Enhanced Dielectric Breakdown Strength of Cryogenic Gas Mixtures to be Used in Superconducting Power Devices

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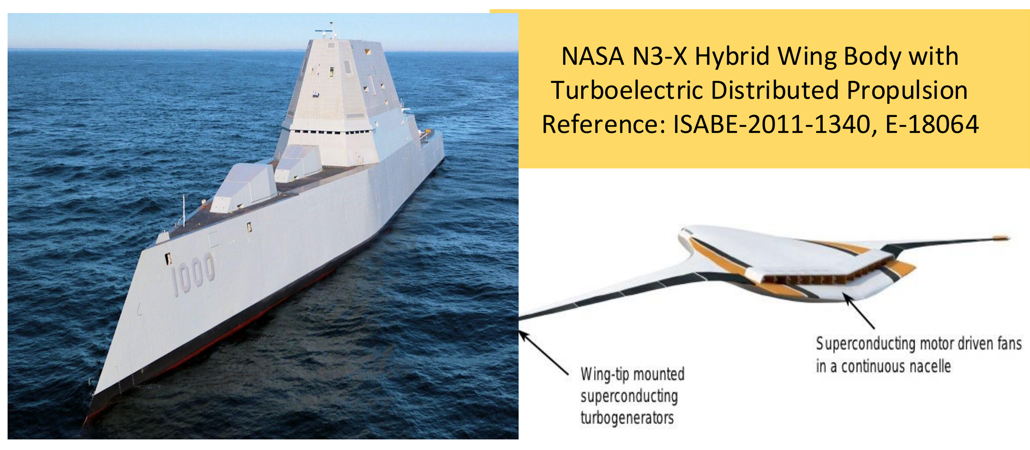
Introduction and Objectives

- Gaseous helium (GHe) is the preferred cryogen by the US Navy for superconducting devices
- GHe allows lower operating temperature than allowed by liquid nitrogen (LN2) with reduced risk of asphyxiation
- Critical current (Ic) of high temperature superconducting (HTS) cables increases significantly at lower temperatures – Ic at 67 K is twice as much as it is at 77 K
- The dielectric strength of GHe is currently limiting GHe cooled superconducting devices to low-medium voltage applications
- We have shown that addition of small mol% of H_2 and/or N_2 to GHe improves dielectric strength significantly without safety concerns
- Investigations have been undertaken to develop a GHe cooled superconducting cable suitable for 12 kV DC for US Navy all-electric ship applications

Constraints of Gas Mixtures

- While the addition of N_2 and H_2 allows for superior dielectric properties to be observed there is a limitation on the maximum mol%
- For H_2 the limiting factor it the flammability risk.
- Therefore for safety purposes a maximum of 4 mol% hydrogen was selected
- Additional studies are being undertaken to determine the maximum H_2 mol% which can be included without any safety concerns
- For N_2 the limiting factor is condensation of the gas. The condensation temperature of nitrogen is dependent on gas pressure and N_2 mol%
- 8 mol% N_2 was selected to allow for measurements to be completed at 1 MPa at 77 K

Applications



- GHe cooled HTS Technology provides high power density, lightweight and compact solutions
- HTS technology is useful in naval, aerospace and many other applications where high power density and efficiency are demanded

Conclusion

- The versatile model provides a method of estimating the breakdown voltage of binary and ternary gas mixtures at room and cryogenic temperatures
- The experiments demonstrate the possibility of developing a GHe based mixture with equivalent dielectric properties to liquid nitrogen
- Further research is still required in developing an optimized GHe mixture with regards to N_2 and H_2 mol%

