Performance Characteristics of Fused-Core® Particles.

Who Knew 5µm Particles Could Be So Good?

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Abstract

Fused-core (superficially porous or porous shell) particles have been shown to have distinct advantages over comparable totally porous particles for separating small molecules. Columns of fused-core particles show higher efficiency than totally porous particles of similar size because of superior eddy diffusion properties (smaller van Deemter A term) resulting from the exceptionally narrow particle size distributions of the fused-core particles. The efficiency for columns of 2.7 µm fused-core particles actually rivals that for sub-2 µm totally porous particles with only about one-half the back pressure. Fused-core particles with a wide range of particle sizes and porous shell thicknesses have been synthesized to allow the preparation of stable, efficient packed columns for this study of the effects of these physical characteristics on chromatographic performance. This report describes the effect of these particle characteristics on several factors of separation importance, including reduced plate height, separation efficiency, and sample loading. Surprisingly, the performance of the larger fused-core particles (5 µm) exceeded expectations, likely because larger particles are easier to pack into homogeneous packed beds. Not surprisingly, thinner shells on fused-core particles provide performance advantages but at the cost of decreased sample retention and loadability.

Report Objectives

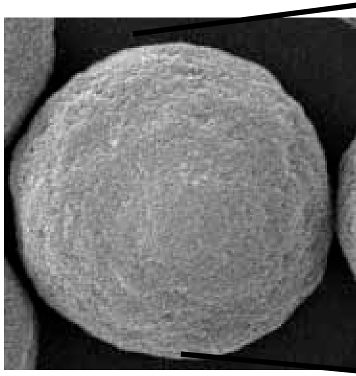
Vary Characteristics of Fused-core particles that are controllable

- **Particle Size – affects efficiency, pressure**
- **Shell Thickness – affects efficiency, sample loading, retention**
- **Pore Size – defines molecular weight range for solutes (not discussed here)**

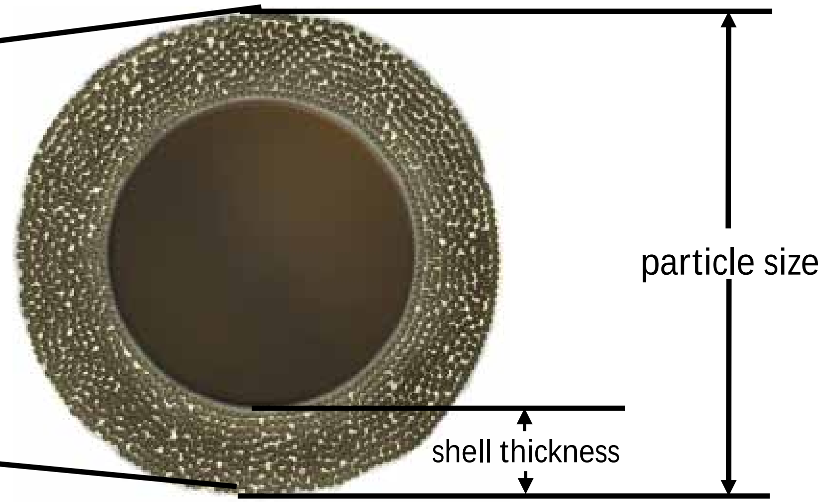
Demonstrate Features and Benefits of Different Fused-core particles

- **Examine performance trade-offs resulting from particle size differences, shell thicknesses**
- **Compare performance of 5 µm totally porous particles with new 5 µm Fused-core particles**
- **Demonstrate advantages of selecting the characteristics of fused-core particles for high-speed or high-resolution separations.**

HALO® Fused-Core Particles



SEM of HALO Fused-core



Graphical representation of HALO Fused-core

Effect of Particle Size

Effect of Particle Size on Plate Height

Columns: 4.6 x 150 mm; Temperature: 30 ^{0}C
Mobile phase: 50% acetonitrile/50% water
Solute: 1-Cl-4-nitrobenzene; Injection: 1 mL
Instruments: <400 bar, Agilent 1100; >400 bar, Agilent 1200

