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Direct Numerical Simulation of Water Behavior in Sealing Gaps of High-Voltage Inverters Including Evaporation Effect

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Extended Abstract

High-voltage inverters with high power density and effective switches are continuing to attract attention due to the automotive industry's move towards vehicle electrification. The vulnerability of high-voltage inverters to fluid penetration results in strict requirements to prevent leaks and gaps. To create a deeper understanding and ensure more reliable product designs in terms of sealing efficiency, 3D transient multiphase flow simulations can provide a better insight. In this study, they are conducted with the geometrical Volume-of-Fluid (VoF) method in OpenFOAM. Surface tension, wetting, and phase change effects are taken into account to complete the physical description of the flow regime surrounding housing joints with artificial weak spots. Special attention is paid to account for industrial relevant complex geometries, their dimensions and fluid wetting characteristics.

While continuous progress in unstructured VoF methods (see [1] for a recent review) is made, capillary flows in small-scale regimes for low Reynolds numbers still pose considerable challenges for the accurate numerical solution, especially with increasing geometrical complexity.

Adding phase change phenomena to this regime with vapor being considered as a diluted specie in air, multiple physical effects need to be captured correctly, hence, validation and verification are highly prioritized.

Simulation credibility is supported by academic comparisons from literature, as well as an in-house test stand. In the test stand microchannels with different geometry (width × depth = 0.554mm × 0.406mm) are formed between hydrophilic (PMMA $\theta_1 = 80°$) and hydrophobic (TPU $\theta_2 = 104°$) substrates to cover common circumstances in industrial applications. As working fluid, de-ionized water and 50 wt% Glycerin/water mixture are used, which is pumped into the channel by a syringe pump with defined volumetric flow rate. The experimental setup allows a visual access to the temporal progression of interface displacement as well as a quantitative link between capillary number *Ca* and dynamic contact angle, which can be further confirmed by the Molecular Kinetic Theory (MKT) with physically reasonable parameters. The academic comparisons comprise of dynamic wetting cases [2][3], as well as film and droplet evaporation and condensation.

Based on the validation results, complex geometries as present along component joints and sealings are numerically investigated regarding fluid penetration and accumulation. Of special interest is the penetration volume and depth of ambient fluid and its retention over time, since fluid might evaporate and then condensate in disadvantageous structure spots, causing unexpected damage to electronics. For this purpose, different wetting properties, operating points and geometrical aspects are investigated and their outcome is presented in this talk.

The present findings extent the current understanding of reliability topic in high-voltage inverters regarding sealing performance. In the future, they shall provide a basis for improved housing designs on product level including corrosion resistance, thermal management, and compact structure.

References

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