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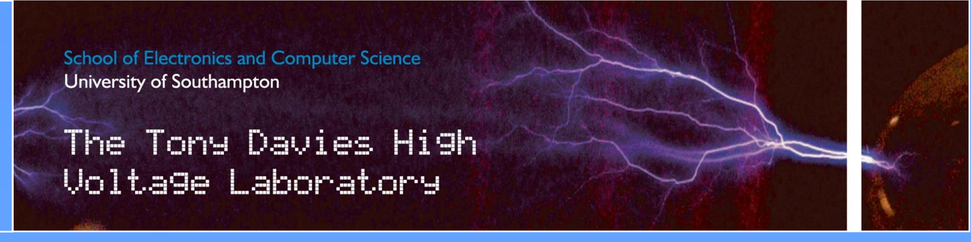

Mathematical Modelling on Bridge Formation in Contaminated Transformer Oil

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Introduction

Oil is an essential insulating and cooling medium used in a vast range of high voltage equipment from cables to transformers and switchgears. Analysis on power transformer failures has revealed that insulation/oil contamination is a major factor, accounting for nearly 30% of the total failures. As a result there is a great deal of research interest in understanding the composition, insulating performance, ageing processes and breakdown mechanisms in such oils. In the present project we are focussing on the effect of particle contamination of transformer oil on electrical performance of the power transformer using mathematical modelling. COMSOL Multiphysics simulation software package is used for the initial mathematical model development.

Expression for Delectrophoretic Force on Fibre Particle

The model is based on the current knowledge of dielectrophoresis (DEP) whereby a neutral body placed in an electric field becomes polarized and is equivalent to an electric dipole with an excess of positive charge on one end and negative charge on the other. The forces acting on the two ends do not balance in non-uniform electric field region and the particle moves. Our initial model is based on fibrous particles using velocity equation presented below,

$$v_{\mathrm{P}} = \begin{cases} 0, & \&c \geq \mathrm{c_{crit}} \\ \lim_{\beta\to\infty} \dfrac{K_m \varepsilon_0}{24\eta} L^2 \dfrac{\ln 2\beta - 0.5}{\ln 2\beta - 1} \nabla E^2 * \left(1 - \left(\dfrac{\mathrm{c}}{\mathrm{c_{crit}}}\right)^4\right), & \&c < \mathrm{c_{crit}} \end{cases}$$

Where, v_{P} = Velocity of fibre, L = Length of fibre, D = Diameter of fibre, β = aspect ratio $\frac{L}{D}$, K_f = Dielectric constant of fibre, K_m = Dielectric constant of oil, η = Viscosity of oil, ε_0 = Permittivity of vacuum, ∇E = Electric field, c = Initial concentration, $\mathrm{c_{crit}}$ = Critical concentration

Experimental Results

Two spherical electrodes of 10mm diameter placed in a glass build tank submerged in mineral oil. One connected to power supply of 20kV and the other connected to ground via a picoammeter to measure the current. Three different level of pressboard fibre concentration by mass used in this experiment along with three different voltage level.

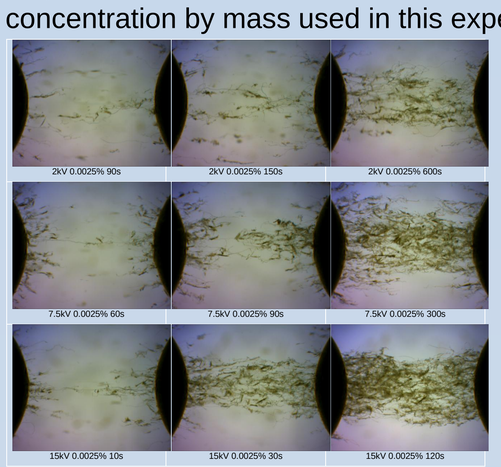
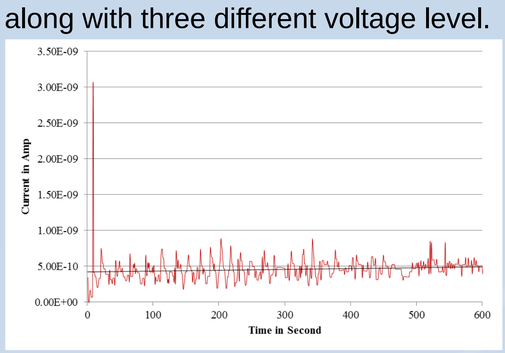