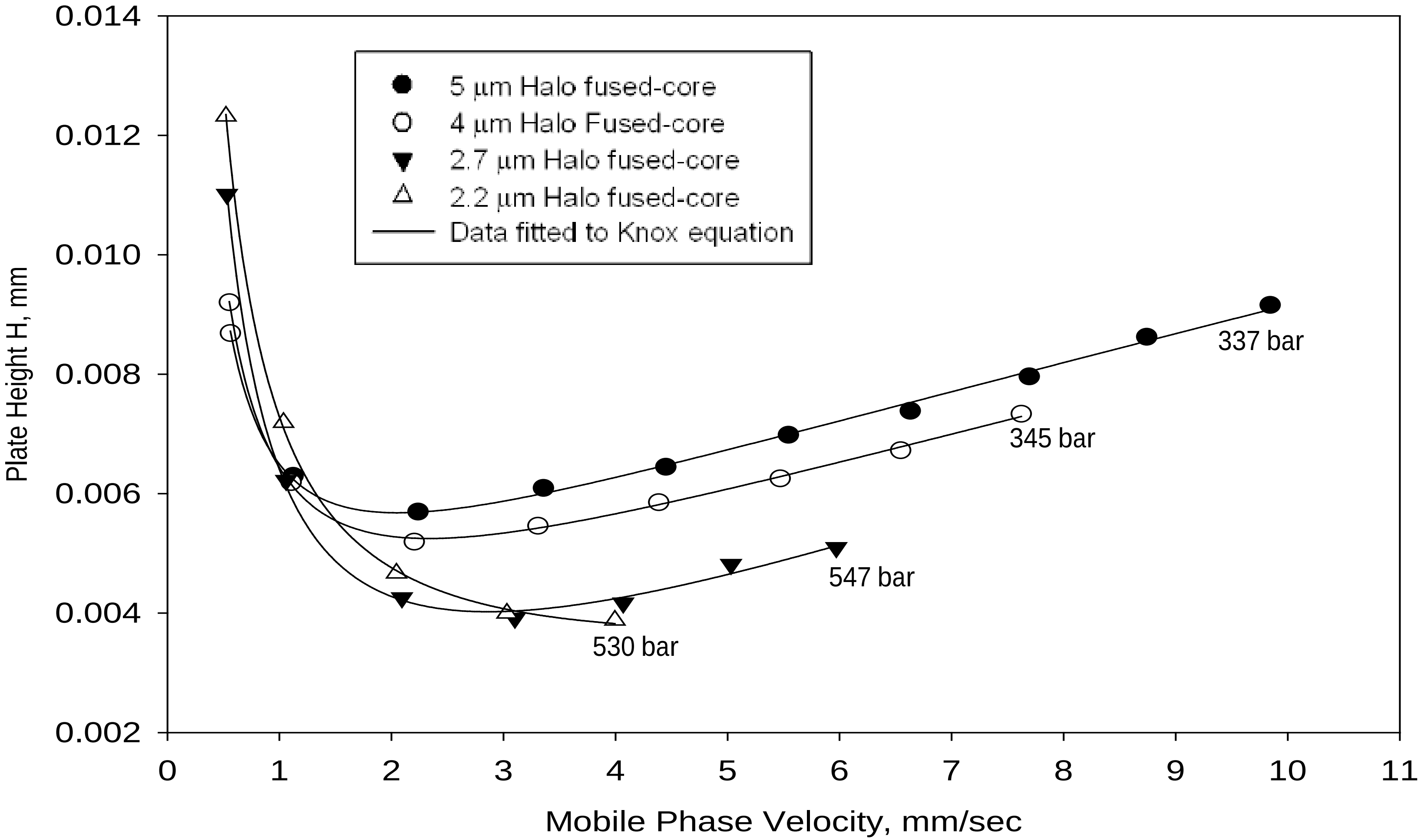


Plate height decreases with decreased particle size, as expected.

2.2, 2.7 µm column limit – 600 bar; 2.2 µm does not reach plate height minimum

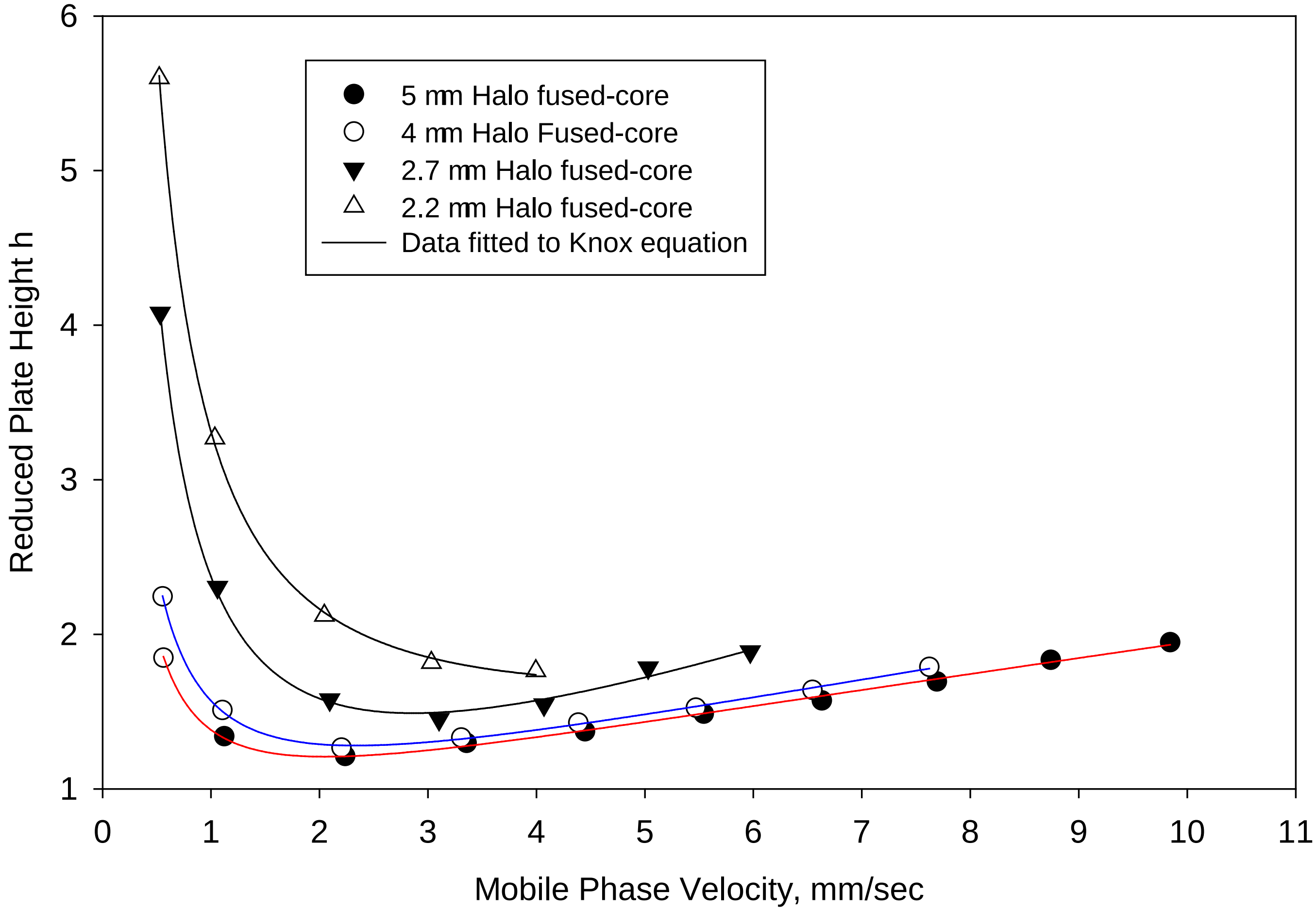
Effect of Particle Size on Reduced Plate Height

