



Project 089 Characterization of Compositional Effects on the Dielectric Constant

University of Dayton Research Institute

Project Lead Investigator

Zachary West, PhD
Principal Research Engineer
Group Leader, Fuel Science
University of Dayton
300 College Park
Dayton, OH 45458
937-255-4062
zachary.west@udri.udayton.edu

University Participants

University of Dayton Research Institute (UDRI)

- P.I.: Zachary West, PhD
- FAA Award Number: 13-C-AJFE-UD, Amendment 056
- Period of Performance: January 1, 2025, to December 31, 2025
- Task:
 1. Measurement of dielectric constant and density

Project Funding Level

Amendment	Funding
Amendment No. 47	\$499,999.67
Amendment No. 53	\$110,607.00
Total	\$610,606.67

Investigation Team

Dr. Zachary West (P.I.)
Shane Kosir (Staff Scientist)
Dr. William H. Steinecker (Staff Scientist)
Taylor Nicely (Undergraduate Student)
CJ Nesbit (Undergraduate Student)

Project Overview

Aircraft fuel tanks use capacitive gauges to determine fuel capacities during flight. Two crucial fuel properties, the dielectric constant and density, are used to calculate fuel volume from the response determined from the concentric, cylindrical gauging sensors. In recent years, the airframe original equipment manufacturers (OEM) have closely monitored the behavior of the dielectric constant (also referred to as relative permittivity) of candidate synthetic aviation turbine fuels (SATF), sometimes referred to as sustainable aviation fuels (SAF), because small changes in this property can result in atypical fuel tank gauging. This project involves measuring the behavior of fuel dielectric constants over a range of temperatures and fuel blends, by using a new dielectric constant instrument. While previous efforts (Kosir et al., 2024) focused on bulk hydrocarbon composition effects on dielectric constant, the current effort focuses primarily on the effects of trace polar species, including additives and incidental materials.



Task 1 – Measurement of Dielectric Constant and Density

University of Dayton Research Institute

Objective

The objective of this effort is to study the effect of trace polar species on jet fuel dielectric constant. An additional focus is the development of a dielectric constant blending rule that can be used by fuel producers, researchers, and other interested parties. This effort extends on previous work that focused on the effects of bulk composition on jet fuel dielectric constant.

Research Approach

The approach of this program is to measure the behavior of fuel dielectric constants over a range of temperatures and fuel blends, by using the Stanhope-Seta® JetDC instrument. UDRI purchased and commissioned the JetDC, which meets the requirements of specification IP 638: *Determination of relative permittivity (dielectric constant) of aviation fuels, small scale automated temperature scanning method* (Energy Institute, 2023). Previously, measurements were taken for conventional petroleum-based jet fuels and SATFs conforming to ASTM D7566 (ASTM International, 2022), reflecting a range of bulk hydrocarbon compositions. A major finding was that the bulk hydrocarbon composition influenced the dielectric constant, with the Clausius-Mossotti (CM) slope (historically used by airframe OEMs for fuel gauging) varying significantly with aromatic content (Kosir et al., 2024). This effort builds on the previous effort by focusing on additives and impurities common in jet fuel. Three approved additives were studied: fuel system icing inhibitor (FSII), corrosion inhibitor/lubricity improver (CI/LI), and static dissipator additive (SDA). The allowable concentration ranges for CI/LI, FSII, and SDA per ASTM D1655 (ASTM International, 2024) are 0.07 to 0.15 vol%, 0 to 23 mg/L, and 0 to 5 mg/L (after field reblending), respectively. A preliminary attempt was also made to study the effect of water contamination on jet fuel dielectric constant. Water concentration was measured using a Mettler Toledo® C30S Karl Fischer coulometer following the ASTM D6304 (ASTM International, 2025). Dielectric constant data for polar species from this effort, as well as bulk hydrocarbon data from the previous effort, are being compiled to validate a volume fraction dielectric constant blending rule. Future efforts will investigate dielectric constant models trained using linear solvation energy relationships (LSERs) as inputs to provide a deeper understanding of what governs the dielectric constant.