Figure 1: Bridge formation at Low level of concentration 0.0025%



Graph 1: Current at 2kV with 0.0025% concentration

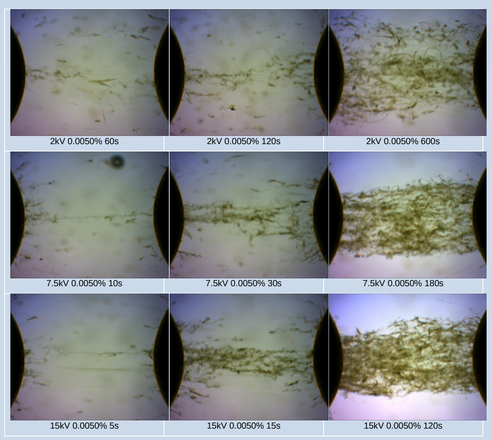
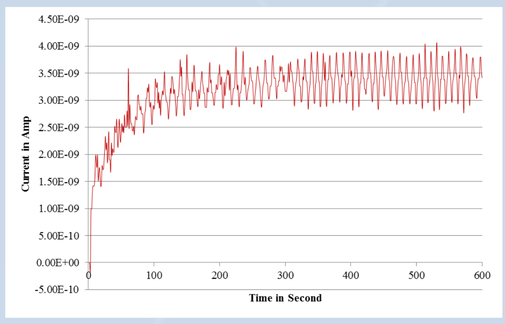


Figure 2: Bridge formation at Medium level of concentration 0.005%



Graph 2: Current at 7.5kV with 0.0050% concentration

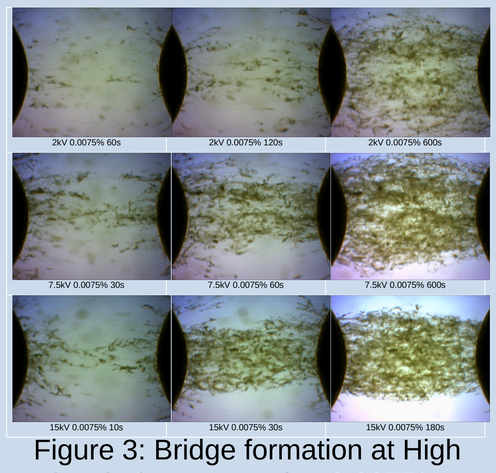
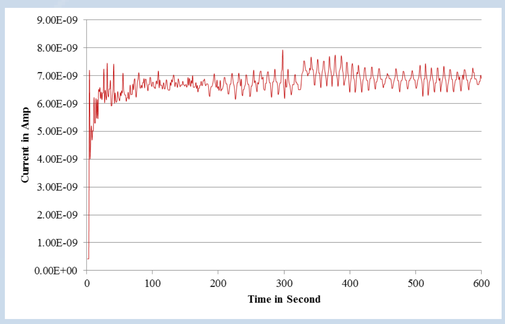


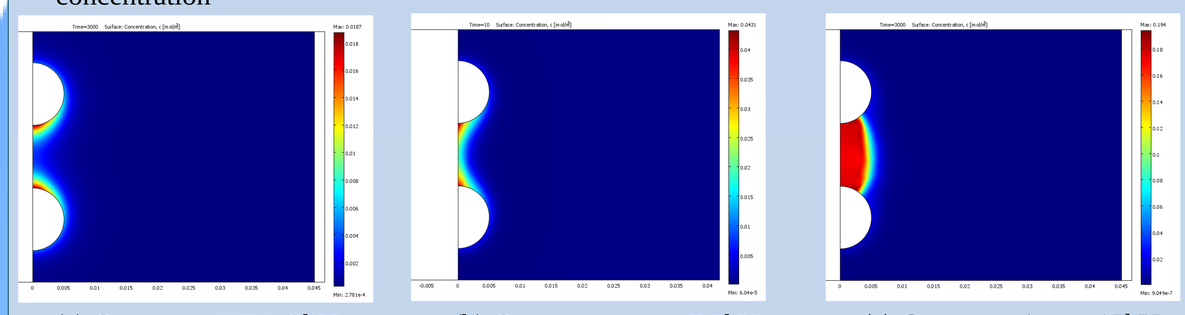
Figure 3: Bridge formation at High level of concentration 0.0075%



Graph 3: Current at 15kV with 0.0075% concentration

Simulation Results

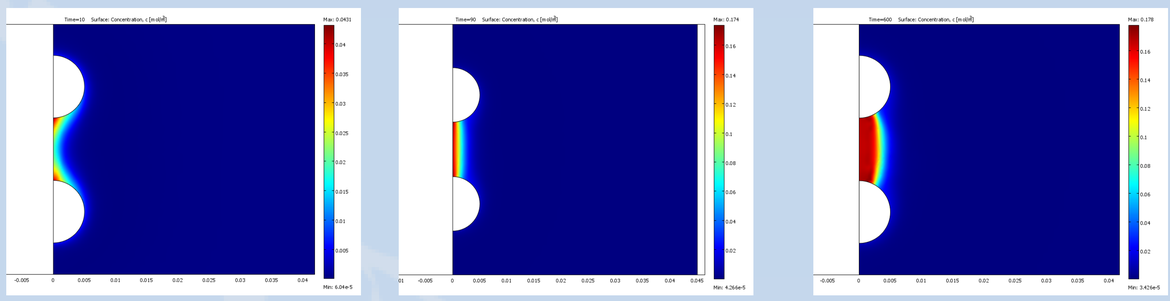
- The influence of DC voltages on Concentration of particles investigated at fixed initial concentration



