→ Corona discharge is important in high voltage engineering where most of the fields encountered are non-uniform fields. 55

→ 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 ~~2Hz - 20kHz~~

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

→ Corona event produces a noise and ozone gas.

mainly depen...

Breakdown in Electronegative Gases:

SF_6 (sulfur hexafluoride) has excellent insulating strength because of its affinity (cazibe, çekim) 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 attach.

$$\begin{cases} SF_6 + e \rightarrow SF_6^- \\ SF_6 + e \rightarrow SF_5^- + F \end{cases}$$

(57) (88)

→ The dielectric strength of SF6 at normal pressure and temperature is 2-3 times that of air

(D.S of SF6)
→ At 2 atm pressure, it is comparable with transformer oil.

→ SF6 is vapour, it can be liquified at high pressure to be stored in steel cylinders.

Application of Gases in Power Systems

electronegative gas

→ Some gases (air, oxygen, nitrogen, hydrogen, CO_2, SF6) are used to provide insulation to various HV equipment such as circuit breakers, ~~[illegible]~~, GIS (gas insulated switchgear), capacitors, CT, PT, cables

→ The required properties of gases for insulation

1. High dielectric strength
2. Thermal and chemical stability
3. Non-inflammability
4. High thermal conductivity (Aids cooling of conductors)
5. Arc extinguishing ability
6. Commercial availability at moderate cost.

58

→ Air is the cheapest one widely used for circuit breakes.

→ H_2 has better arc extinguishing property but it has lower dielectric strength than air.

→ That's also an disadvantage → $H_2 + O_2 \Rightarrow$ explosive mixture.

(dielectric strengths)

→ $\boxed{N_2 \approx air}$, $\boxed{CO_2 \approx air}$

→ SF6 is the best for arc extinguishing, but it is toxic. Therefore electrical industry is looking for alternative solutions such as (SF6 + N_2)?
%70 + %30

→ SF6 Türkiyede kullanımı yasaklandı mı? varsa Belge?

CH2: Breakdown in Liquid Dielectrics (59) (24)

→ 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 (extinguish) arc developed between breaker contacts.

→ In HV cables and HV capacitors, they are used for insulating 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 pure oil.

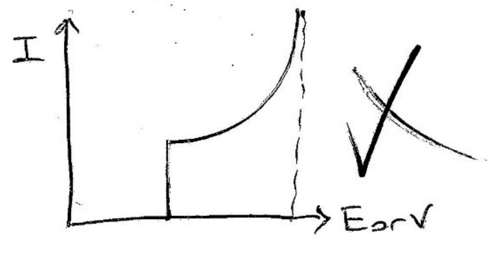
Dielectric Properties of some ~~liquids~~ oils

	Transformer oil	Capacitor oil	Cable oil	Silicone oil
Breakdown strength at $20^{\circ}C$, 2.5mm, 1 min.	12 kV/mm	18 kV/mm	25 kV/mm	35 kV/mm
Resistivity	$10^{12}-10^{13}$ Ω cm	$10^{13}-10^{14}$ Ω cm	$10^{12}-10^{13}$ Ω cm	2.5×10^{14} Ω cm

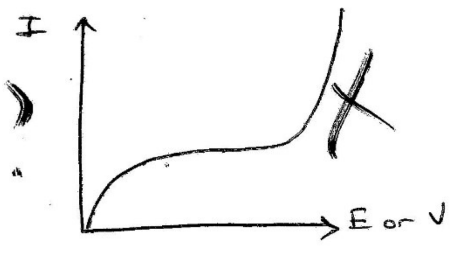
- Mechanism of Liquid Breakdown

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 cathode into the liquid by field emission or thermionic effect.



(a) For High Fields



(b) For Low Fields

This breakdown mechanism explains breakdown only of highly pure liquid and does not apply to explain the breakdown mechanism in commercially available liquids.

(2) 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 break down of bubble the total breakdown of the liquid may be triggered.