Research Results and Discussion

Figure 1 shows dielectric constant at 20°C versus FSII concentration for FSII in Jet A (POSF 10325, left), FSII in *n*-heptane (middle), and FSII in toluene (right). *n*-heptane and toluene were selected as representative solvents representing the paraffinic and aromatic extremes of jet fuel. The repeatability from IP 638 (Energy Institute, 2023) is indicated as error bars, which was relatively small for all three blends compared to the measured dielectric constant values. Linear regression of dielectric constant versus FSII concentration produced R^2 values >0.99 for all three blends, indicating that the effect on dielectric constant is linear with volume at the FSII concentrations studied. The dielectric constant increased by 0.5% for all three blends at the maximum allowable FSII concentration of 0.15 vol% compared to the neat fuels/solvents. This increase will be discussed in the next paragraph.

® Seta is a registered trademark of Stanhope-Seta Limited, United Kingdom.

® Mettler Toledo is a registered trademark of Mettler-Toledo GMBH, Greifensee, Germany.

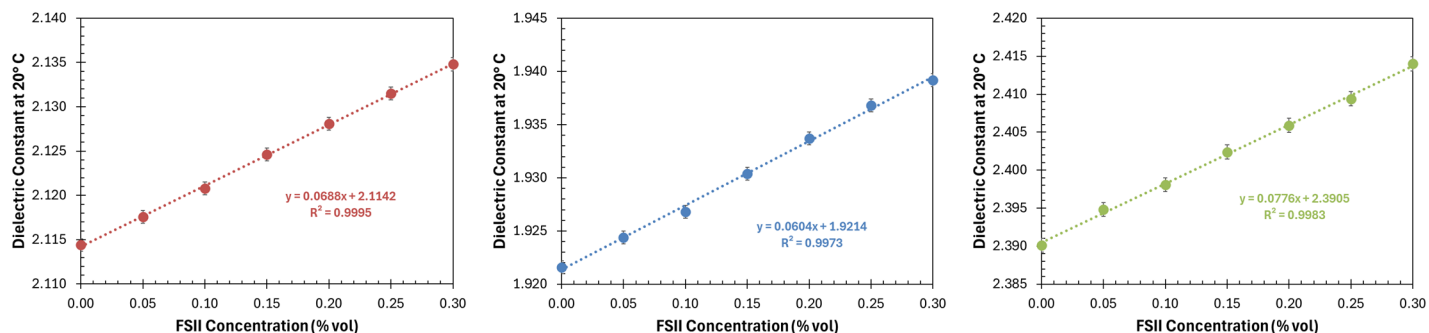


Figure 1. Dielectric constant at 20°C vs. fuel system icing inhibitor (FSII) concentration for FSII in Jet A (left), FSII in *n*-heptane (middle), and FSII in toluene (right).

Figure 2 shows the FSII results plotted over conventional fuel distributions from Aeronautical Radio, Inc. (ARINC) Report 611-1 (Aeronautical Radio, Inc., 1999), Coordinating Research Council (CRC) Report 647 (Hadaller & Johnson, 2006), and AV-33-22 (Kosir et al., 2025). These plots were made to contextualize the effects of FSII relative to bulk hydrocarbon composition. To calculate the CM slope and intercept, CM plots of the form $(K - 1)/\rho$ versus $(K - 1)$ were constructed for Jet A fuel, *n*-heptane, and toluene over a temperature range of 0-40°C. Linear regression was then done to generate the CM slope and intercept, which capture the effect of temperature on the dielectric constant and density in tandem. The CM slope has been shown to provide meaningful distinction between aromatics and *n*-*iso*-cycloalkanes, while the CM intercept further differentiates between *n*-*iso*-alkanes and cycloalkanes (Yang et al., 2025). For all three blends, increasing FSII concentration systematically shifts the CM slope-intercept position along a well-defined linear path. For the FSII/Jet A fuel blend, the trajectory stays within the bounds of the ARINC/CRC contours, confirming that the observed dielectric constant variation remains representative of fuels already in circulation. It is possible that if the starting fuel were positioned further to the right, the addition of FSII could result in a shift outside the conventional experience range. Neat *n*-heptane is positioned at the outer ARINC/CRC contour, but higher FSII concentrations of 0.15-0.30 vol% result in outlier CM behavior. Toluene differs from the FSII/Jet A fuel and FSII/*n*-heptane blends in that the data fell entirely outside the conventional fuel experience range. The FSII/toluene blend has the tightest clustering of the three FSII blends, indicating smaller changes per concentration step.

