Centuries of Cellulose: Lessons Learned from the Molecular Size of Cellulose in Naturally Aged Paper Collections

Size-exclusion chromatography (SEC) has been used successfully for many decades as a tool to quantify the molecular structures of large synthetic polymers and to draw connections between molecular size and material properties. In contrast to the success of SEC for measuring synthetic polymers, paper and cellulosic polymers provide inherent difficulties for similar chromatographic analyses. Improvements in instrumentation and experimental procedures have slowly and markedly improved the current state of molecular characterization of cellulose by SEC. This work begins to draw connections between the size distributions of cellulose molecules to the known properties of variously treated and aged collection materials. The Barrow Books Collection at the Library of Congress provided an excellent starting point for using SEC in complement with other analytical techniques, both noninvasive and destructive, to evaluate the long-term stability and treatment of paper-based collections. Existing data from the well-characterized collection includes chemical-scale properties (e.g., pH and chemical functionality) up to macroscale properties (e.g., mechanical strength and colorfastness). However, a gap has long existed between these two scales. Little data is available at the scale of polymeric macromolecules, where initially minute chemical changes eventually translate to macroscale degradation. Recent work from the Preservation Research and Testing Division at the Library of Congress has used both the Barrow Books Collection as well as a selection of paper from American sources to investigate how SEC might be used to complement existing conservation data and analyses. For example, SEC quantifiably identifies the consequence of alkali treatments on preserving cellulose polymer chain lengths, which strongly correlates to eventual paper embrittlement. Attempts at correlating new experimental data with existing data from books in the library's collection also demonstrates the inherent challenges and opportunities for using SEC to identify structure-property relationships between the molecular structure of cellulose and the properties of aged paper collections. Assessing various conversation treatments in this way could better inform conservators on predicting the efficacy of paper preservation treatments. It appears likely that minute changes in the statistical distribution of polymer sizes in aged paper, easily measured by SEC, could provide an early indicator of degradation and might allow improved design of artificial aging studies. More effectively linking microanalytical determinants to current destructive mechanical testing is critical for assessing the use and condition of paper-based historic collections.

DR. ANDREW DAVIS
Chemist, Preservation Research and Testing Division
Library of Congress
Washington, DC
adavi@loc.gov

DR. FENELLA FRANCE
Chief, Preservation Research and Testing Division
Library of Congress
Washington, DC
frfr@loc.gov

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