→ Corona discharge is important in high voltage engineering where most of the fields encountered are non-uniform fields.

→ Design is carefully made in HV engineering area to try to make the fields uniform.

→ Corona is responsible for power-loss and interference of power lines with the communication lines as corona frequency lies between 0.01 Hz – 100 Hz.

→ Corona also deteriorates the insulation by combined action of discharge ion bombarding the surface.

→ Corona event produces a noise and ozone gas.
mainly copper.

Breakdown in Electro negative Gases:

SF₆ (sulfur hexafluoride) has excellent insulating strength because of its affinity (covalent bond) for electrons (electronegativity). Whenever a free electron collides with neutral gas molecule to form negative ion, the electron is absorbed by the neutral gas molecule.

Two alternative electron attacks:

\[ \text{SF}_6 + e \rightarrow \text{SF}_6^- \]
\[ \text{SF}_6 + e \rightarrow \text{SF}_5^- + \text{F} \]
The dielectric strength of SF6 at normal pressure and temperature is 2-3 times that of air. At 2 atm pressure, it is comparable with transformer oil.

SF6 is a gas, which can be liquefied at high pressure and stored in steel cylinders.

Application of Gases in Power Systems

Some gases (air, oxygen, nitrogen, hydrogen, CO2, SF6) are used to provide insulation to various equipment such as circuit breakers, capacitors, CT, PT, cables, GIS, etc.

The required properties of gases for insulation are:

1. High dielectric strength
2. Thermal and chemical stability
3. Non-flammability
4. High thermal conductivity (Aids cooling of conductors)
5. Arc extinguishing ability
6. Commercial availability at moderate cost.
→ Air is the cheapest one widely used for circuit breakers.
→ H₂ has better arc extinguishing property but it has lower dielectric strength than air.
→ That's also an disadvantage → H₂ + O₂ ⇒ explosive mixture.

DIELECTRIC STRENGTHS

\[
\begin{align*}
\text{N}_2 & \approx \text{air} \quad \text{CO}_2 & \approx \text{air} \\
\end{align*}
\]

→ SF₆ is the best for arc extinguishing, but it is toxic. Therefore, electrical industry is looking for alternative solutions such as (SF₆ + N₂) ?

→ SF₆ usage in Turkish language? norsa belge?
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CH 2.3 Breakdown in Liquid Dielectrics

→ Liquid dielectrics are used in transformers, CBs, HV cables, and capacitors.

→ In transformers, liquids dielectrics are used for both insulating the live parts from the grounded parts and cooling the transformer.

→ In Circuit Breakers, they are used for ① Insulating live parts from the grounded parts ② For quenching arc developed between breaker contacts.

→ In HV cables and HV capacitors, for insulation purposes.

→ Liquid dielectrics are mostly made from petroleum oils, others are synthetic hydrocarbons, halogenated hydrocarbons, silicone oils, fluorinated hydrocarbons.

Important Properties of Liquid Dielectrics

1. The dielectric strength
2. The dielectric constant
3. Electrical conductivity
4. Viscosity
5. Thermal stability
The most important factors which affect the dielectric strength of oil are the presence of fine water droplets, and the fibrous impurities.

The presence of 0.01% water in oil brings down the dielectric strength to 20% of the oil.

**Dielectric Properties of Some Oils**

<table>
<thead>
<tr>
<th></th>
<th>Transformer oil</th>
<th>Capacitor oil</th>
<th>Cable oil</th>
<th>Silicone oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakdown strength at 20°C, 2.5mm, 1mm</td>
<td>12 kV/mm</td>
<td>18 kV/mm</td>
<td>25 kV/mm</td>
<td>35 kV/mm</td>
</tr>
<tr>
<td>Resistivity</td>
<td>$10^{12}$ - $10^{13}$ cm</td>
<td>$10^{13}$ - $10^{14}$ cm</td>
<td>$10^{12}$ - $10^{13}$ cm</td>
<td>$2.5 	imes 10^{14}$ cm</td>
</tr>
</tbody>
</table>

**Mechanism of Liquid Breakdown**

There are two approaches:

1. Similar to the breakdown in gases, this approach is based on avalanche ionisation of the atoms caused by electron collision in the applied field. The electrons are assumed to be ejected from the cathode into the liquid by field emission or thermionic effect.
This breakdown mechanism explains breakdown only of highly pure liquid and does not apply to explain the breakdown mechanism in commercially available liquids.

The second approach says that the presence of foreign particles in liquids has a strong effect on insulation.

(a) The suspended particles can get polarized which have higher permittivity than liquid.

These particles experience electrical force directed towards the place of maximum stress. Thus particles get accumulated and tend to form a bridge across the gap which finally leads to breakdown.