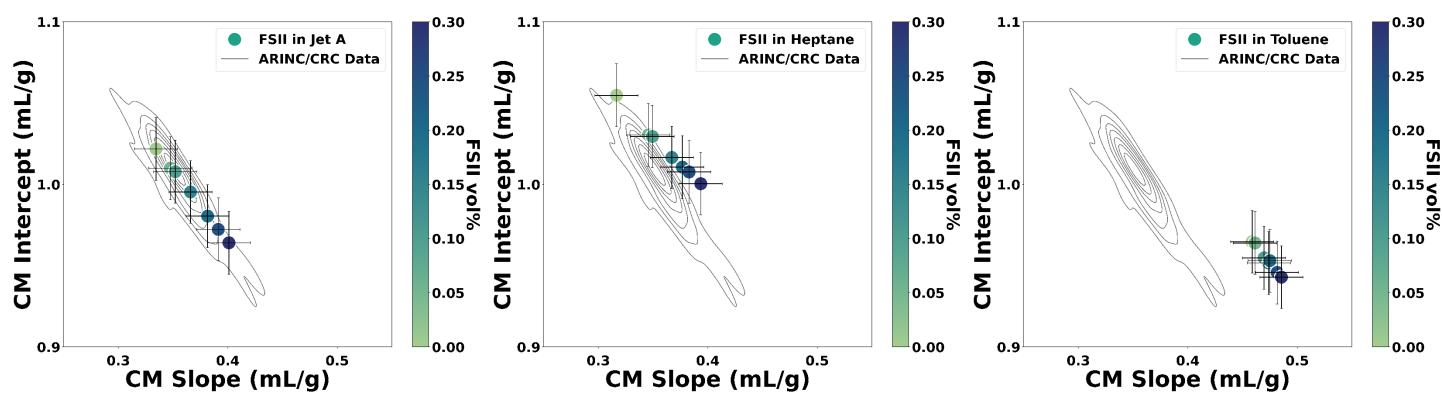


Figure 2. Clausius-Mossotti (CM) slope vs. intercept for fuel system icing inhibitor (FSII) in Jet A fuel (left), FSII in *n*-heptane (middle), and FSII in toluene (right). Colored markers represent data from this effort, with color intensity corresponding to FSII concentration. Error bars reflect measurement uncertainty per IP 638 (Energy Institute, 2023). Black contour lines represent conventional fuel dielectric constant distributions from ARINC Report 611-1 (Aeronautical Radio, Inc., 1999), CRC Report 647 (Hadaller & Johnson, 2006), and AV-33-22 (Kosir et al., 2025).



Dielectric constant measurements for blends of Jet A fuel with either CI/LI at 23 mg/L or SDA at 5 mg/L additive are shown in Figure 3. As shown in Figure 3, there is no significant change in the measured dielectric constant due to inclusion of either additive. Due to the insensitivity at preliminary levels, measurements were not taken at additional concentrations.

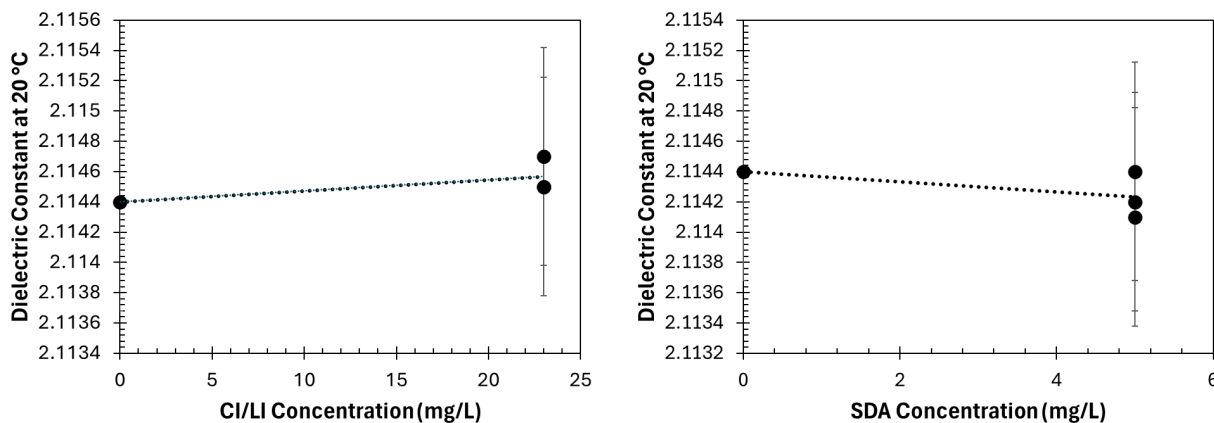


Figure 3. Dielectric constant at 20°C versus additive concentration for corrosion inhibitor/lubricity improver (CI/LI) in Jet A fuel (left) and static dissipator additive (SDA) in Jet A fuel (right).

