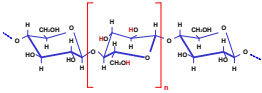




Size-Exclusion Chromatography Method Development to Address Non-Ideal SEC Separations of High Molecular Weight Samples for Molecular Weight Distribution Characterization of Cellulose Ethers

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Cellulose Ethers (CE)



Substituent	Abbreviation	Chemical Structure
methylol	MeO	-OCH ₃
hydroxypropyl	HPO	-(CH ₂) ₃ CH ₂ OH
ethyl	EIO	-CH ₂ CH ₂ OH

- Challenges:
- Variety of Substitution Options
 - Wide Viscosity Ranges: 2% solution viscosity from 3 to 250,000 cp



Challenges for SEC Separation of High MW Cellulose Ethers^{3,4}

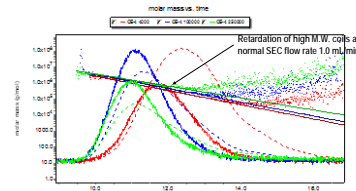
- Shear degradation/deformation
- Non-equilibrium transport between mobile phase and stationary phase
- Polarization effect
- Hydrodynamically induced diffusion
- Stress-induced diffusion
- Multi-path effect

Non-ideal SEC separation as manifested by retardation of larger molecular weight chains

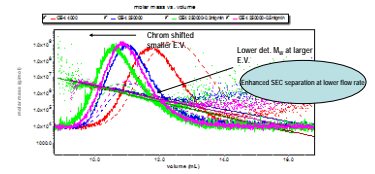
³Giddings, J.G., *Adv Chromatogr.* 20 (1983) 217.
⁴Prosch, B., et al., *J. Chromatogr. A* 2005, 1068, 249-260.



Non-ideal SEC Fractionation of High MW Cellulose Ethers with Similar Substitution Compositions and Differing Nominal Viscosities



Flow Rate Study on 250,000 Nominal cP Cellulose Ethers With Similar Substitution Compositions



The det. M_w at larger elution volume decreased as the flow rate decreased and finally was superimposable with that of products with lower nominal viscosities at the flow rate 0.2 mL/min, indicating the ideal SEC fractionation was obtained at that flow rate.



General Applications

- Construction
 - Binder, thickener, and lubricating agent in tile adhesives and plasters
- Industrial Specialties
 - Paper sizing and ceramics
- Paint
 - Thickener in latex paints
- Personal Care
 - Thickener, lubricating agent, and water retention agent in shampoos and oral care products
- Food
 - Binder and thickener in pastries, dairy products, beverages, meat and fish products
- Pharmaceutical Excipient
 - Binder, tablet coating, controlled release
- Other Industrial Uses
 - Thickener in wood coatings and printing inks

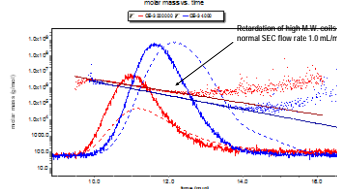


Experimental

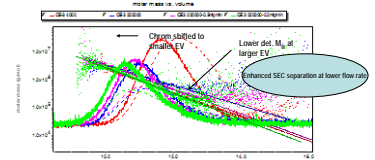
- Sample preparation
 - Solutions were prepared in mobile phase (0.05 wt% NaCl) to minimize interference from any salt peak. All solutions were filtered through a 0.45 µm nylon syringe filter prior to injection. Sample concentration was about 0.3°C to ensure that polymer chain entanglements were minimized.
- Instruments
 - Waters 2690 set at the optimum flow rate according to the SEC fractionation study.
 - A Wyatt DAWN DSP MALLS detector connected with a Wyatt Optilab rEX DRI detector. The Wyatt DAWN DSP is equipped with a red laser operating at a wavelength of 632.8 nm and operated at room temperature. The Wyatt Optilab rEX DRI detector was operated at 28 °C.
- Calibration
 - The Wyatt DAWN MALLS was calibrated with HPLC grade toluene filtered through a 0.05 µm syringe filter. The individual light scattering detectors were normalized to the 90° light scattering detector using mono-dispersed bovine serum albumin (BSA) monomer as the isotropic scatterer. The inter-detector delay volume was determined as 0.170 mL by aligning the 90° light scattering peak with DRI peak of BSA.
- Data Processing
 - The signals from the MALLS and DRI detectors were analyzed using ASTRA V software, version 5.3.2.17. M_w and R_g were determined at each SEC elution volume increment. A Δ of 0.140 mL/g for all samples was used.



Non-ideal SEC Fractionation of High MW Cellulose Ethers with Similar Substitution Compositions and Differing Nominal Viscosities



Flow Rate Study on 220,000 Nominal cP Cellulose Ethers With Similar Substitution Compositions



The det. M_w at larger elution volume decreased as the flow rate decreased and finally was superimposable with that of products with lower nominal viscosities at the flow rate 0.2 mL/min, indicating the ideal SEC fractionation was obtained at that flow rate.

