hexafluoride as an insulating gas for Van de Graaff accelerators have resulted in the decision to use it in the HP tandem accelerator presently being installed at Chalk River. Observations on a 3 megavolt vertical Van de Graaff and the EN 10 kV tandem accelerator show that there are no problems due to the use of SF6 which cannot be solved with normal engineering procedures. An outline will be given of the physical and electrical properties, and a method of detecting and removing the corrosive breakdown products will be described. The gas handling system for the HP accelerator and a system for air removal will be described. An economic and functional comparison with a system using N2-CO2 is given.

**INTRODUCTION**

The decision to use SF6 gas instead of N2-CO2 as the insulating medium for our HP 20 MeV Van de Graaff accelerator was based primarily on three main factors.

First, experience with our three megavolt vertical accelerator and our model EN tandem accelerator, both of which have run with N2-CO2, showed that operation with SF6 at 60 psig was as good as operation with N2-CO2 at 225 psig. The three megavolt machine has run intermittently since 1956 and the tandem machine has run an average of sixty hours a week since January, 1963 using pure SF6, although some air contamination of the insulating gas has occurred during this time. There has been no fault encountered, either electrical or mechanical, which could be attributed to the SF6 insulating gas or its breakdown products.

Secondly, a cost analysis made on comparable N2-CO2 and SF6 gas storage and handling systems (including initial gas costs) showed that there is no appreciable difference in overall capital costs. The SF6 yearly operating costs for replacement gas should be lower and can be more than offset by the saving in accelerator pump out time.

The third and most significant factor was the possibility of increasing the limit on the operating voltage by increasing accelerator tank pressure to 100-125 psig. With the development of the inclined field accelerator tubes and improvements in solid dielectrics, this holds promise.

**PROPERTIES OF SF6**

The usefulness of SF6 as an insulating medium for Van de Graaff accelerators is due to its unique electrical, physical and chemical properties. The following characteristics are most important.

**Dielectric Strength**

The relative dielectric strength of SF6 (N2-CO2 = 1) in the electric fields existing in the EN tandem accelerator is about 3.0. This is based on experiments by Philp, Camilli, Gordon and Plump, and on our own experience with the EN-1 tandem accelerator. Spark-over tests were performed on the EN-1 tandem accelerator with SF6 at 60 psig in the tank and 15 psig in the accelerator tubes. Sparking did not occur below 7.5 megavolts and it is estimated that the most of the sparking occurred down the accelerator tube spark gaps at approximately 6.0 megavolts. These results are as good as any achieved in an EN tandem using N2-CO2 mixtures up to 250 psig.

Typical operating pressures for our EN tandem are 40 psig to five million volts and 60 psig to seven million volts.

**Heat Transfer**

Good heat transfer characteristics are essential, particularly in the HP tandem accelerator as most of the heat from the 100 HP charge-belt drive motor must be transferred by the tank gas. Although the thermal conductivity of pure SF6 is lower than air (7.56 x 10^-7 vs 7.18 x 10^-5 calories per sec/cm°C/cm) its high density results in excellent cooling by natural and forced convection.

**Density**

The density of SF6 at standard conditions is 0.37 lbs/ft³ (about five times as heavy as air). The high density results in greater loads on the main drive motor. The drive motor load appears to vary directly as the density of the insulating gas. Figure 1 shows the results using our EN tandem accelerator. The tests were conducted without changing other operating conditions.

**Chemical Properties**

The insulating gas must be compatible with the materials of construction. It must also be stable at the elevated temperature of the motors and other electrical components used in Van de Graaff machines. SF6 is stable up to 500°C which is higher than normally found in Van de Graaff accelerators except during an electrical spark.

**Toxicity and Corrosion**

SF6 is non-toxic and non-corrosive. Rats exposed to 80% SF6-20% O2 mixtures for two hours were unaffected. Tests by Allied Chemical Co.,3 Camilli, Gordon and Plump4 and others, have shown pure SF6 is physiologically safe. As SF6 is stable under normal operating conditions, equipment and piping are carbon steel. However, thermal and electrical breakdown products are quite toxic and corrosive. Thermal decomposition probably occurs during accelerator sparking and electrical decomposition during sparking and corona discharge.
Small peaks occurring one and two mass units above a gas peak result from air contamination of the tank gas. Peaks at 102, 83 and 64 are tentatively identified as being from $\text{SF}_2$. The nitrogen, oxygen and argon chromatograph should clarify these identifications.

Further analysis is intended using an infra-red absorption spectrograph and a gas chromatograph. These devices permit a non-destructive analysis which should clarify the results obtained with the mass spectrograph.

A comparison of the spectra of samples subjected to corona discharge shows that activated alumina effectively removes all breakdown products. Earlier experiments by Camilli et al. on acidic and oxidizing breakdown products, and by Schumb et al. on acidic at Chalk River have always contained varying amounts of air (up to 20%) mixed with the $\text{SF}_6$. Sufficient storage volume has therefore been provided to allow the MP accelerator to operate with up to 20% $\text{N}_2$. The gas will be stored in two interconnected tanks with a total volume of 1600 ft$^3$. Because of the large quantities of $\text{SF}_6$ required, it will be stored as a liquid in the 606 ft$^3$ tank. This tank is capable of holding 51,000 lb of liquid $\text{SF}_6$, a quantity sufficient to charge the accelerator to 140 psig. The pressure in the storage tanks will be the vapor pressure of $\text{SF}_6$, plus that due to non-condensable gases up to a maximum working pressure of 600 psig.