Columns: 4.6 x 150 mm; Temperature: 30 ^{0}C

Mobile phase: 50% acetonitrile/50% water

Solute: 1-Cl-4-nitrobenzene: Injection: 1 mL

Instruments: <400 bar, Agilent 1100; >600 bar, Agilent 1200

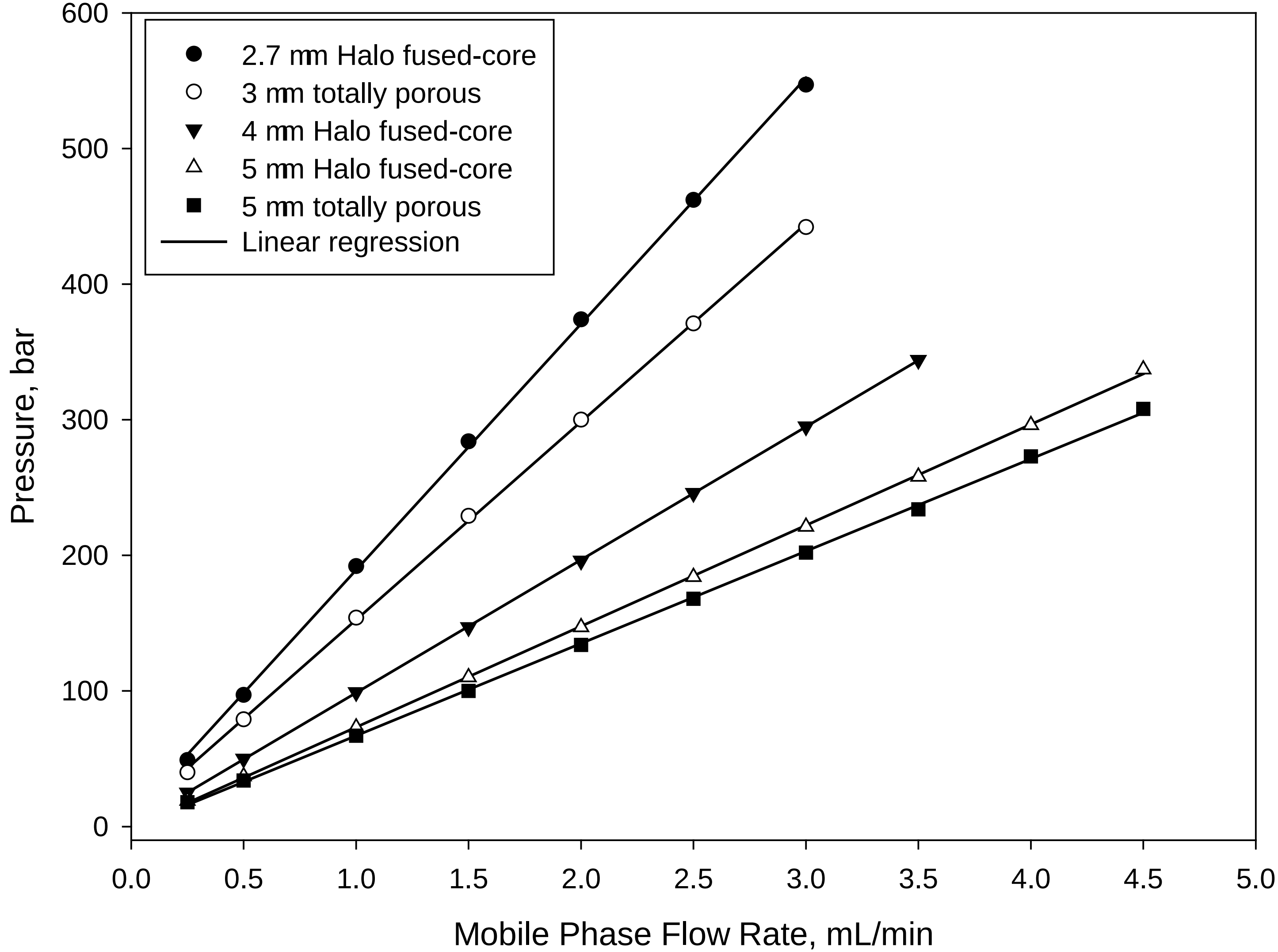


h values lower for 5 µm HALO (h = 1.2) - more homogeneously packed bed structure

Effect of Flow Rate on Column Pressure

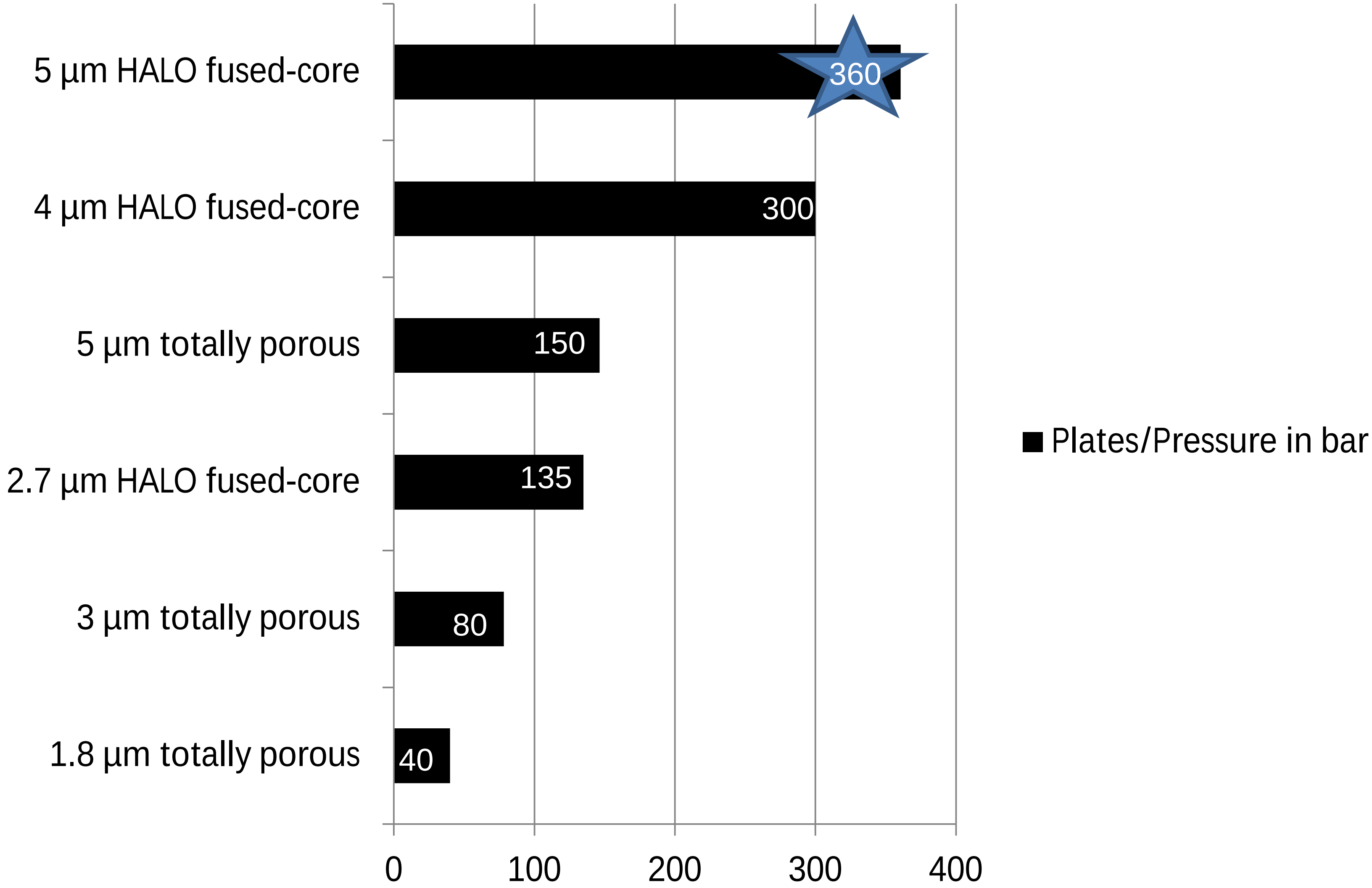
Columns: 4.6 x 150 mm; Temperature: 30 °C

