Biofeedstock-induced metal corrosion: Reactions between carbon steel and triacylglycerol-based solutions at elevated temperature

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\textbf{ARTICLE INFO}

\textbf{Keywords:}
Carbon steel
Fatty acids
Nonaqueous corrosion
IR spectroscopy
TEM

\textbf{ABSTRACT}

Triacylglycerol-based feedstocks are crucial for renewable fuel production, but their increased reactivity results in accelerated corrosion of process equipment. We performed systematic corrosion experiments of carbon steel at 274 °C in the presence of a 10 wt. % soybean oil in white oil solution throughout the early stages of corrosion (0–30 h). The corrosion rate peaked at 10 h, followed by substantial iron oxide growth on the surface. The maximum corrosion rate was preceded by an increase in fatty acid concentration and succeeded by an increase in iron and water concentration in solution. Our findings provide insight into the fundamental mechanisms of biofeedstocks-induced corrosion.

1. Introduction

There has been extensive research towards the development of alternative fuel sources to petroleum. Concerns regarding energy security, long-term renewability and the carbon cost of petroleum feedstocks have spurred interest in substitute feedstocks. First generation biofeedstocks, such as triacylglycerol (TAG)-based biological oils and fats, are an essential supplement to traditional feedstocks. They are commercially attractive due to a mature supply chain and renewability [1,2]. TAGs in particular have the additional advantage of being “drop-in” feedstocks, i.e. they can be co-refined with petroleum feedstocks without additional front-end process units or equipment upgrades. Despite the commercial success of TAGs in the energy sector, their use is currently limited by concerns regarding corrosion [2]. TAG feedstocks have substantially different chemistry than traditional petroleum feedstocks—namely, they contain a large number of oxygen-containing moieties including esters, carboxylic acids, and alcohols. These chemical differences result in a feedstock with higher reactivity, lower thermal stability, and increased hydrophilicity relative to a petroleum feedstock. These features result in increased corrosiveness of the feedstocks towards process equipment [3]. Increased equipment corrosion is one of the many challenges that must be addressed as petroleum feedstocks are replaced with biofeedstocks.

Current accepted best practice for using TAG feedstocks involves either conservative blending with existing petroleum feedstocks or installing dedicated process units with upgraded metallurgy [3]. However, these practices limit the processable volume of the biofeedstocks within existing infrastructure and thus the commercial and environmental benefit of switching. There is a critical need for improved understanding of the mechanisms that lead to biofeedstock-induced corrosion. This would enable processors to design the mitigation methods needed to increase biofeedstock volume while minimizing the potential for corrosion-caused equipment failure.

The corrosive capability of a feedstock is historically determined by its total acid number (TAN), defined as the mg of KOH required to neutralize the acids present in 1 g of sample [4]. An unblended TAG feedstock has a wide range of possible acid numbers (e.g. 2–3 for purified soybean oil to ~80 for pyrolysis oil), but the TAN is generally far above the industry standard of 0.5 [3]. Interestingly, biofeedstock-induced corrosion is typically less aggressive than what would be predicted using only the TAN. For biofeedstocks, the acid content is merely one of many factors affecting corrosion. Factors such as fatty acid carbon tail length [5], acid structure [6,7], oxygen concentration [8], water concentration, and salt concentration [9] have all
been shown to affect corrosion behavior. In some cases involving polar solvents at ambient temperatures, fatty acids have actually been shown to be protective against corrosion of mild steels, hypothesized to occur due to complexation of the carboxylate group with iron at the metal surface that creates a functional passivation layer [10]. While, a rare study using nonpolar solvents at elevated temperature (220°C) reported a consistent correlation between increased free fatty acid concentration and corrosion of carbon steel [11]. There is, to date, no comprehensive understanding of how different factors intrinsic to a chosen feedstock-metallurgy combination (e.g. blend chemistry and composition) mechanistically affect the corrosion process, particularly at process-relevant temperatures. Systematic experiments quantifying corrosion are thus essential to provide insight into the corrosion behavior of TAG-based biofeedstocks. In addition to enabling fundamental mechanistic insights, these experiments can also inform process conditions that allow increased use of TAG-based biofeedstocks without causing excessive corrosion.