Acknowledgements

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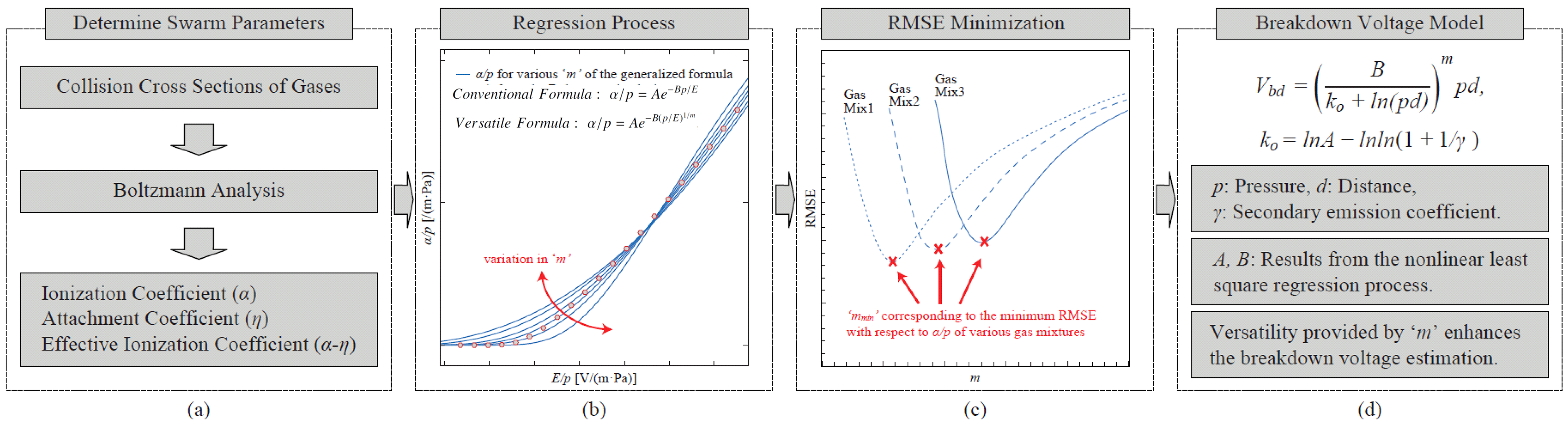
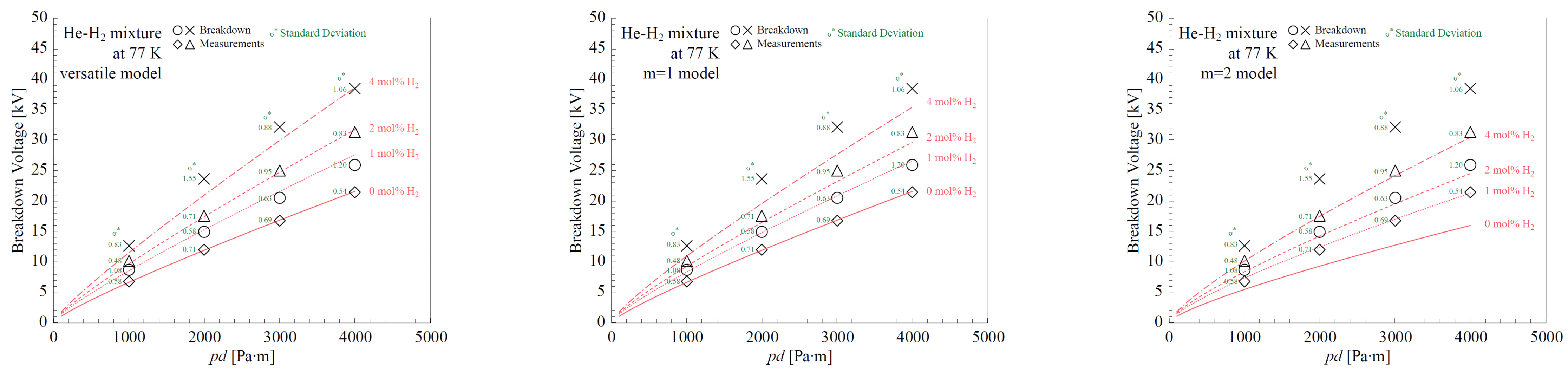
Versatile Model for Estimating Breakdown Voltage