Mobile phase: 50% acetonitrile/50% water



Pressure increases with $\left(\frac{1}{d_p}\right)^2$; small particles require high pressure

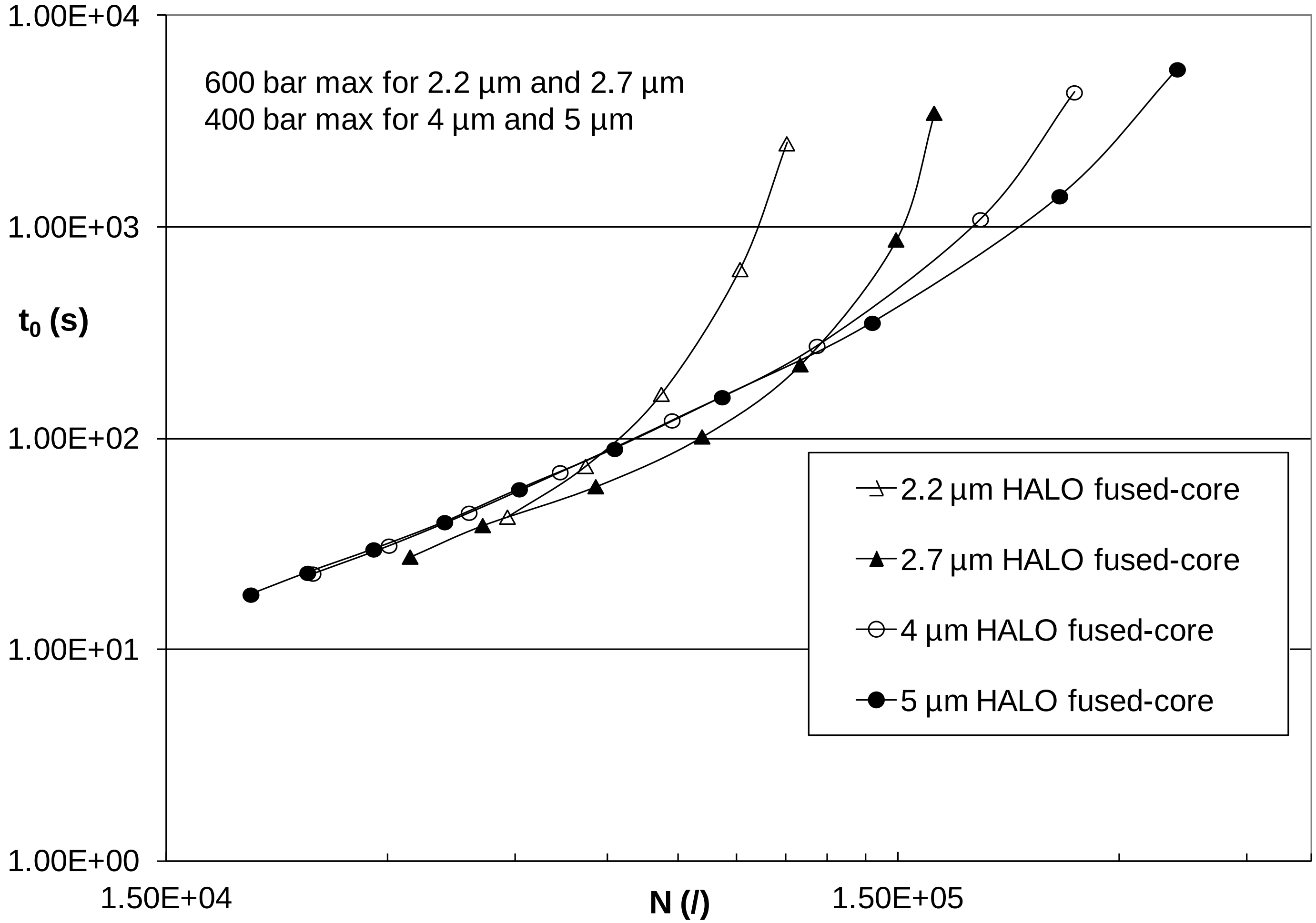
Plates/Pressure for Various Particle Sizes



The 5 µm HALO fused-core particle has more than double the number of plates/pressure of the 5 µm totally porous particles and four times the number of plates/pressure of the 3 µm totally porous particles. Data on 4.6 x 150 mm columns at the plate height minimum, except for 1.8 µm particle (estimated).

Kinetic Plots of HALO Fused-Core Particles

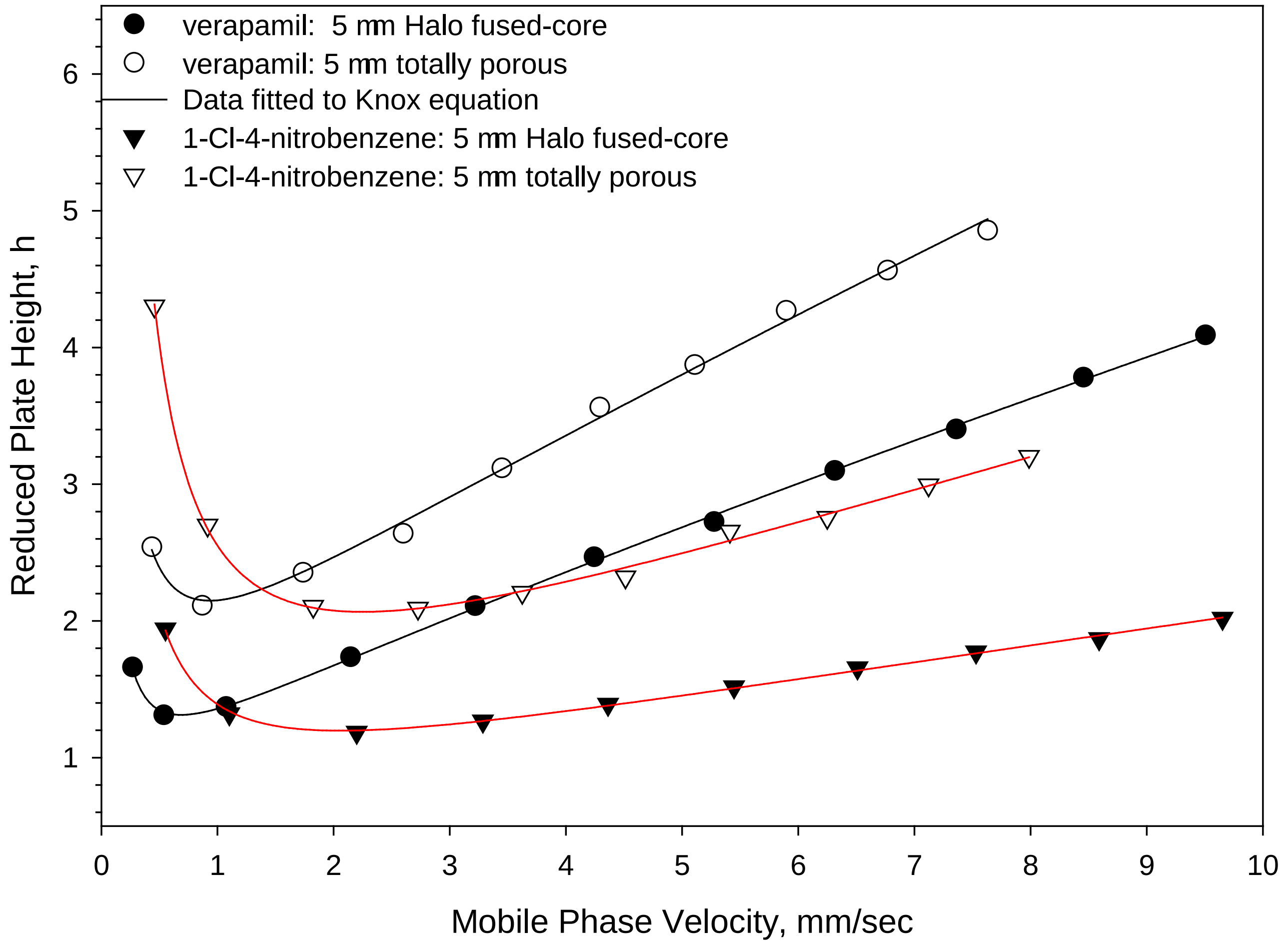
Experimental conditions are as indicated on the Effect of Particle Size panels