(b) Gaseous bubbles in the liquids have lower dielectric strength than liquid and hence on breakdown of bubble the total breakdown of the liquid may be triggered.
Electronic Breakdowns

Once an electron is injected into the liquid, it gains energy from the electric field applied between the electrodes. It is presumed that some electrons will gain more energy due to field than they would lose during collision. These electrons are accelerated under the electric field and would gain sufficient energy to knock out an electron and thus initiate the process of avalanche. The threshold condition for beginning of avalanche is achieved when the energy gained by the electron equals the energy lost during ionisation and is given by:

\[ e\lambda E = C\nu \]

Dielectric Strengths of Some Liquids

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>1.1 MV/cm</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.1 - 1.3 MV/cm</td>
</tr>
<tr>
<td>Oxygen</td>
<td>2.4 MV/cm</td>
</tr>
</tbody>
</table>
Suspended Solid Particle Mechanism

Commercial liquids will always contain solid impurities (fibers, lifted, edge, dispersed solid particles). These particles get polarized in electric field $E$ and experience a force

$$F = r^3 \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + 2\varepsilon_2} E \cdot \frac{dE}{dx}$$

$\varepsilon_1$: permittivity of the solid particle
$\varepsilon_2$: " " the liquid
$E$: electric field
$x$: distance between electrodes
$r$: radius of sphere particles
$x$: distance between electrodes

1. If $\varepsilon_1 > \varepsilon_2 \Rightarrow \text{[Force is directed to higher sample]}
2. If $\varepsilon_1 < \varepsilon_2 \Rightarrow \text{[Force is directed to lower sample]}
3. If $\varepsilon_1 \to \infty$ (very high) $\Rightarrow 0$

$$F = r^3 \frac{\varepsilon_1/\varepsilon_1 - \varepsilon_2/\varepsilon_1}{\varepsilon_1/\varepsilon_1 + 2\varepsilon_2/\varepsilon_1} E \cdot \frac{dE}{dx}$$

$$F = r^3 E \frac{dE}{dx} \Rightarrow \text{The force will tend the particle to move towards the strongest region of the field.}$$
These forces align the particles to form a bridge across the gap. The field in liquid between the gap will increase and if it reaches critical value, breakdown will take place.

Cavity Breakdown:

1. The higher the hydrostatic pressure, the higher the electric strength of liquid.
2. The smaller the head of the liquid, the more are the chances of partially ionized gases coming out of the gap and higher the chances of breakdown.

The following might be responsible for the formation of bubbles in the liquids:

1. Gas pockets on the surface of electrodes.
2. Irregular surface of electrodes can lead to corona discharge, thus vaporizing the liquid.
3. Changes in temperature and pressure.
4. Dissolve of products by electron collision.

The electric field in a gas bubble \( E_b \) in a liquid is given by:

\[ E_b = \frac{3E_o}{E_2 + 2} \]

where:
- \( E_b \): field in the liquid in absence of bubble.
- \( E_o \): field in the liquid.
Bubble breakdown strength is given by:

\[ Eb = \frac{1}{\varepsilon_2 - \varepsilon_1} \left\{ \frac{2\pi \sigma (2\varepsilon_2 + \varepsilon_1)}{r} \left[ \frac{\pi}{4} \sqrt{\frac{V_b}{2\varepsilon_0}} - 1 \right] \right\}^{1/2} \]

- \( \sigma \rightarrow \) Surface tension of the liquid
- \( \varepsilon_2 \rightarrow \) Permittivity of liquid
- \( \varepsilon_1 \rightarrow \) " of bubble
- \( r \rightarrow \) Initial radius of the bubble
- \( V_b \rightarrow \) Voltage drop in the bubble

**Electroconvection** Breakdown:

\( \rightarrow \) When a highly pure insulating liquid is subjected to high voltage, electrical conduction results from charge carriers injected into the liquid from the electrode surface.

\( \rightarrow \) The interaction between this conduction and the electric field can produce eddy motion of liquid.

The speed of eddy motion is:

\[ v_e = \sqrt{\frac{\varepsilon_2}{\rho}} \]

\[ \downarrow \text{Liquid density} \]

\[ \downarrow \text{Permittivity of liquid} \]
In liquids, the ionic drift velocity

\[ \mathbf{v}_d = \mathbf{KE} \rightarrow \text{electric field} \]

mobility of ions

We can define a constant \( \mathbf{M} \) for liquids

\[
\mathbf{M} = \frac{\mathbf{v}_d}{\mathbf{v}_e} \sqrt{\frac{\mathbf{\varepsilon}_2}{\mathbf{P}}/\mathbf{KE}}
\]

- The bigger value of \( \mathbf{M} \), the lower chance of occurring electroconvection breakdown.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Ion</th>
<th>( \mathbf{M} )</th>
<th>( \mathbf{M} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>( \mathbf{cl}^- )</td>
<td>2.5</td>
<td>26.5</td>
</tr>
<tr>
<td>Methanol</td>
<td>( \mathbf{H}^+ )</td>
<td>33.5</td>
<td>4.1</td>
</tr>
<tr>
<td>Nitrobenzene</td>
<td>( \mathbf{Cl}^- )</td>
<td>35.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Transformer oil</td>
<td>( \mathbf{H}^+ )</td>
<td>2.3</td>
<td>20.0</td>
</tr>
</tbody>
</table>

The criterion for instability is that the local flow velocity should be greater than the drift velocity.
Treatment of Transformer Oil

→ The use of oil/paper combination is popular for high voltage insulation.

→ Oil provides a good insulation medium and also be a good disperser of heat.

→ Oil also allows transfer and absorption of water, air and residues created by the ageing of solid insulation (toroidal).

→ Oil therefore should be treated to acquire high degree of purity.

→ All impurities (including solid, liquid or gaseous type) reduce the dielectric strength of oil.

→ The presence of water in paper accelerates the process of ageing.

→ Air dissolved in oil produces a risk of formation bubble and reduces the dielectric strength of oil.