To remove impurities from oil, some methods are:

A. Filtration and Treatment Under Vacuum (Above figure)

B. Centrifugal Method for extracting solid impurities

C. Adsorption Columns: → example → Silica gel to remove moisture

D. Electrostatic Filters: The impurities are charged by electrostatic field
Testing of Transformer Oil:

![Diagram of transformer setup]

- Sphere diameter = 13 mm (made of brass [piling])
- Sphere gap, d = 4 mm

The simplified experimental setup for finding out the dielectric strength of oil sample:

**Steps**

1. The gap distance is adjusted with a gauge.
   (3/4/5/6/7 mm)
2. The voltage is increased gradually till a flashover of the gap is seen. (This voltage is known as "rapidly applied voltage" or "flashover voltage").
3. Bring the voltage to zero voltage and start with 40% of the rapidly applied voltage and wait for 1 minute. See if the gap is broken. If not, increase the voltage every time by ~ 10% of the rapidly applied voltage, and...
(b) Start again with zero voltage and increase the voltage to a value just obtained in the previous step and wait for a minute. A few trials around this point will give us the breakdown value of the dielectric strength.

Today’s standards around 65 kV for 60 kV for 1 minute.

8. $V < 30$ kV → then the oil should be sent to the shop for reconditioning. (yellow)

Application of Oil in Power Apparatus

- Oil is used for providing insulation between live parts of power apparatus.
- Oil provides cooling effect.
- Oil helps to quench the arc in circuit breakers.

END OF BREAKDOWN OF LIQUID DIELECTRICS

Viscosity for
(A) Treatment of Transformer Oil
(B) Recovery of transformer oil
Solid insulating materials are used almost in all electrical equipment to provide insulation of live parts from the equipment and ground.

They also provide mechanical support to the equipment.

When breakdown occurs, the gases regain their dielectric strength very fast.

"""" the liquids regain partially their dielectric strength.

"""" the solid dielectrics lose their dielectric strength completely.

The breakdown of solid dielectrics depends on two factors:

1. Magnitude of voltage
2. Duration of applied voltage.

\[ V_b \times t_b = \text{Constant} \]

(Breakdown voltage) (Time of applied voltage)
Intrinsic Breakdown:

When voltage is applied only for short durations of the order of $10^{-8}$ seconds, the dielectric strength of a solid dielectric decreases very rapidly to an upper level called the intrinsic dielectric strength. Maximum strength usually obtainable ranges from 5-10 MV/cm.

Intrinsic breakdown depends upon the presence of free electrons which capable of migration through the lattice of the dielectric. Usually small numbers of conduction electrons are present with some structural imperfections and small amounts of impurities. The impurity atoms or molecules act as traps for the conduction electrons up to certain ranges of electric fields and temperatures. When these ranges are exceeded, additional electrons and trapped are released and participate in the conduction process.
**Summary of paragraph A**

**Intrinsic Breakdown**

→ Assumed to be electronic in nature that occurs in the order of time $10^{-8}$ sec.

→ Initial density of conduction (free) electrons assumed to be large and electron-electron collisions occur.

→ When electric field is applied, electrons gain energy and cross the forbidden gap from the valency to the conduction band. This process repeated, more and more electrons movable in conduction band, eventually leading to breakdown.

**Electromechanical Breakdowns**

→ When a dielectric material is subjected to an electric field, charges of opposite nature are induced on the two opposite surfaces of material and hence a force of attraction is developed, and the specimen is subjected to electrostatic compressive forces and when these forces exceed the mechanical withstand strength of the material, the material collapses.

![Diagram](image.png)

- Compressive force
- Relative permittivity of solid dielectric
- Compressed thickness of the solid dielectric
- Applied voltage
- Permittivity of free space ($\varepsilon_0 = 8.85 \times 10^{-12}$ F/m)
If we equate the above two equations, we have:

\[ \frac{1}{2} E \varepsilon_r \frac{d^2}{d^2} = \gamma \ln \frac{d_o}{d} \]

\[ \frac{v^2}{d^2} = 2 \frac{\gamma}{E \varepsilon_r} \ln \frac{d_o}{d} = K d^2 \ln \frac{d_o}{d} \]

where \[ K = \frac{2 \gamma}{E \varepsilon_r} \]

Rubber is a material with an extremely low Young's modulus.

Differentiating with respect to \( d \), we have:

\[ 2v \frac{dv}{dd} = K \left[ 2d \frac{\ln d_o}{d} - d^2 \frac{d^2}{d^2} \frac{d_o}{d^2} \right] = 0 \]

\[ 2d \ln \frac{d_o}{d} = d \]

\[ \ln \frac{d_o}{d} = \frac{1}{2} \]

\[ \frac{d}{d_o} = 0.6 \]

\[ d_o = 0.6d \]
Comment of $d = 0.6d_0$.  For any voltage $V$, the reduction in thickness of the specimen cannot be more than 40%.