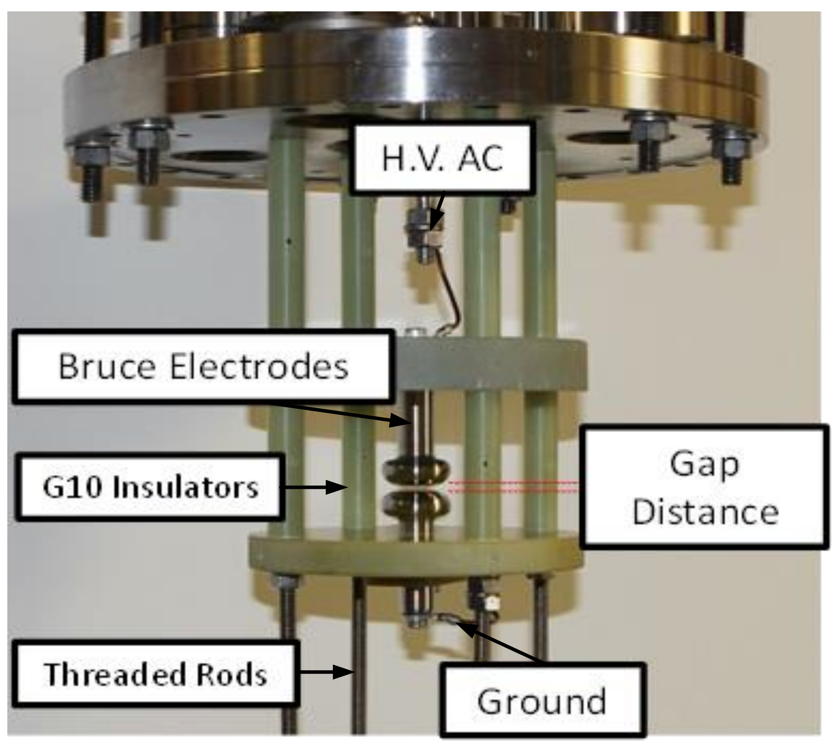


- Boltzmann analysis is conducted to generate the ionization coefficient (a)
- The proposed model incorporates a **generalization factor *m*** into the formula of α/p: Townsend's first ionization coefficient, which **increases the accuracy** in the regression process (b)
- **Identify *m*** that corresponds to the minimum regression error (c)
- Apply Townsend's breakdown criterion to derive the **versatile breakdown voltage model** (d)

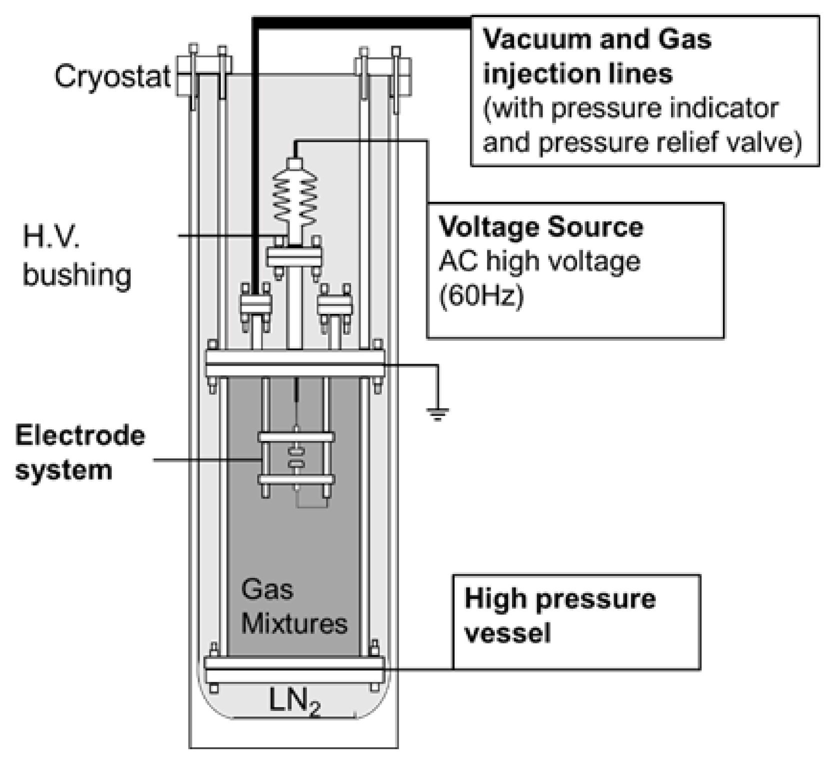


- Estimations from various models were compared with the experimental measurements
- The **proposed versatile model** leads to **the closest agreement** with the experimental values
- The estimation **accuracy is maintained throughout the varying gas compositions** (i.e., 0-4 mol% H_2 balanced with GHe)

Experimental Setup

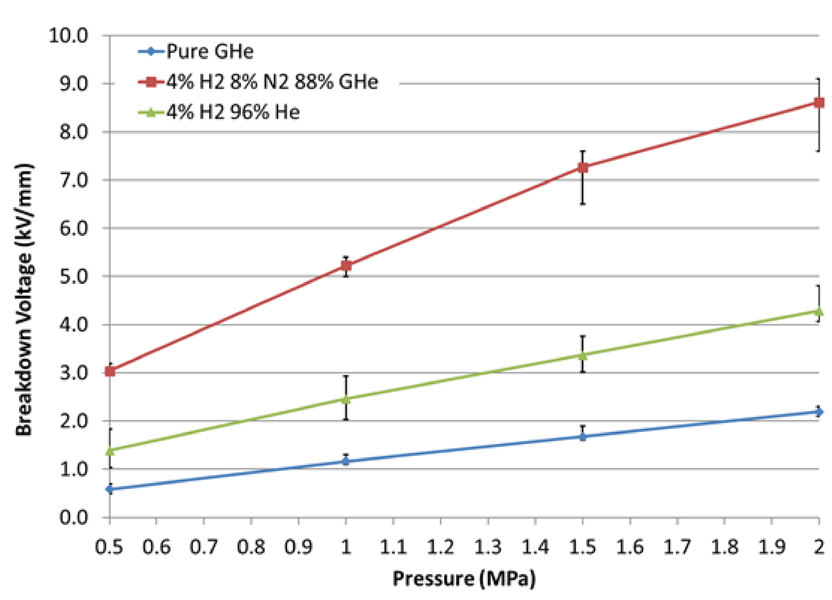


- 25 mm uniform electric field electrodes with fixed gap distance
- Multiple flushing and pumping cycles to obtain a pure environment
- 15 AC and DC breakdown measurements performed at pressures between 0.5-2.0 MPa at room temperature and 77 K
- Constant ramp rate used to obtain consistent results

