solution has not been found yet in spite of great efforts in the concerned field.

The actions to be addressed are as follows:-
1. Suppression of SF₆ emission from the development stage to the removal stage of gas insulated equipment
2. Establishment and promotion of recycling system
3. Brush up the current SF₆ Inventory system
4. Development of new technology to minimize the use of SF₆ in equipment

4. SET-UP THE RECOVERY GUIDELINE

As a result of joint study, recovery target was set up as shown in table 4-1, which summarizes the current recovery rates and the target value in future. Points of guideline at respective stages are as follows.

(1) During Development Stage of Equipment
In the past, SF₆ had not been fully recovered at interrupting test or switching test during development stage because such tests generate dissolved gases. However, we set up the target and decided to promote the recovery by applying filters and the like so as to remove dissolved gases to a sufficient degree.

(2) During Equipment Manufacturing
Product testing during manufacturing is only the work related to SF₆ handling. Though recovery had been performed during manufacturing, further efforts shall be required.

(3) During Equipment Installation
Since the duration of SF₆ recovery during installation becomes longer to satisfy the target, further improvement for work process shall be strongly required.
(4) During Maintenance work
When internal inspection, recovery of SF₆ before opening the gas compartment, and vacuum up procedure and SF₆ filling process after internal inspection are required. When SF₆ is recovered to the higher degree, out-of-service time is expected to be longer than before. Since it is very difficult to secure the required out-of-service time especially in urban area, reclaimer with higher efficiency or maintenance strategy to extend maintenance interval are required.

(5) During Equipment Removal
When remove SF₆ gas-insulated equipment, SF₆ should be reclaimed to the target degree, which is similar to the case of the maintenance in principle.

Table 4-1: Current recovery rates and future gas recovery guidelines (The indicated recovery rates apply to cases where recovery is performed on equipment/facilities with a rated gas pressure of 0.4 MPa-Gage.)

<table>
<thead>
<tr>
<th>Recovery terminal pressure</th>
<th>Recovery rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower than 110 kV or higher</td>
<td>No Recovery</td>
</tr>
<tr>
<td>110 kV or higher</td>
<td></td>
</tr>
<tr>
<td>Lower than 110 kV</td>
<td>No Recovery</td>
</tr>
<tr>
<td>110 kV or higher</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Before 1995</th>
<th>Recovery terminal pressure</th>
<th>Recovery rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>During testing</td>
<td>0 - 0.05 MPa-gage</td>
<td>Approx. 70%</td>
</tr>
<tr>
<td>During manufacture</td>
<td>0 - 0.05 MPa-gage</td>
<td>No Recovery</td>
</tr>
<tr>
<td>During installation/ Maintenance</td>
<td>No Recovery</td>
<td>No Recovery</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Future (Not later than 2005)</th>
<th>Recovery terminal pressure</th>
<th>Recovery rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>During Testing/ Manufacture/ Installation/ Maintenance</td>
<td>0.015 MPa-abs (114 Torr) or lower</td>
<td>97% or higher</td>
</tr>
<tr>
<td>During removal</td>
<td>0.005 MPa-abs (38 Torr) or lower</td>
<td>99% or higher</td>
</tr>
</tbody>
</table>

5. SF₆ GAS QUALITY CRITERIA
For decreasing the emission of the SF₆, it is essential to minimize the SF₆ emission and recover it for recycling. For such recycling, a new SF₆ quality control standard should be indispensable. The representatives of Academy, Utilities, Equipment Manufactures and gas producers jointly set up the criteria as shown in table 5-1 as the achievement of the Joint study.

Table 5-1: Quality control criteria for SF₆ gas

<table>
<thead>
<tr>
<th>Permissible limits</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF₆ gas purity</td>
<td>95 vol. %</td>
</tr>
<tr>
<td>Air</td>
<td>(5 vol. %)</td>
</tr>
<tr>
<td>Moisture content</td>
<td>Equipment without current interruption</td>
</tr>
<tr>
<td>Equipment with current interruption</td>
<td>300 ppm (vol.)</td>
</tr>
<tr>
<td>Dissolved gases/decomposition products</td>
<td>–</td>
</tr>
</tbody>
</table>
6. \( \text{SF}_6 \) RECYCLING FLOW

A RECYCLING FLOW for \( \text{SF}_6 \) which is shown in Fig. 6-1, has been established based on the above \( \text{SF}_6 \) handling criteria as the achievement of the Joint study. In each phase of the flow, recycling should be promoted when handling \( \text{SF}_6 \). Provision shall be made to enable the use of not only new \( \text{SF}_6 \) but also recycled one at every step of the flow.

![Fig.6-1: \( \text{SF}_6 \) recycling flow](image)

To make efficient gas-recovery operations possible, the following principles should be observed:

1. Recovered \( \text{SF}_6 \) that meet the required quality control level should be reused by electric power companies and gas-insulated equipment manufacturers.
2. Even when \( \text{SF}_6 \) recovered from removed equipment satisfies the required quality control level, its reuse in electric power companies is not efficient if the \( \text{SF}_6 \) is available in large quantities. If this is the case, recovered \( \text{SF}_6 \) should be brought in to gas insulated equipment manufacturers.
3. If recovered \( \text{SF}_6 \) fails to reach the required quality control level, the \( \text{SF}_6 \) should be returned to its producers for refining or destruction.