In this work, we performed systematic high-temperature corrosion experiments using a TAG-based biofeedstock blend and carbon steel coupons. A variety of characterization methods were used to investigate the evolving chemistry and morphology of the steel surface and the biofeedstocks over time. Andari et al. [11], leveraged similar characterization techniques and feedstocks for extended exposures of 120+ hours. Our results offer new insight into the complex interplay between the steel and biofeedstock chemistry during early-stage corrosion (timeframes of 30 h and less). Emphasis was placed on this early-stage timeframe with the goal of providing insight for development of corrosion mitigation strategies and the increased use of TAG-based biofeedstocks. Different mechanisms are shown to contribute to corrosion at various timepoints, suggesting that methods for controlling corrosion may differ depending on the relevant dominant mechanism.

2. Material and methods

2.1. Materials

The biofeedstock used in this study was prepared as a mixture of 10 wt. % soybean oil in white mineral oil, which has been designated as S10W in the following experiments. Soybean oil is comprised mostly of triglycerides, and most of the fatty acids are unsaturated [12]. The white oil is a mixture of large alkanes (>C20), Carbon steel 1018 (CS1018) metallic coupons, 5 mm × 5 mm × 0.5 mm, were machined by electrical discharge machining (EDM). All oils and metallic coupons were supplied by bp.

2.2. Autoclave corrosion testing

A 316 stainless steel autoclave manufactured by Park Hannifin (model 60 mL EZE Seal Pressure Vessel) was used for the experiments. The autoclave is rated to 78 bar at 274 °C. Prior to corrosion testing, the CS1018 coupons were polished using 320 grit SiC paper, sonicated in isopropyl alcohol for several minutes and rinsed with additional isopropyl alcohol. Then, they were mounted in a 316 stainless steel sample holder, configured with three slits over a deeper groove [13]. The samples were then submerged in 10 mL of S10W before being sealed in the autoclave. The atmosphere in the autoclave was the ambient air of the laboratory. The autoclave was placed in a Mellen Microtherm 1200 °C box furnace. The furnace was heated to 274 °C at 10 °C/min and held for the specified experimental time. (An Aspen HYSYS simulation estimated maximum pressure inside the autoclave at 1 bar during the temperature hold.) For each sample, the autoclave was sealed for the full experimental time indicated (1 h, 5 h, 10 h, 20 h, or 30 h); i.e. each time indicates a separate trial, and the autoclave headspace was not exposed to air throughout the experiment. After heating, the autoclave was subsequently allowed to cool inside the furnace until safe to handle (about 14 h). For all experiments, prior to characterization, the coupons were removed from the autoclave, rinsed with toluene and sonicated for 5 min in toluene. This process removed loosely adhered species from the surface.

2.3. Substrate characterization

The coupons were weighed before and after the autoclave process using a XPE26 microbalance from Mettler-Toledo. The corrosion rate was determined by measuring the net mass loss from the cleaned coupon after the autoclave experiments were completed. Uniform corrosion rates are calculated from the coupon mass loss through $MPY = \frac{MW}{D}$, where $W$ is mass loss in milligrams, $D$ is density in grams per cubic centimeter, $A$ is the area in square inches, and $T$ is time in hours [14].

Scanning electron microscopy (SEM) was performed on a Scios 2 DualBeam from Thermo Fisher Scientific. Transmission electron microscopy (TEM) and associated selected area electron diffraction (SAED) was performed on a JEOL 1010 LaB6 from JEOL Ltd. Samples were prepared by cross-section lift-out using a Scios 2 DualBeam focused ion beam (FIB) from Thermo Fisher Scientific. All CS1018 coupons were coated with a 5–7 nm thick gold palladium layer before observation under the electron microscopes.

X-ray photoelectron spectroscopy (XPS) was performed using a Kratos Axis Ultra from Shimadzu Corporation. Coupons were rinsed and sonicated, as described previously, before analysis. The analyzed spot size was 2 mm × 2 mm. Pass energy of 40 eV was used with averaging over six scans of elemental regions. Analysis of data was performed using the software package by CasaXPS.

2.4. Solution characterization

Inductively coupled plasma mass spectrometry (ICP-MS) was performed on a Perkin Elmer Optima 8300 ICP-optical emission spectrometer (ICP-OES). Samples were first digested in a CEM MARS6 microwave digestion system with a mixture of 4 mL hydrogen peroxide (30 %), 5 mL nitric acid (70 %), 2 mL hydrochloric acid (36 %), and 2 mL 18 MΩ-cm Millipore water. Emission at 238.204 nm was recorded in axial view, and final Fe concentration was calculated with a linear regression.