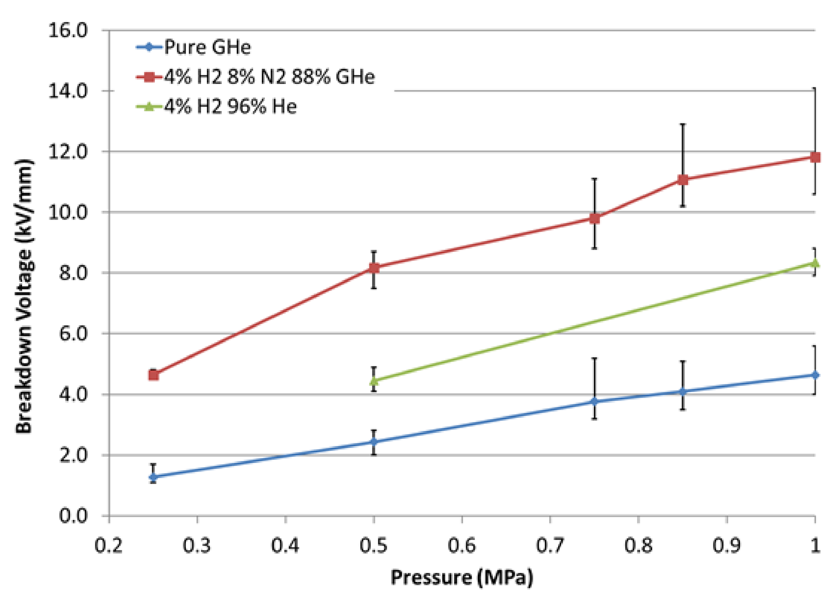


Dielectric Properties of Binary and Ternary Helium Gas Mixtures

AC (RMS) breakdown at 295 K

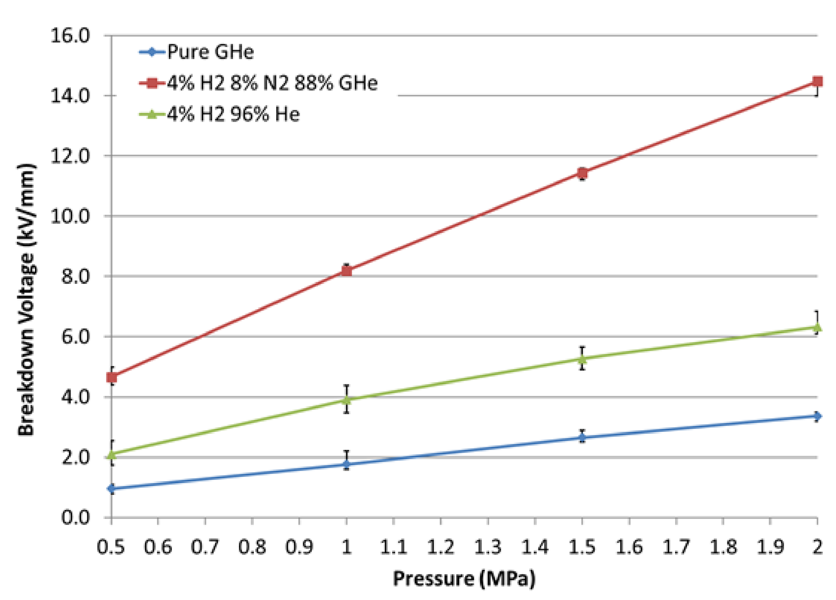


AC (RMS) breakdown at 77 K



- The dielectric strengths of a **binary mixture** containing 4 mol% H_2 balanced with GHe and **ternary mixture** containing 4 mol% H_2, 8 mol% N_2 balanced with GHe were measured
- The dielectric strength of GHe has been significantly improved with the introduction of small mol% of H_2 and/or N_2
- DC breakdown strengths are higher than the AC (RMS) breakdown by ~ 1.4 times
- Room temperature measurements ensured condensation of N_2 did not occur for ternary mixtures
- Experimental data suggests condensation of N_2 occurred at 1.0 MPa at 77 K for the ternary mixtures

DC breakdown at 295 K



DC breakdown at 77 K