For fast separations, use small particles; for highest resolution, use large particles

Comparison: Fused-core vs. Totally Porous Particles

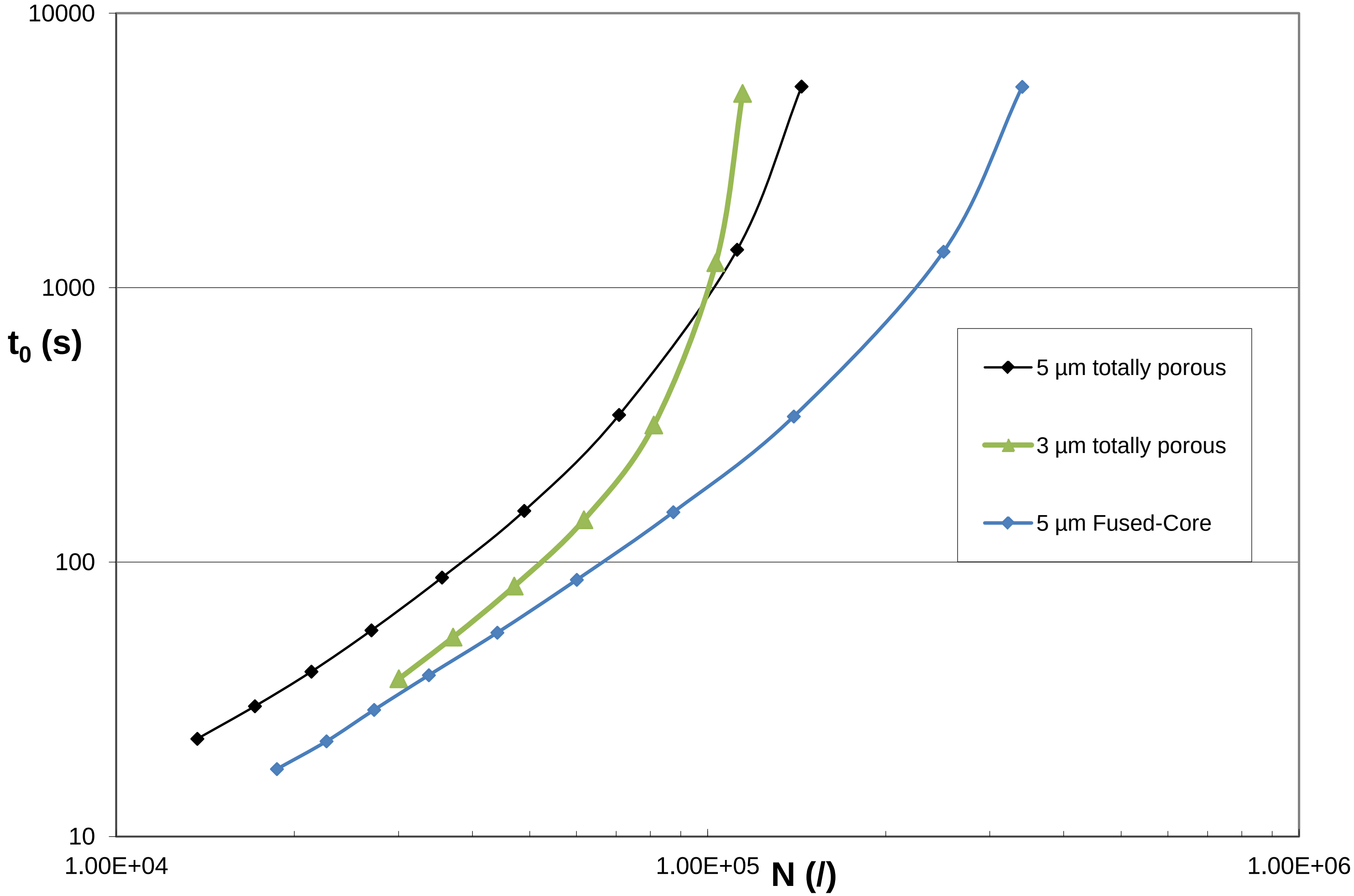
Columns: 4.6 x 150 mm; Instrument: Agilent 1100, autosampler
Verapamil - Mobile phase: 35% acetonitrile/65% 0.1% aqueous trifluoroacetic acid;
Temperature: 40 ^{o}C; fused-core k = 2.8, totally porous k = 6.3
1-Cl-4-Nitrobenzene - Mobile phase: 50% acetonitrile/50% water;
Temperature: 30 ^{o}C: fused-core k = 2.7, totally porous k = 4.3



Fused-core particles: reduced plate height = 1.2 (no extra-column band broadening corrections)
: higher efficiency than totally porous particles

Kinetic Plots

600 bar max for 3 µm totally porous
400 bar max for 5 µm Fused-Core and totally porous



5 µm Fused-Core particle shows 3 µm totally porous performance for fast separations and is superior to both 5 µm and 3 µm throughout the range of use.