A blending rule is explored here as a practical extension of this work for fuel producers, researchers, and other interested parties. The blending rule is shown in Equation 1. Here, ε_{blend} is the predicted dielectric constant of the blend, v_i is the volume fraction of blend component i , ε_i is the dielectric constant of blend component i , and n is the number of components in the blend. In the case of the binary blends explored here, $n = 2$. Previous work validated both a volume fraction and a polarizability blending rule using 40 mixtures of neat molecules and fuels (Yang et al., 2025). The species used were hydrocarbons (i.e., n -alkanes, iso -alkanes, cycloalkanes, and aromatics). The blending rule effort here builds on Yang et al. by validating Equation 1 using polar species. Because the JetDC is limited to a dielectric constant measurement range of 1.000-2.500, values for FSII, isopropyl alcohol (IPA), and aniline were pulled from the literature.

$$\varepsilon_{blend} = \sum_{i=1}^n (v_i \times \varepsilon_i) \quad (\text{Eq. 1})$$

Figure 4 shows parity plots of dielectric constant predictions (using the volumetric blend rule) and measurements at 20°C for blends of hydrocarbons with polar components and complex hydrocarbons. While Figure 5 shows relative error for dielectric constant predicted using the volume fraction blending rule versus the concentration of blend component #1 (e.g., concentration of FSII in FSII/Jet A fuel blend). Polar blends from this effort are shown on the left, and synthetic blend components (SBC) from a previous effort are shown on the right. Errors were positive in both plots, which means that Equation 1 tended to overpredict the dielectric constant. Prediction errors for polar species increased in a linear manner from left to right, indicating a systematic bias. Errors for the FSII blends were $\leq 0.7\%$ in the allowable FSII range of 0.07-0.15 vol%. This makes the volume fraction blending rule a promising tool for interested users. Errors for FSII, IPA, and aniline in n -heptane generally become significant at concentrations ≥ 1 vol%. However, these concentrations are unlikely in a real-world fuel and would likely cause other operational issues.

As shown on the right of Figure 5, dielectric constant predictions were made for binary blends from the previous effort (Kosir et al., 2024) using to further validate the volume fraction blending rule. These data consisted of three SBC/Jet A fuel blends, three binary SBC blends, and three neat molecule/Jet A fuel blends. The specific SBCs used were alcohol-to-jet-synthetic paraffinic kerosene (ATJ-SPK), cycloparaffinic kerosene (CPK), hydroprocessed esters and fatty acids-synthetic paraffinic kerosene (HEFA-SPK), and synthetic aromatic kerosene (SAK). The blending rule proved to be effective, with a maximum relative error of 0.5% for decalin. The relative error changed linearly with concentration for four of the blends. However, the relative error for the SAK/Jet A and CPK/SAK blends had a nonmonotonic trend, reaching a maximum at the 50/50 blend ratio.