Attenuated total reflectance – Fourier transform infrared spectroscopy (ATR-FTIR) was performed on a Bruker Alpha II with Platinum-ATR module. A liquid sample was placed on the ATR, fully covering the diamond ATR crystal. The IR spectra was measured from 4000 to 400 cm⁻¹ with a total of 64 scans and a resolution of 4 cm⁻¹. For quantitative analysis, FTIR peaks were first fit via the peak-fitting function in Origin Pro 2020. The total peak area was then assigned to a concentration based on a linear calibration curve constructed with mixtures containing known concentrations of the relevant species in white oil. Further details of the calibration are available in the Supporting information (Fig. S1).

Water content was measured via coulometric Karl Fischer (KF) Titration, using a Metrohm 917 Coulometer equipped with a Metrohm 885 autosampler oven. Water vapor was extracted from the samples at a furnace temperature of 120 °C under a constant flow of dry air at 50 mL/min and directed into the reaction vessel.

3. Results

The corrosion of CS1018 coupons immersed in S10W was performed in the autoclave at 274 °C for the specified time before the steel coupons and the solution were removed for detailed characterization. The corrosion rates for the CS1018 coupons can be seen in Fig. 1 a for S10W (at various times). These results revealed that S10W is significantly more corrosive than pure white oil after 10 h at 274 °C; in fact, no measurable mass loss was observed for the coupons in white oil after 10 h. For S10W
samples, the sample loses mass through 20 h, with the rate of mass loss peaking at 10 h. A slight mass gain is observed between 20 and 30 h (Fig. S3).

The elemental composition on the coupons’ surface from the XPS analysis before (0 h) and after corrosion is shown in Fig. 1b. Carbon, oxygen, and iron were detected on the uncorroded, as-polished surface of the coupons. Surface carbon content peaked after 1 h in the autoclave. The Fe 2p3/2 spectra of the as-polished CS1018 coupon and corroded samples are presented in Fig. 2. The as-polished sample shows two peaks at around 706.8 and 711 eV. The binding energy value of the first peak centered around 706.8 eV represents iron metal, while the second peak is attributed to the presence of oxidized iron species. After corrosion, the relative intensity of the iron metal peak decreased considerably, while the convoluted intensity of Fe(II) and Fe(III) peaks increased relative to the 0 h spectra. Peak fitting of the O 1(s) core-level spectra indicates the oxygen observed at the surface is bound to the iron as oxide and hydroxide (Fig. S4).

The changes in the surface morphology of corroded carbon steel coupons after cleaning were imaged using SEM (Fig. 3). The polishing scratches in the as-polished surface are a useful guide for estimating the amount and nature of the corrosion. Polishing marks gradually and uniformly disappear with longer autoclave time, within the resolution of the time steps used. A small number of pits were observed at 10 h, but only in a small region near the sample holder (Fig. S5). After 20 h, the polishing marks are barely visible. There are also some deposits visible in the sample after 20 h, which have been encircled in Fig. 3e. In contrast, the surface morphology is unchanged for a coupon exposed to pure white oil for 10 h in the autoclave (Fig. S6).

To further visualize these corrosion-induced morphological changes, cross-sectional TEM was used (Fig. 4). A thin native oxide layer was observed in the as-polished sample. After 1 h in the autoclave, a bilayer was observed, comprised of oxide and an amorphous carbonaceous layer ~15 nm thick (Fig. 4b). The amorphous layer disappears by 5 h in the autoclave. After 20 h of corrosion, the oxide layer grows significantly (Fig. 4e). Results showed that the sample surface is covered by a layer of discontinuous octahedral oxide precipitates as well as a more conformal oxide layer. SAED reveals the octahedral oxide precipitates are magnetite (Fe₃O₄) precipitates (Fig. S7), but the continuous oxide layer was too thin to obtain diffraction patterns. XRD data from this sample shows a small Fe₂O₃ peak, with no peak identified for Fe₃O₄ or iron carbonate (Fig. S8).

In addition to the characterization of the steel surface, the biofeedstock solution was characterized with ICP-MS, ATR-FTIR and KF titration before and after the autoclave process. The iron content in solution as measured by ICP-MS (Fig. 1d) is initially negligible but begins to grow starting at 10 h and continues to increase through the 30 h sample.