The highest strength is then obtained by substituting $d = 0.6d_0$ in the above equations:

$$S_{ma} = \sqrt{\frac{V^2}{d^2} \frac{2\varepsilon}{\varepsilon_0} \ln \frac{d_0}{d}}$$

$$\frac{V}{d_0} = 1.67$$

$$V = d \sqrt{\frac{2\varepsilon}{\varepsilon_0} \ln 1.67}$$

Or

$$\frac{V}{d} = \sqrt{\frac{2\varepsilon}{\varepsilon_0} \ln 1.67}$$

Or

$$\frac{V}{0.6d_0} = 0.6 \sqrt{\frac{2\varepsilon}{\varepsilon_0} \ln 1.67}$$

The possible electric field for breakdown of solid dielectrics.

$$E_a = \frac{V}{d_0} \text{ then }$$

$$E_a = 0.6 \sqrt{\frac{2\varepsilon}{\varepsilon_0} \ln 1.67}$$
Breakdown due to Treeing and Tracking. $pdf = 66.$
Breakdown due to Trapping and Tracking

- Whenever a solid material has some impurities (gas pockets, liquid pockets), the dielectric strength of the solid will be reduced.
- Gas pockets can be trapped in the solid material during manufacture.

\[ E_s \approx \frac{E_{gas}}{\varepsilon_r} \]

\[ \varepsilon_r \gg E_{gas} \implies E_s \gg E_{gas} \]

**Why?**
- The charge concentration in the gas pocket is too large which makes the field non-uniform.
- Breakdown is caused by a tree-like structure as shown below.

Experiment for perspex sheet plastik.
Thermal Breakdown:

When an insulating material is subjected to an electric field, the material gets heated up due to conduction and dielectric losses. The conductivity of the material increases with increase in temperature and a condition of instability is reached when the heat generated exceeds the heat dissipated by the material.

Breakdown:

Heat generated > heat dissipated in the solid material.

Heat dissipated > work or heat because of electric field.

Because of electric field, thermal instability at different electric field.

\[ \text{E}_3 > \text{E}_2 > \text{E}_1 \]

Heat generated:

\[ \text{E}_3 \]

\[ \text{E}_2 \]

\[ \text{E}_1 \]

Temperature:

To
\[ W_{dc} = E^2 \sigma (\text{m}^{-3}) \]

- dc conductivity of solid material
- applied dc electric field.

\[ W_{ac} = \frac{E^2 f \varepsilon_r \tan \delta}{1.8 \times 10^{12}} \text{ W/cm}^3 \]

- frequency (Hz)
- \( \varepsilon_r \): Relative permittivity of solid.
- \( \tan \delta \): tangent of loss angle of dielectric material.

\[ W_T = C_v \frac{dT}{dt} + K \frac{d}{dx} \left( \frac{dT}{dx} \right) \text{ W/cm}^3 \]

- Specific heat of solid material
- Thermal conductivity of solid material
- Distance for heat flow through solid material
- Time over which heat is dissipated.

Thermal breakdown voltage

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum Thermal Voltage in kV/cm</th>
<th>dc</th>
<th>ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceramic porcelain</td>
<td>2.4</td>
<td>-</td>
<td>9.8</td>
</tr>
<tr>
<td>Ebonite (lacquer, shellac)</td>
<td>1.45 - 2.75</td>
<td>-</td>
<td>2.8</td>
</tr>
<tr>
<td>Polythene (polyethylene)</td>
<td>3.5</td>
<td>-</td>
<td>7 - 18</td>
</tr>
<tr>
<td></td>
<td>(plastikposthen)</td>
<td></td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>mineral rock salt</td>
<td></td>
<td>1.4</td>
</tr>
</tbody>
</table>
Important Notes

1. Thermal breakdown sets up an upper-limit for increasing the breakdown voltage when the thickness of
insulation is increased.

2. Heat generated is proportional to the frequency and hence thermal breakdown is more severe at high frequency.

3. Thermal breakdown stress (MV/cm) are lower under ac condition than dc.

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Electro Chemical Breakdown

At artificially formed anode and cathode, 
Chemical degradation occurs (including ozone) due to electrons colliding with anode and positive ions bombarding the cathode.

This chemical degradation causes a slow erosion of the material and consequent reduction in the thickness of the material.

\[ t \cdot E_b^n = \text{constant} \]

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For chemical field

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