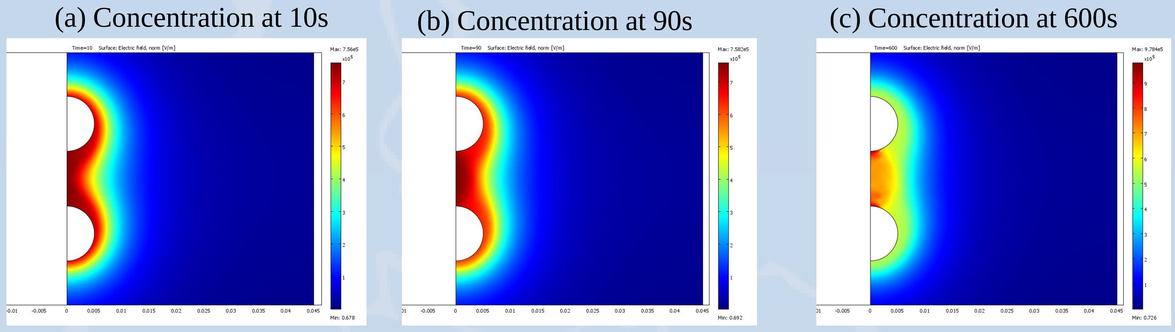
(a) Concentration at 2kV (b) Concentration at 7.5kV (c) Concentration at 15kV

Figure 4: The particle concentration between the electrodes gradually increased with the applied voltage.

- The evolution of particle concentration and electric field investigated at different time with fixed initial concentration at 7.5 kV

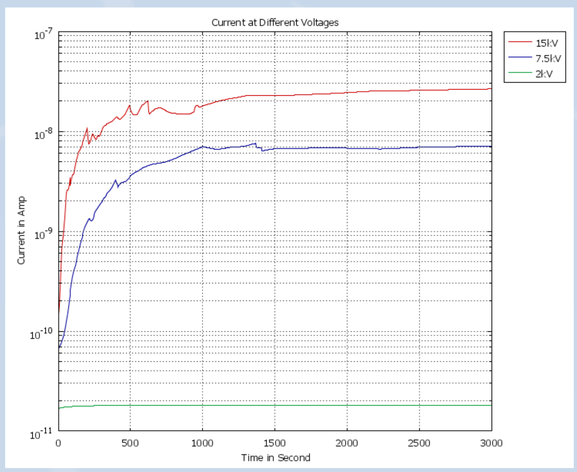


(a) Concentration at 10s (b) Concentration at 90s (c) Concentration at 600s

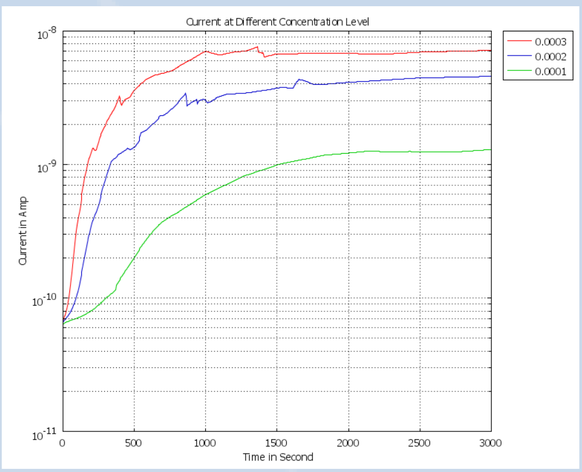


(a) Electric field norm at 10s (b) Electric field norm at 10s (c) Electric field norm at 10s

Figure 5: The particle concentration slowly increased over time but the electric field decreased.



Graph 4: Current through the bridge at different voltages



Graph 5: Current through the bridge at different level of initial concentration

Discussions

On comparison with the experimental data, the model is a successful means of predicting bridge formation rate. The electric current does not match with that observed in the experiment as the contamination level used in experiment is by weight rather than volume as for simulation. Furthermore, the simulation model is based on several assumptions of unknown variables in our initial attempt. The rate of change in terms of current increase is similar to the experiment. Continual improvements to the model will allow us to make more accurate predictions regarding the current.

Conclusions

- The initial simulation model demonstrated the phenomenon of the bridge formation in pressboard fibre contaminated transformer oil.
- The COMSOL model successfully illustrated the process of particle concentration at different time and contamination level which are identical to the experimental results.
- The conduction currents from the simulation are not quantifiable with the experiments. This is due to many unknown variables and assumptions made for the model.

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