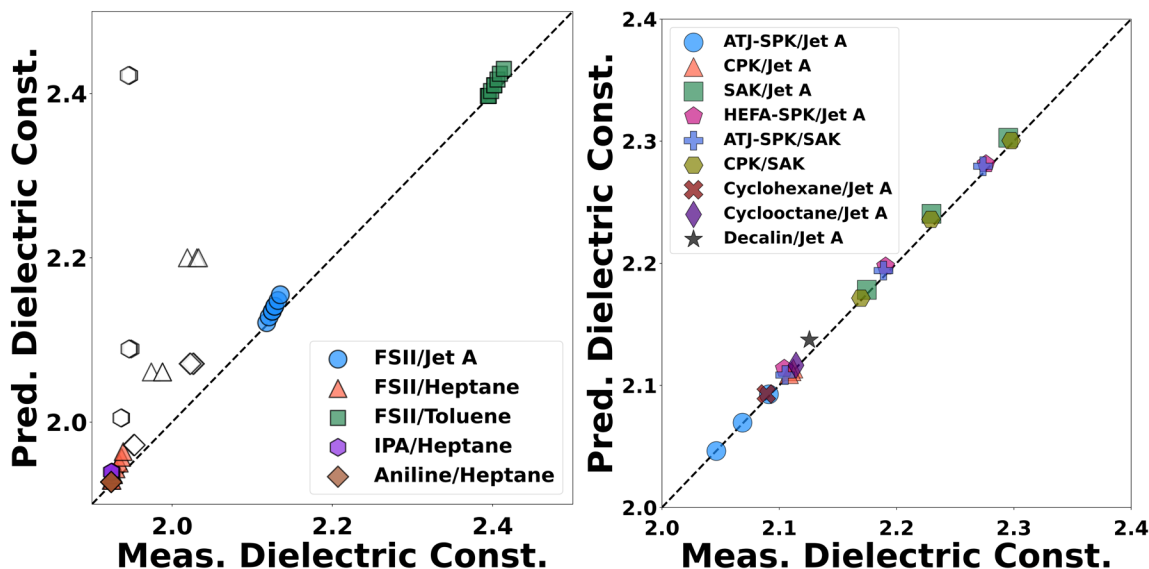


Figure 4. Parity plots of predicted versus measured dielectric constants at 20°C for polar/hydrocarbon mixtures (left) and cd complex hydrocarbon mixtures (right); polar species blended at greater than 0.3 vol% are filled white on the left plot.

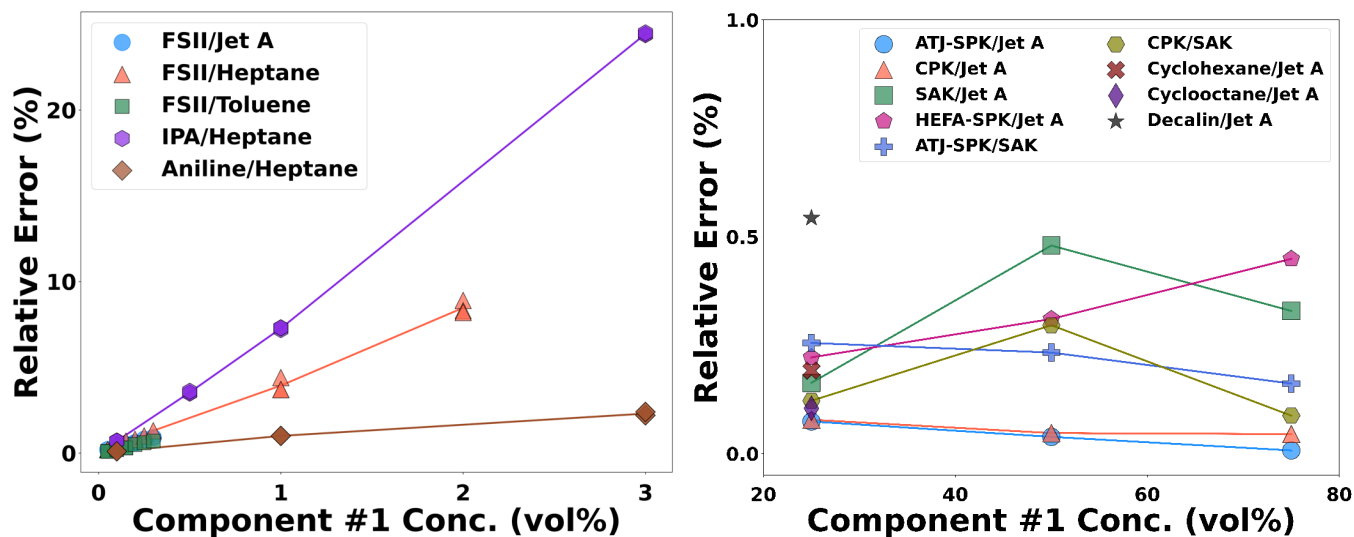


Figure 5. Validation of volume fraction blending rule at 20°C for blends containing polar species (left, current effort) and complex hydrocarbon mixtures (right, data from Kosir et al., 2024).

Milestones

- Acquired and commissioned the JetDC instrument.
- Participated in the interlaboratory study (ILS) and measurements of dielectric and density on fuel/SBC blends.
- Presented our work at two major international conferences, and published journal publication of major findings.

Major Accomplishments

- Published peer reviewed journal publication in *Energy & Fuels*.



- Presented our work at two major international fuels conferences: 2024 CRC Aviation Committee Meeting and 18th International Conference on Stability, Handling, and Use of Liquid Fuels (September 2024).