ATR-FTIR spectroscopy was performed to identify chemical species evolution in the biofeedstock (Fig. 5). In these data a few key regions reveal systematic changes in the peak intensity as a function of autoclave time. The peak at ~1740 cm⁻¹, highlighted in Fig. 5b, decreases with increasing autoclave time. This peak is assigned to the stretch mode of the carbonyl bond in an ester [15], which in the current system corresponds to the esters that attach the fatty acids to the glycerol in the TAG. There is also a systematic decrease in the peaks between 1050 and 1250 cm⁻¹. These peaks correspond to the stretch of the alkyl- and acyl-C-O bonds [15], which may be associated with ester carbon-oxygen bonds in the present system. The final peak with significant change is at ~1715 cm⁻¹. This peak is initially not present but is present by 1 h and increases in height through 10 h (Fig. 5b). The peak remains approximately constant between 10 and 20 h but decreases by 30 h. This peak corresponds to the carbonyl stretch of a non-ester bond, e.g. a carboxylic acid, a ketone or an aldehyde [16].

Calibration curves for ATR-FTIR measurements were developed to quantify the concentration of the various carbonyl molecules in the solution with time. Calibration curves for the ester peak at 1740 cm⁻¹
were developed using triolein as a model triglyceride molecule (Fig. S1a). The corresponding concentrations of the ester molecules, as determined from application of these calibration curves, can be seen in Fig. 1e. These data show that the glycerol-attached ester concentration decreases with increasing autoclave time until the esters are completely gone by 30 h. Non-ester carbonyls (e.g. aldehydes, carboxylic acids or ketones) vary in relationship between peak area and species concentration, and thus the area of the peak centered around ~1715 cm$^{-1}$ cannot be strictly correlated to concentration (Fig. S1b). However, it is apparent that the peak increases in area for the first 10 h, then plateaus and decreases through 30 h (Fig. S2). This indicates that either species concentration in solution is decreasing (sorption to surfaces or volatile to gas phase) or some species are converting to other species with weaker signal intensity in FTIR (e.g. carboxylic acids to ketones or aldehydes).

Lastly, the evolution of water concentration was tracked throughout the autoclave process via KF coulometric analysis. It was determined that neat soybean oil has a water content of 239.0 ± 25.5 ppm (5 measurements) and white oil has a water content of 11.9 ± 0.5 ppm (3 measurements). The water content of the solutions increases with autoclave time (Fig. 1f) throughout the process. Interestingly, substantially more water (399 ppm) is present in a feed autoclaved for 10 h when a carbon steel coupon is present relative to a system without a carbon steel coupon (81 ppm).

4. Discussion

It is clear from these results that the evolution of both the solution and surface chemistry are intimately coupled through a complex and diverse set of reactions. While the current effort does not aim to exhaustively explore all of these reactions or potential mechanisms, three key stages of the corrosion process are identified and expounded upon in the following discussion.

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**Fig. 2.** Fe 2p3/2 spectra as measured by XPS for the a) as-polished sample, b) 10 h post-autoclave sample, and (c) the 20 h post-autoclave sample. The binding energies correspond to iron metal (blue) and oxidized iron (red and green). Fe(II) and Fe(III) peaks (711 eV) have increased in relative intensity, but the pure Fe(0) peak has reduced considerably. This indicates the presence of Fe(III) and Fe(II,III) oxides when combined with analysis of the O 1(s) core-level spectra in Fig. S4.

**Fig. 3.** SEM reveals the evolution of surface morphology with a) 0 h, b) 1 h, c) 5 h, d) 10 h, e) 20 h and e) 30 h at 274 °C. Clearly distinguishable residual polishing scratches (marked by arrows) are visible through 5 h (a-c), but are barely visible after 10 h in the autoclave. The encircled features are deposits that are observed on the surface after 20 h.
4.1. Onset of corrosion (0–5 h)

Evaluation of the relative kinetics of these chemical and morphological changes shows that the earliest stages of the corrosion process in the autoclave (Fig. 1, purple region) are dominated by the accumulation of carbon species on the surface of the steel coupons (cf XPS data in Fig. 1b). In the as-polished coupons, the carbon and oxygen originate from absorption of organic contaminants onto the surface from the atmosphere and the formation of metal oxide during polishing. Carbon accumulation peaks at 1 h, but remains in significant quantities after 5 h in the autoclave. The thin amorphous layer identified in the cross-sectional TEM images (Fig. 4) is also reasonably assumed to be carbonaceous given the contrast and imaging conditions used. In both cases, the coupons were cleaned prior to XPS and TEM analysis, so these carbon deposits had good adhesion to the surface. The exact chemical nature of these deposits is unknown. Intact triglycerides could bond through van de Waals interactions, while partially hydrolyzed triglycerides (or free fatty acids) could chemisorb through free hydroxyl groups.