7. IMPROVEMENT OF INVENTORY SYSTEM

Another joint study among the representatives of the electric power companies, the equipment manufacturers and gas producer was set up to promote the recovery and reuse of \( \text{SF}_6 \) in electric power industry in Japan in October 1999.

Main issue of the said joint study is as follows.

(1) Efficient use of \( \text{SF}_6 \) recovery equipment among the electric industry

Electric power companies in Japan set up the plan to purchase the \( \text{SF}_6 \) recovery equipment for the gas insulated equipment with relatively small \( \text{SF}_6 \) quantity, which is for example suitable for 110kV GIS. However, quite a lot of investment could be required if the recovery equipment which can handle the large amount of \( \text{SF}_6 \) for gas insulated equipment with much \( \text{SF}_6 \) volume, such as GIS of 300kV and above.

Under such background, electric power companies and equipment manufactures exchange the information relating to the numbers of units and their capability which they possess and share the
information when, where and how long periodical maintenance works will be carried out. By this cooperation, SF₆ recovery can be carried out efficiently without much investment for SF₆ recovery equipment with larger capability.

(2) Brush up the existing inventory system
As a result of the former joint study by Academy, Utilities, equipment manufacturers and gas producer, a concept of SF₆ recycle flow was established. However, standardization of procedure and common understanding for SF₆ handling are strongly required to secure the proper handling. Followings were intensively discussed intensively and common understandings were established.

a. Standardized procedure for SF₆ handling
As far as banking quantity of SF₆ in the equipment is concerned, SF₆ volume on the nameplate of respective gas insulated equipment is used. And as far as SF₆ emission from gas insulated equipment is concerned, the calculated values based on the SF₆ volume and its pressure are basically applied, while mass measuring method can be also applied if measuring equipment is available on site. In addition, SF₆ quantity is added to the logbook of electric company, when the ownership is transferred, while sometime, the time of commencement of operation was applied. Standardized slip is applied to all the gas handling work and record the SF₆ quantity including the emission. And responsible organ is nominated at every SF₆ handling works.

b. Standardized measuring method and equipment
Minimum requirement for measuring equipment was specified based on the results of former joint study and all the measuring equipment should be proofread every year. The SF₆ handling report should contain the standardized items such as manufacture, type form, registration number of measuring equipment and date, time, day, ambient temperature, relative humidity and result of measurement.

c. Common understanding for the handling of recycled gas
Followings understanding were established.

i. The electric power company who recovers the SF₆ should basically reuse recovered SF₆ that meets the recycling criteria.

ii. The electric power company who has a larger volume of SF₆ than he could use within the company, should ask the equipment manufacture if excess amount can be utilized or not, to promote the recycling and reuse of SF₆.

iii. SF₆ quantity from electric power company to equipment manufacturer should not exceed 500 kg per manufacture per month.

8. SF₆ EMISSIONS FROM ELECTRIC INDUSTRY IN JAPAN

Based on the aforementioned targets, securing the countermeasure for promoting SF₆ recovery, the amounts of SF₆ emissions by gas insulated equipment were estimated as follows.

Through the implementation of the said measures, the Japan Electrical Manufacturers' Association presumes that it may be possible to reduce the amount of discharge from gas insulated equipment manufacturers to less than one tenth of the current emissions of approximately 400 tons in the future. On the other hand, it is expected that the amount of leakage from the equipment in operation increase because of the growing amount of facilities. As a result, the number of equipment to be inspected and replaced increases which, in turn, creates new factors for increasing gas emissions. Even under such situation, it is considered possible to maintain the electric power companies' current emission level in future by increasing the recovery rate, namely by improving the performance of gas-recovery equipment and increasing the number of such equipment to offset increases in the amount of leakage. Through the implementation of these measures, it becomes possible to reduce the total amount of emissions from both gas-insulated equipment manufacturers and electric power companies as shown in Fig. 8-1.
9. SF₆ EMISSION FROM THE OTHER INDUSTRY IN JAPAN

With the implementation of measures, the SF₆ gas production industry has set a quantitative reduction target for emissions of SF₆ as follows:
- Actual 2000 emissions: 23 kg/ton

In addition, it is reported that SF₆ is applied to the Magnesium casting process and approximately 20 tons of SF₆ is used in 1999 by Magnesium industry. However, from the standing point of environmental protection, substitute gas is now being researched and therefore, the quantity of SF₆ used in Magnesium industry will be reduced, thanks to substitute gas and other measures.

10. CLOSE/FUTURE PERSPECTIVE FOR SF₆ EMISSION

By setting up the recovery target, the recycling criteria and the closed recycle system concept, SF₆ emission from 1996 to 2001 was gradually reduced. In the future, we are confident that the further efforts by the continuing cooperation of relevant parties will be made to reduce SF₆ emissions in accordance with the guidelines established by this joint study.