Nitrogen and Ar may be added to the accelerator from the 1000 ft$^3$ tank and then $\text{SF}_6$ from the liquid storage tank until the desired accelerator pressure is obtained. The $\text{SF}_6$ is removed from the storage tank as a liquid, ensuring a pure, dry gas for the accelerator. Liquid $\text{SF}_6$ is vaporized in a steam-heated vaporizer and then superheated. Superheating is necessary to prevent complications due to condensation during expansion from storage pressure (up to 600 psig) to accelerator pressure (initially 1 torr) through a throttling valve. The temperature of the gas entering the accelerator is controlled to within $\pm 10^\circ\text{F}$ of the accelerator temperature to eliminate thermal shock. The vaporizer and superheater will deliver 160 lb of $\text{SF}_6$ per minute.

The gas is removed from the accelerator with a 300 std ft$^3$/min compressor and condensed for liquid storage. The condenser will liquefy 100 lb of $\text{SF}_6$ per minute from a gas mixture containing up to 20% $\text{N}_2$. When the accelerator pressure drops below atmospheric, a 500 ft$^3$/min vacuum pump is used in series with the compressor to remove the remaining gas from the accelerator. Mixtures of $\text{SF}_6$ and non-condensable gas will be vented to the gas storage tank to keep the liquid storage tank pressure below 600 psig. The accelerator pressure is maintained at 100 psig with a 200 std ft$^3$/min compressor, augmented by the accelerator pump as necessary.
The pressure can be reduced from 90 psig to 5 torr in 6 hours.

A comparison of the operating conditions
for the $N_2-CO_2$ and $SF_6$ system is given below.

<table>
<thead>
<tr>
<th></th>
<th>$SF_6$</th>
<th>$N_2-CO_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Accelerator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Pressure (psig)</td>
<td>70</td>
<td>225</td>
</tr>
<tr>
<td>Max. Storage Pressure (psig)</td>
<td>600</td>
<td>2400</td>
</tr>
<tr>
<td>Gas Requirements (standard ft$^3$/lb)</td>
<td>67,800</td>
<td>180,000</td>
</tr>
<tr>
<td>Compressor H.P.</td>
<td>100</td>
<td>150</td>
</tr>
</tbody>
</table>

Pumping times for different phases of the operating cycle are given in the following table for $N_2-CO_2$ and $SF_6$ systems.

<table>
<thead>
<tr>
<th>Operation</th>
<th>$SF_6$</th>
<th>$N_2-CO_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowering accelerator pressure to atmosphere</td>
<td>4 hrs</td>
<td>10 hrs</td>
</tr>
<tr>
<td>Evacuate gas from accelerator tank</td>
<td>2*</td>
<td>1**</td>
</tr>
<tr>
<td>Fill accelerator with air</td>
<td>1/2</td>
<td>1/2</td>
</tr>
<tr>
<td>Exhaust air from accelerator</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Recharge with dielectric</td>
<td>5-1/2</td>
<td>2 - 4</td>
</tr>
</tbody>
</table>

* $SF_6$ evacuated to 5 torr and exhausted to storage system.
** $N_2-CO_2$ evacuated to 50 torr and exhausted to atmosphere.

Purification System

The build-up of non-condensable gases over a period of time makes the condensing of $SF_6$ difficult. With a non-condensable gas content of 40%, $SF_6$ will not condense below 600 psig with the cooling water temperature available. A system for separating $SF_6$ from any non-condensable gas, such as air, has been provided and is shown in figure 4. Gas may be drawn from either storage tank, compressed to 3000 psig using a 25 std ft/min diaphragm compressor, and condensed. The condenser is cooled by a refrigeration system. When the pressure in the condenser increases to 3000 psig, due to the build-up of non-condensable gas the temperature is reduced to -50°F. At these conditions the percentage of $SF_6$ in the gas phase is less than 1.5%. The gas mixture is then vented to atmosphere and liquid $SF_6$ returned to the storage tank.

The purification system will be used only when necessary and may be operated independently of the gas transfer system so that the accelerator is not affected by the purification system.

Leak Testing

As $SF_6$ is expensive, methods of sensing and locating leaks are important. Halide leak detectors are commercially available which are suitable for locating leaks in welds, valve stems and gaskets etc. For detecting $SF_6$ in equipment areas, a device is being developed at Chalk River which will respond to an increase as small as .01%. This device detects a change in the velocity of sound in the air being sampled. Detectors will be located at low points under the accelerator and storage tanks.

Economics

The capital cost of the $SF_6$ system, including the purification system and initial gas charge is within ten percent of an $N_2-CO_2$ system. Estimates of the operating costs vary depending on the vacuum pulled on the accelerator tank when exhausting insulating gas and the value assigned to shutdown time of the accelerator. Assuming $150.00/hr for accelerator shutdown time, a $N_2-CO_2$ system exhausted to atmospheric pressure, and an $SF_6$ system exhausted to 5 torr, then $SF_6$ operating costs will be approximately $350.00/6 cycle less than the $N_2-CO_2$ system. This assumes 16-1/2 hour and 14 hour cycle times respectively for the $N_2-CO_2$ and $SF_6$ systems.

References

3. Allied Chemical Co. report No.28-85605.
Fig. 1. Drive motor load vs tank pressure for SF₆ and N₂-CO₂.

Fig. 2. Mass spectra of SF₆ and its breakdown products.

Fig. 3. MP accelerator dielectric gas handling system.

Fig. 4. MP accelerator dielectric gas purification system.