By 5 h, measurable corrosion is observed (Fig. 1a). Increasing corrosion is concurrent with a decrease in the carbon content of the surface (Fig. 1b) and the elimination of the amorphous layer in the cross-sectional TEM (Fig. 4). As the corrosion rate increases, the carbon layers are unable to bond as strongly to the evolving steel surface. It is reasonable to correlate this corrosion to the simultaneous increase in acidity associated with free fatty acid formation; however, as will be discussed in the next section, this is likely an oversimplification.

Following the initial accumulation of carbon on the surface, the hydrolysis of the TAG-species into free fatty acids and glycerol becomes significant (Scheme 1). The initial water content of the S10W solution is nontrivial (25 ± 10.5 ppm); this ambient water can promote the formation of free fatty acids and, eventually, the corresponding glycerol.
through the aforementioned hydrolysis reactions. Fig. 1e shows that the concentration of ester steadily decreased through hour 5. Interestingly, the water content in the solution remains relatively stable throughout this time, even though one mole of water would need to be consumed for each mole of generated free fatty acid. This could be explained in one of three ways: 1) water is being generated by some other chemical reaction in the system, 2) water is pulled into solution from the autoclave headspace, or 3) we are at the resolution limit of the KF titration method and we cannot accurately measure the decrease in the water concentration. A brief calculation (Calculation S1) reveals that the water present in the headspace of the autoclave, plus water initially measured in the biofeedstock, is insufficient to hydrolyze the present triglycerides to the degree that was observed via FTIR. While it is difficult to rigorously eliminate the impact of the resolution limit, it is likely that there is a water-generating reaction occurring during the autoclave process that accounts for the concomitant triglyceride hydrolysis and increase in the water content of solution. This becomes more apparent when considering that the water content of the solution begins to increase after 5 h, which is discussed in the following section.

4.2. Peak corrosion and water content evolution (~10 h)

Stage 2 of the corrosion process is dominated by water accumulation and a maximum in the corrosion rate (Fig. 1, blue region). Water concentration in the solution increases dramatically between hour 5 and hour 10. This is surprising, as the presumed primary method of water consumption – TAG hydrolysis – is simultaneously at its maximum rate.

Water may be plausibly generated through a few mechanisms, as shown in Scheme 2. First, free glycerol can dehydrate in an acidic environment to generate water and various ketone species [17]. Second, free carboxylic acids may undergo ketonization, generating water and carbon dioxide. Ketonization is known to be accelerated by the presence of certain metal oxides [18] including iron oxide [19,20]. Additionally, the ATR-FTIR data in Fig. 5b shows the development of a shoulder at 1720 cm\(^{-1}\), which could be associated with the formation of ketone molecules from two free fatty acids. Lastly, free fatty acids can react with the basic hydroxyl molecules on the iron oxide [21] surface, releasing water. It is important to note that this is an extremely limited selection of reactions among the many that could be occurring in the autoclave. However, the proposed subset of reactions do proceed readily at the experimental temperature (274 °C) and are consistent with the experimental observations in this work. More studies will be needed to elucidate which water-generating reactions are the most prominent in these systems.

Although the concentration of ester bonds in the solution has also dropped by more than half (Fig. 1e) over the same time increment, the corresponding growth of free carbonyl species does not completely account for the decreased concentration of attached carbonyls (Fig. S2). This suggests a mechanism for the consumption of free carbonyls in the solution, either through additional solution reactions (e.g. ketonization of fatty acids), sorption of the carbonyls to surrounding surfaces, or decomposition to volatile species. These reactions are consistent with our hypotheses for water-generating reactions.

Interestingly, control experiments with either no coupons present or with only stainless steel coupons, both of which are in the stainless steel autoclave, show significantly more esters remaining in solution and significantly less water present after 10 h in the autoclave (Fig. 1f). These control experiments suggest that carbon steel, rather than stainless steel, is important to the process.

The corrosion rate of the coupons has reached a maximum at 10 h and the fiducial polishing scratches are no longer readily apparent via SEM observation (Fig. 3). The surface carbon content as measured by XPS dropped to the baseline levels (Fig. 1b), indicating that carbon species are no longer strongly adhering to the surface. The 10-hour time increment also corresponds to an observable increase in the concentration of iron in solution (Fig. 1d), as mass is lost from the carbon steel coupon into solution.