Publications

Peer-Reviewed Journal Publications

- Kosir, S., Landsaw, A., Steinecker, W. H., West, Z. J., & Zabarnick, S. (2024). Synthetic blend component study: the effects of hydrocarbon composition on aviation fuel dielectric constant. *Energy & Fuels*, 38(17), 16451–16457, <https://doi.org/10.1021/acs.energyfuels.4c02342>
- Nicely, T., Nesbit, C. J., Kosir, S., Steinecker, W. H., & West, Z. (In process). Influence of Additives and Impurities on the Dielectric Properties of Jet Fuel. *Energy & Fuels*.

Conference Presentations

- Kosir, A., Landsaw, A., West, Z., & Zabarnick, S. (2024, September 8-12). *Synthetic blend component study: the effects of hydrocarbon composition on aviation fuel dielectric constant* [Conference presentation]. 18th International Conference on Stability, Handling and Use of Liquid Fuels, Louisville, Kentucky.
- Kosir, S., Landsaw, A., West, Z., & Zabarnick, S. (2024, April 29 - May 2). *Composition effects on the dielectric constant for blends of aviation fuel synthetic blend components (SBCs)* [Conference presentation]. 2024 CRC Aviation Committee Meeting, Alexandria, Virginia.

Outreach Efforts

A presentation was made at the ASCENT Spring 2024 meeting, and a poster was presented at the Fall 2024 ASCENT meeting. Presentations were also made at the 2024 CRC Aviation Committee Meeting and the 18th International Conference on Stability, Handling and Use of Liquid Fuels; both meetings were well attended by aviation fuels industry experts (from OEMs and producers). The goal of these meetings is to receive feedback from industry experts on future steps to enable this work to most effectively contribute to the approval of new SAF candidates.

Awards

- Dr. Steven Zabarnick, ASTM D02 Award of Excellence, December 2023

Student Involvement

- Undergraduate student, Taylor Nicely, was responsible for taking dielectric constant measurements. She also presented a poster for her work on this project at an undergraduate chemical engineering research symposium hosted by the Ohio State University.
- Undergraduate student, CJ Nesbit, was responsible for taking dielectric constant and water content measurements. He was also awarded the Ohio Space Grant Consortium (OSGC) undergraduate STEM scholarship for his work on this project.

Plans for Next Period

- Report on impacts of trace water on the dielectric constant.
- Further develop model predictions to include LSER based models.
- Draft final report and second journal publication.

References

- Aeronautical Radio, Inc. (1999). *Guidance for the design and installation of fuel quantity systems (ARINC Report 611-1)*. https://img.antpedia.com/standard/files/pdfs_ora/20230613/ARINC/ARINC%20REPORT%20611-1-1999.pdf
- ASTM International. (2024). *ASTM D1655-24b: Standard specification for aviation turbine fuels*. <https://doi.org/10.1520/D1655-24B>
- ASTM International. (2025). *ASTM D6304-25: Standard test method for determination of water in petroleum products, lubricating oils, and additives by coulometric Karl Fischer titration*. <https://doi.org/10.1520/D6304-25>
- ASTM International. (2022). *ASTM D7566-22a: Standard specification for aviation turbine fuel containing synthesized hydrocarbons*. <https://doi.org/10.1520/D7566-22A>
- Energy Institute. (2023). *IP 638: Determination of relative permittivity (dielectric constant) of aviation fuels, small scale automated temperature scanning method*.



- Hadaller, O. J., & Johnson, J. M. (2006). *World Fuel Sampling Program* (CRC Report No. 647), Coordinating Research Council, Inc. <https://crcao.org/wp-content/uploads/2025/07/CRC-647.pdf>
- Kosir, S., Landsaw, A., Steinecker, W. H., West, Z. J., & Zabarnick, S. (2024). Synthetic blend component study: the effects of hydrocarbon composition on aviation fuel dielectric constant. *Energy & Fuels*, 38(17), 16451–16457, <https://doi.org/10.1021/acs.energyfuels.4c02342>
- Kosir, S., Arts, A. M., Nicely, T., Nesbit, C. J., Mueller, S., Landsaw, A., Baker, M., Brown, L., Thompson, J., Anderson, C., Shafer, L., Steinecker, W. H., Zabarnick, S., & West, Z. J. (2025). *World Jet Fuel Survey Part 1: 2023-2024* (AV-33-22). Coordinating Research Council, Atlanta, Georgia.
- Yang, Z., Bell, D. C., Boehm, R., Marques, P. F., Boze, J. A., Kosilkin, I. V., & Heyne (2025). Assessing the effect of composition on dielectric constant of sustainable aviation fuel. *Fuel*, 380. <https://doi.org/10.1016/j.fuel.2024.133230>