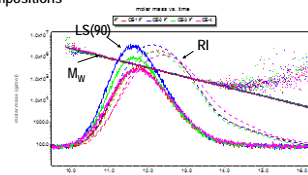


Introduction

- Importance of Molecular Weight Distributions (MWD)
 - Differentiate materials during development of new products and new applications
 - Establish structure-property relationships to better understand product performance
- Size-exclusion Chromatography-Multi-angle Laser Light Scattering (SEC-MALLS)
 - Key advanced characterization tool to obtain both MWD and R_g



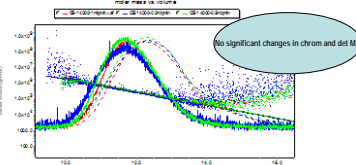
SEC Separation of Four Nominal 4000 cP Cellulose Ethers (CE) with Differing Substitution Compositions



Fractionation of CE samples was under ideal SEC separation. No retardation of high MW coils was detected. These samples were used for evaluation of the SEC separation of high MW CE samples (later slides).



Flow Rate Study on 4000 Nominal cP Cellulose Ethers



Sample	Mn (g/mol)	Mw (g/mol)	Mw/Mn
1.0ml/min	3.88E+04	2.82E+05	8.14
0.5ml/min	3.89E+04	2.82E+05	7.28
0.2ml/min	3.92E+04	2.82E+05	7.20



Impact on M.W. Averages by Flow Rate

CE-4 100000			
Flow rate	Mn (g/mol)	Mw (g/mol)	Mw/Mn
1.0ml/min	2.21E+05	8.37E+05	3.80
0.5ml/min	1.65E+05	8.35E+05	5.05
CE-4 250000			
Flow rate	Mn (g/mol)	Mw (g/mol)	Mw/Mn
1.0ml/min	3.60E+05	1.14E+06	3.17
0.5ml/min	2.20E+05	1.12E+06	5.10
0.2ml/min	1.36E+05	1.06E+06	7.83
CE-3 220000			
Flow rate	Mn (g/mol)	Mw (g/mol)	Mw/Mn
1.0ml/min	2.92E+05	1.05E+06	3.64
0.5ml/min	1.81E+05	1.05E+06	5.82
0.2ml/min	1.45E+05	9.97E+05	6.88

Significant impacts on det M_w and PD.

Ideal SEC separation is necessary for accurate MWD characterization.



Determination of MWD^{1,2}

Basic Light Scattering Equation: $\frac{KC}{R_\theta} = \frac{1}{M_w P(\theta)} + 2A_2 C + \dots$

Form Factor P(θ): $P_\nu = 1 - \frac{16\pi^2 n_0^2}{3\lambda_0^2} R_g^2 \sin^2 \frac{\theta}{2}$

Debye Plot (R_θ/KC vs. $\text{Sin}^2(\theta/2)$): $\frac{R_\theta}{KC} = M_w (1 - \frac{16\pi^2 n_0^2}{3\lambda_0^2} R_g^2 \sin^2 \frac{\theta}{2})$

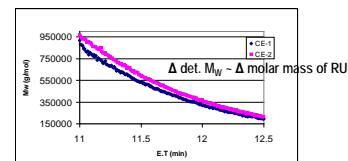
When $\theta \rightarrow 0$: $M_w = [KC/R_\theta]^{-1}$ and $(R_g)^2 = \frac{3m_w^2 M_w}{16\pi^2 n_0^2}$

¹ M_w is the weight average molecular weight of solute
² n_0 is Rayleigh ratio at 9 angle
³ c is the solute concentration
⁴ n_0 is an optical constant: $K = 4\pi^2 n_0^2 (dn/dc)^2 / N_A^2$
⁵ dn/dc is the specific refractive index increment
⁶ n_0 is the refractive index of the solvent
⁷ λ_0 is the vacuum wavelength of the incident laser
⁸ N_A is the Avogadro's number

¹Zimm, B. H., *J. Chem. Phys.*, 16, 1093 (1948)
²Wyatt, P. J., *Anal. Chim. Acta.*, 272 1-40, 1993.



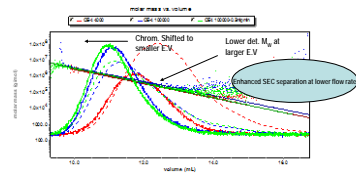
M_w vs. Elution Time for Two Nominal 4000 cP Cellulose Ethers with Differing Substitution Compositions



Polymer backbone dictates hydrodynamic volume, short branches do not contribute to the hydrodynamic volume, but do contribute to molar mass.



Flow Rate Study on 100,000 Nominal cP Cellulose Ethers With Similar Substitution Compositions



The det. M_w at larger elution volume decreased as the flow rate decreased and was superimposable with that of products with lower nominal viscosities, indicating the ideal SEC fractionation was obtained at lower flow rate (0.5 mL/min).



Summary and Conclusions

- A thorough study of the flow rate dependence on the SEC separation of cellulose ethers of varying compositions and molecular weight ranges was performed.
- The fractionation of cellulose ethers with nominal viscosities of 4000 cP was found under ideal SEC separation mechanism. These samples can be used for evaluation of the SEC fractionation of high MW samples having the same chemical compositions.
- The flow rate required to attain ideal SEC fractionation of the cellulose ethers was highly dependent on sample molecular weight. Thus, using carefully selected SEC experimental conditions such as flow rate and sample concentration, SEC coupled with MALLS and DRI can provide accurate MWD characterization of cellulose ethers covering the entire ranges of compositions and molecular weights of commercial interests.