Scheme 2. Possible mechanisms for water generation. a) dehydration of a glycerol species b) Ketonization of two fatty acids into a ketone species, with an appropriate catalyst c) Reaction of a fatty acid with a free surface hydroxyl species, to generate a chemically bonded fatty acid and water.
4.3. Rapid oxide growth (20–30 h)

Stage 3 in the autoclave reactions is dominated by rapid oxide growth (Fig. 1, green region). The calculated corrosion rate by mass loss peaked at 10 h, but the water content continues to increase while the total carbonyl solution concentration drops considerably (Fig. 52). Nearly all glycerol-attached ester groups are consumed (Fig. 1e) by 20 h. The iron concentration in solution has continued to increase and the oxide layer (Fe₂O₃) thickness begins to grow significantly (Fig. 1c). The carbonyl concentration does not change significantly between 20 and 30 h.

The corrosion rate continues to decrease, partially attributable to the mass gained via oxide growth. Some have reported that Fe₂O₃ may act as a protective layer thereby reducing the corrosion rate [5]. However, the significant and increasing concentration of Fe in solution after 30 h makes it apparent that this oxide layer is not protective and that continued dissolution of the steel substrate persists despite the Fe₂O₃ layer.

These experiments make clear the intricacies of the chemical and morphological evolution associated with soybean oil feed in contact with a carbon steel surface at elevated temperatures. While some of the mechanisms are likely the same as what would be observed under ambient conditions (only faster), there are also likely some novel reactions that become dominant with increasing temperatures. Future, in-depth studies are needed to pinpoint and understand the underlying mechanisms that distinguish the high temperature behaviors initial observed and reported herein.

5. Conclusions

In this work, systematic early-stage corrosion studies were performed on carbon steel coupons exposed to a biofeedstock comprised of 10 wt. % soybean oil in white oil. Both coupon and feed were sealed together in an autoclave at 274 °C and the chemical and morphological evolution was characterized over the first 30 h.

Corrosion of carbon steel by triacylglycerol-based feeds is understood to be a complex process, wherein bulk solution reactions affect surface reactions and vice versa. And while a traditional understanding of corrosion attributes the corrosivity of a feed to a single feature (the acid content), the present results show a complex reaction space that may reveal opportunities for corrosion mitigation through continued understanding of the earliest stages of the corrosion process. Evolution of both the solution and steel surfaces was found to proceed through three distinct phases. The onset of corrosion was characterized by carbon accumulation and TAG hydrolysis. Intermediate timesteps revealed unanticipated water generating reactions and rapid iron dissolution.

Finally, the longest exposures investigated did not show evidence of meaningful surface passivation—instead significant oxide growth was associated with rapidly increasing iron concentrations in solution. This suggests that despite near complete consumption of glycerol-attached ester groups, corrosion of the steel coupon progressed readily. Any efforts to anticipate corrosion behavior in more complex industrial settings or to develop mitigation strategies will depend on continued dissection of the broad progression of reactions observed and postulated by this study. In particular, the present study highlights the importance of understanding nontrivial water generation due to the presence of biofeedstocks and of alloy selection and surface chemistry in propagating corrosion reactions, while also emphasizing the need for long-term, elevated temperature corrosion experiments to explore the possibility of eventual passivation.

CRediT authorship contribution statement

Deborah Liu: Investigation; Formal Analysis; Writing – original draft. Samyukta Shrivastava: Investigation; Formal Analysis; Writing – original draft. Soheil Daraydel: Investigation; Formal Analysis. Nathan Levandovsky: Investigation; Formal Analysis. Hyosung An: Investigation; Formal Analysis. Siddhesh Shevade: Conceptualization; Project Administration; Writing – review & editing. Qian Chen: Conceptualization; Funding Acquisition; Project Administration; Supervision; Writing – review & editing. Jessica A. Krogstad: Conceptualization; Funding Acquisition; Project Administration; Supervision; Writing – review & editing. Daniel V. Krogstad: Conceptualization; Funding Acquisition; Project Administration; Supervision; Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data may be provided upon request pending a review period of at least 30 days.

Acknowledgements

This work was supported by bp through the bp International Centre for Advanced Materials (bp-ICAM). This work was further enhanced and supported by discussions with and feedback from Dr. John Shabaker, Dr. Eric Doskocil and Dr. Tom Eason (bp).

The authors thank Dr. Ashley Blystone and Crislyn Lu for assistance with ICP-MS, Dr. Roddel Remy for assistance with Karl Fischer titration, Dr. Zhiheng Lyu and Jiahui Li for many helpful discussions, and Dana Yun for collecting XRD data.

This work was carried out in part in the Materials Research Laboratory Central Research Facilities, University of Illinois.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.corsci.2023.111088.

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