Particle Characteristics

Particle Type	Shell thickness (µm)	BET Surface Area (m^2/g)	Average Pore Diameter (Å)	Plates*	Pressure* (bar)
2.7 µm HALO	0.5	135	90	38300	284
5 µm HALO	0.6	90	90	28300	78
3 µm totally porous	N/A	300	100	24200	309
5 µm totally porous A	N/A	300	100	14600	100
5 µm totally porous B	N/A	170	120	14400	63
5 µm totally porous C	N/A	450	100	15300	120

Columns: 4.6 x 150 mm
Mobile Phase: 50/50 ACN/water
Temperature: 30°C
Injection: 1 uL
Instrument: Agilent 1100 or Agilent 1200 with autosampler
***Plates and Pressure: reported for 1-chloro-4-nitrobenzene at the flow rate corresponding to the plate height minimum**

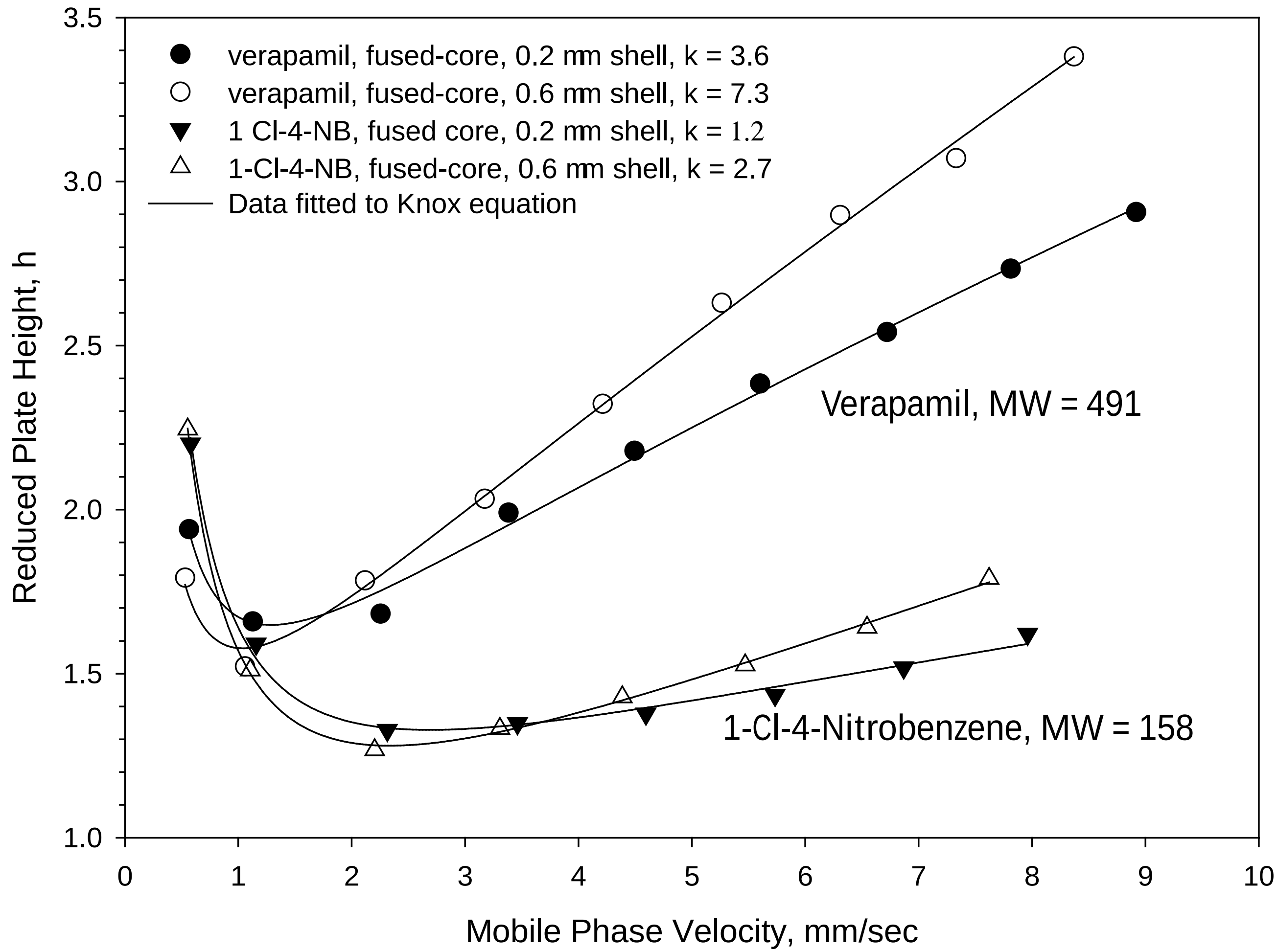
Effect of Shell Thickness

Effect of Shell Thickness and Solute Size on Particle Efficiency

Columns: 4.6 x 150 mm; Instrument: Agilent 1100 with autosampler

Verapamil - Mobile phase - 30% acetonitrile/70% 0.1% trifluoroacetic acid in water, temperature 40 °C, injection: 0.5 mL

1-Cl-4-Nitrobenzene - 50% acetonitrile/50% water, temperature: 30 °C, Injection: 1.0 mL