Electronic Breakdown:

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:

$$\boxed{\underbrace{e}_{\text{electron charge}}\ \underbrace{\lambda}_{\text{mean free path}}\ \underbrace{E}_{\text{electric field}} = \underbrace{C}_{\text{constant}}\ \underbrace{h\nu}_{\text{ionisation energy}}}$$

Dielectric Strengths of Some Liquids

Liquid	Strength
Benzene	1.1 MV/cm
Nitrogen	1.1 – 1.3 MV/cm
Oxygen	2.4 MV/cm

Suspended Solid Particle Mechanism:

Commercial liquids will always contain solid impurities (fibers (lif, tel, elyaf), dispersed solid particles)

These particles get polarized in electric field E and experience a force

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

ε_1 : permittivity of the solid particle

ε_2 : " " the liquid

E : electric field.

x : distance between electrodes. → assumption

r : Radius of sphere particles

- If $\varepsilon_1 > \varepsilon_2 \Rightarrow F > 0$, [Force is directed to higher stress]
- If $\varepsilon_1 < \varepsilon_2 \Rightarrow F < 0$ { Force is directed to lower stress.
- If $\varepsilon_1 \to \infty$ (very high)

$$F = r^3 \frac{\varepsilon_1/\varepsilon_1 - \underbrace{\cancel{\varepsilon_2/\varepsilon_1}}_{\to 0}}{\varepsilon_1/\varepsilon_1 + \underbrace{2\cancel{\varepsilon_2/\varepsilon_1}}_{\to 0}} E \cdot \frac{dE}{dx}$$

$$\boxed{F = r^3 E \frac{dE}{dx}}$$

→ 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:

→ The higher the hydrostatic pressure, the higher the electric strength of liquid.

→ 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 followings 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 vapourizing the liquid.
3. Changes in temperature and pressure.
4. Dissolve of products by electron collision.

The electric field in a gas bubble in a liquid:

$$\boxed{E_b = \frac{3E_0}{\varepsilon_2 + 2}}$$

E_0: field in the liquid in absence of bubble.

ε_2 → permittivity of liquid.

Electroconvection and Ionic Drift in Dielectric Liquids

Eddy Velocity and the Liquid Material Constant M

Lecture Note

1 Motivation

When a dielectric liquid is subjected to a strong electric field, two competing transport mechanisms occur simultaneously:

(i) **Ionic conduction**: free ions in the liquid drift under the direct force of the electric field.

(ii) **Electroconvection (eddy motion)**: the interaction between the conduction current and the electric field can produce bulk fluid motion — circulating eddies within the liquid, analogous to the way a magnetic field drives motion in a conducting plasma (the electrohydrodynamic analogue of the MHD Alfvén speed).

Both effects are field-driven, but they scale differently with the applied field E. This note derives the eddy velocity and the ionic drift velocity, and combines them into a single material constant M that characterizes the liquid independently of the applied voltage.

2 Ionic Drift Velocity

The ionic drift velocity is proportional to the applied field:

$$V_d = KE$$

where:

- K = mobility of ions in the liquid,
- E = applied electric field.

This relation is the liquid analogue of Ohmic drift: the ions simply move at a speed proportional to the local field, scaled by how mobile they are in that medium.

3 Eddy Motion (Electroconvection) Velocity

The eddy motion speed is given by:

$$V_e = E\sqrt{\varepsilon_2/\rho}$$

where:

- E = electric field,
- ε_2 = permittivity of the liquid,
- ρ = liquid density.

This form is structurally identical to the Alfvén speed $V_A = B/\sqrt{\mu\rho}$ in magnetohydrodynamics — here the electric field and permittivity play the role that the magnetic field and permeability play in MHD.

4 Defining a Field-Independent Material Constant M

The physical goal is to define a constant M that characterizes *only* the liquid (through K, ε_2, ρ), independent of how strong a field is applied.

Taking the ratio of the two velocities:

$$M \equiv \frac{V_d}{V_e} = \frac{KE}{E\sqrt{\varepsilon_2/\rho}}$$

The field E cancels exactly, leaving:

$$\boxed{M = K\sqrt{\frac{\rho}{\varepsilon_2}}}$$

M depends only on the intrinsic properties of the liquid: ion mobility K, density ρ, and permittivity ε_2.

5 Physical Interpretation

M represents the ratio of ionic drift transport to electroconvective (eddy) transport, independent of the applied field strength.

- A **high** M means ionic mobility dominates over the electroconvective response — charge is carried mainly by ion drift.
- A **low** M means the eddy (bulk fluid) motion becomes comparatively more significant relative to ionic drift.

6 Summary

Quantity	**Expression**
Ionic drift velocity	$V_d = KE$
Eddy velocity	$V_e = E\sqrt{\varepsilon_2/\rho}$
Material constant	$M = K\sqrt{\rho/\varepsilon_2}$

The bigger value of M, the ~~higher~~ lower chance of occuring electro ~~convection~~ breakdown.

Table

Liq. type	Ion	ε	M
Ethanol	Cl^-	2.5	26.5
methonal	H^+	33.5	4.1
Nitro benzene	Cl^-	35.5	22
Transformer oil	H^+	2.3	200

→ 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.
(torda, artik)

→ 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.