Lower MW solute: small difference in h due to shell thickness

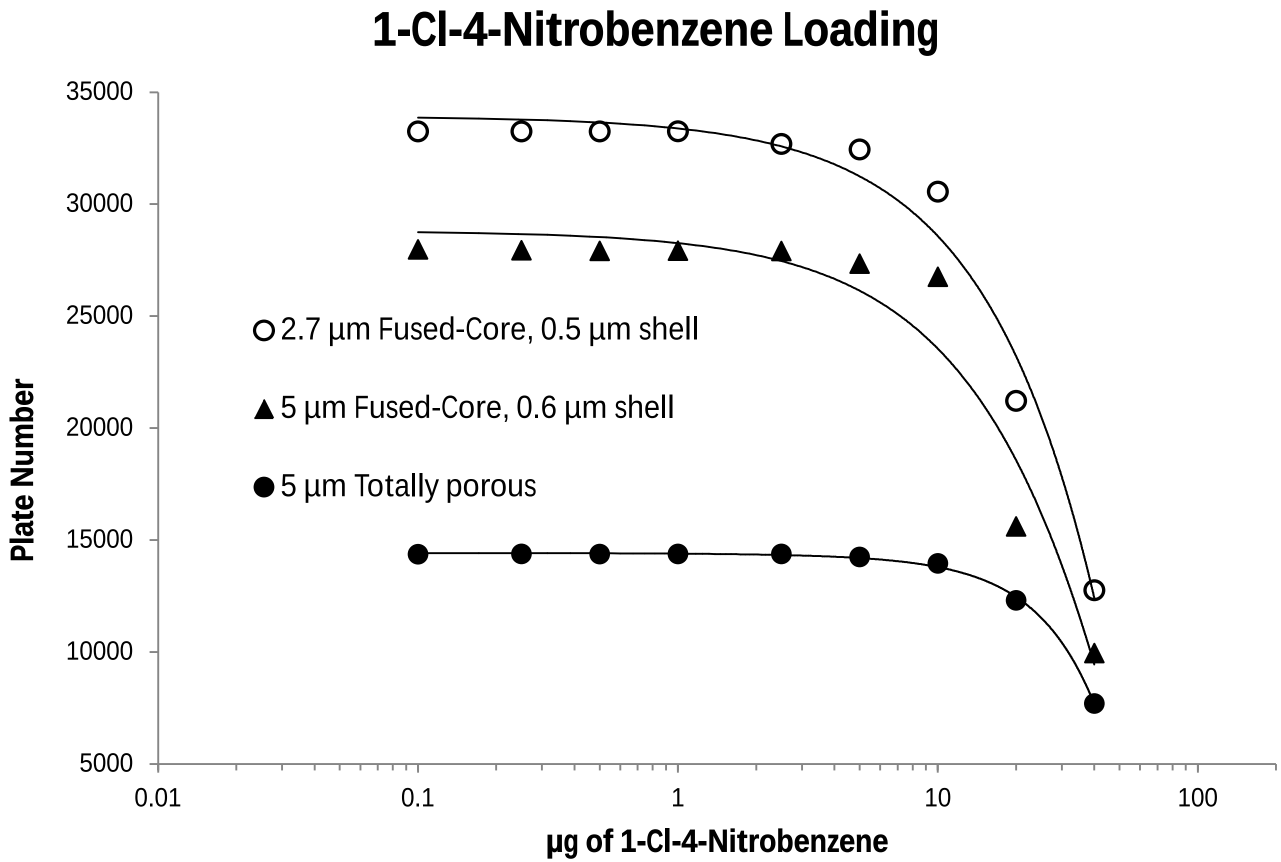
Higher MW solute: larger h with thicker shell; mass transfer poorer

Thinner shell: lower surface area yields reduced retention and solute loading

Effect of Particle on Sample Loading

Columns: 4.6 x 150 mm; Temperature: 30 ℃

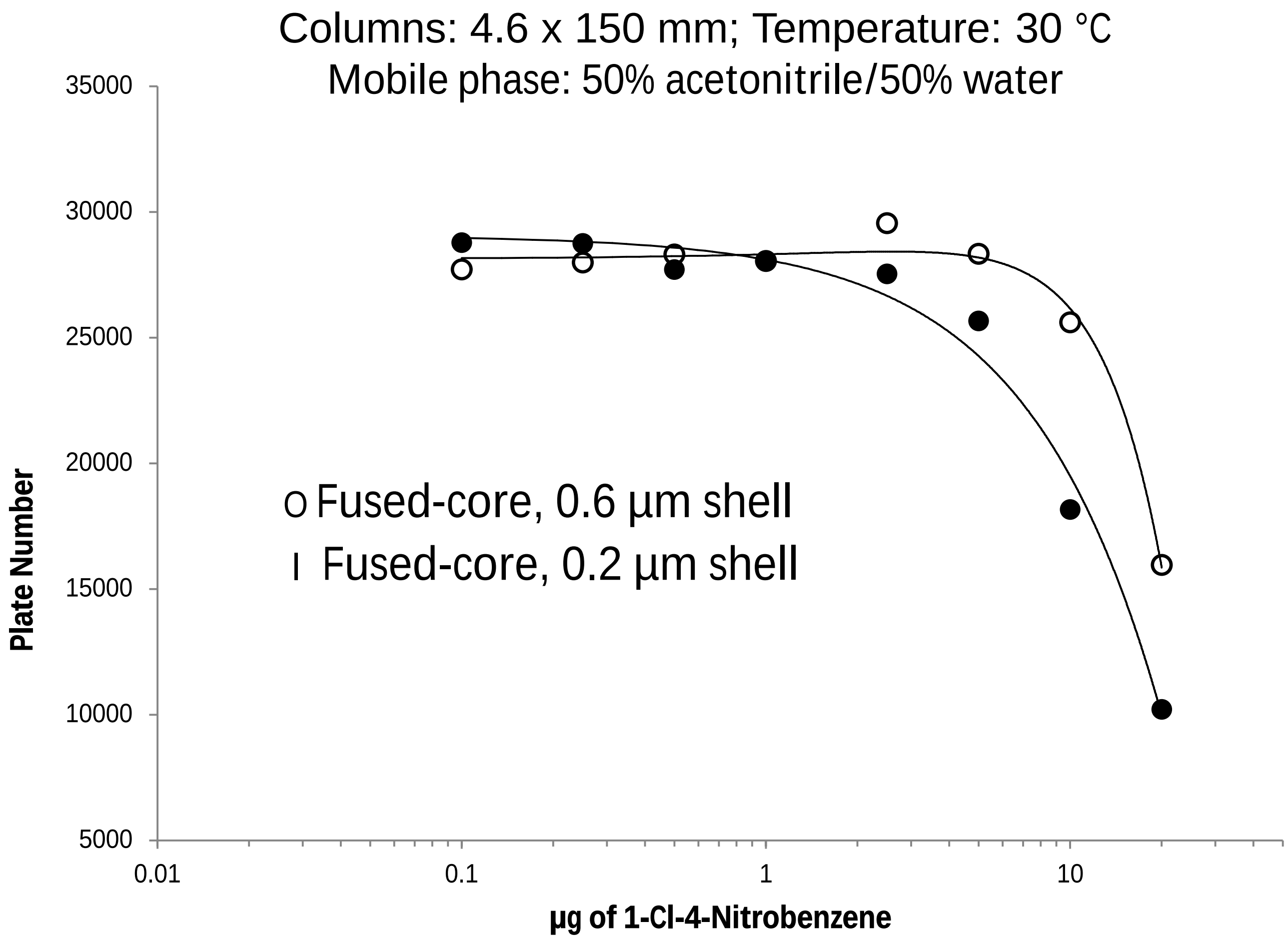
Mobile phase: 50% acetonitrile/50% water



Fused-core particles: solute loading competitive with totally porous particles

Particle size does not affect sample loading.

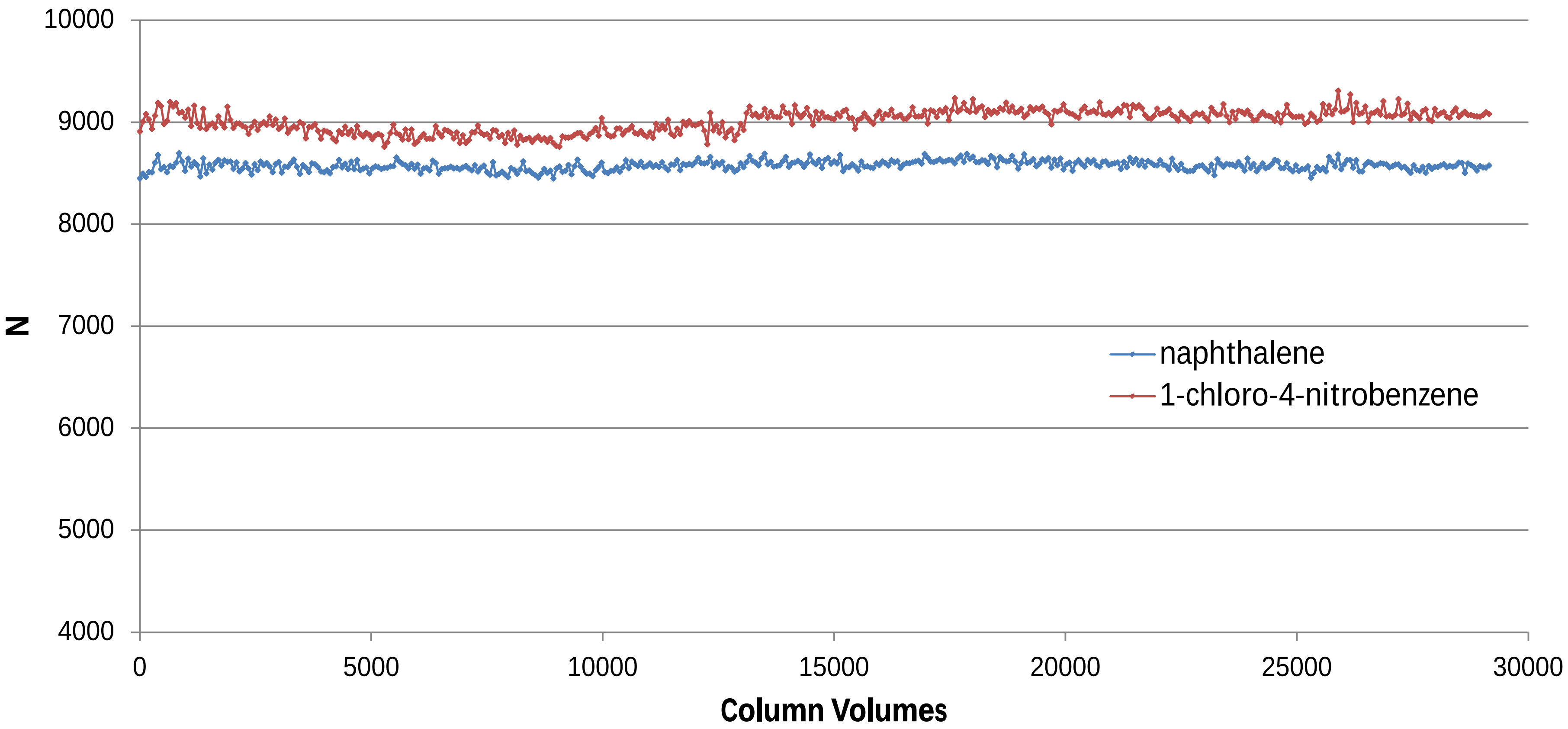
Effect of Shell Thickness on Sample Loading



Greater sample loadability with thicker porous shell.

Stability of 5 µm HALO Fused-Core

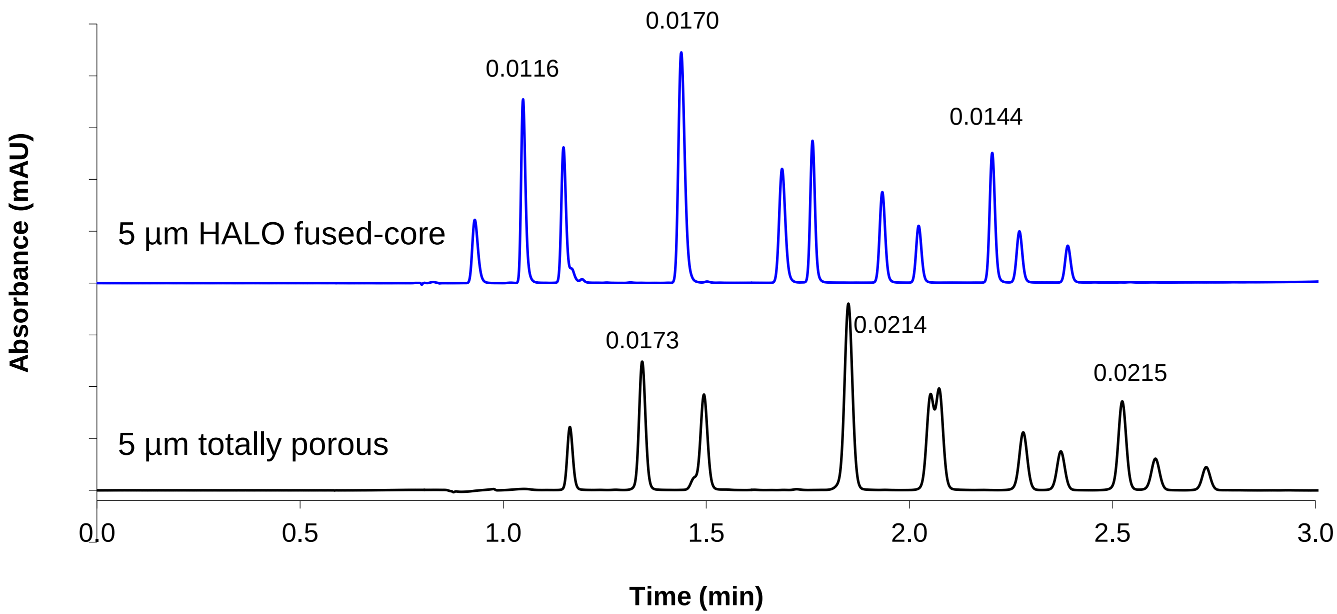
Column: 4.6 x 50 mm of 5 µm HALO C18 fused-core
Instrument: Shimadzu Prominence UFLC XR
Flow rate: 1.8 mL/min, Injection Volume: 1 µL
Mobile Phase: 50% ACN/50% water/0.1% TFA
Temperature = 60 C



No performance change after 450 injections and about 30,000 column volumes of mobile phase.

5 µm HALO Fused-core vs. 5 µm Totally Porous: Phenolics Gradient

Columns: 4.6 x 50 mm Instrument: Agilent 1100 Quaternary
Flow rate: 2.0 mL/min, Injection Volume: 4.8 µL,
Injection Delay 0.41 min.; Detection: 275 nm
Mobile Phase: 3–70% ACN/water w/0.1% HCOOH in 2.7 min.
Temperature = 45 °C
Values above peaks are widths at half height

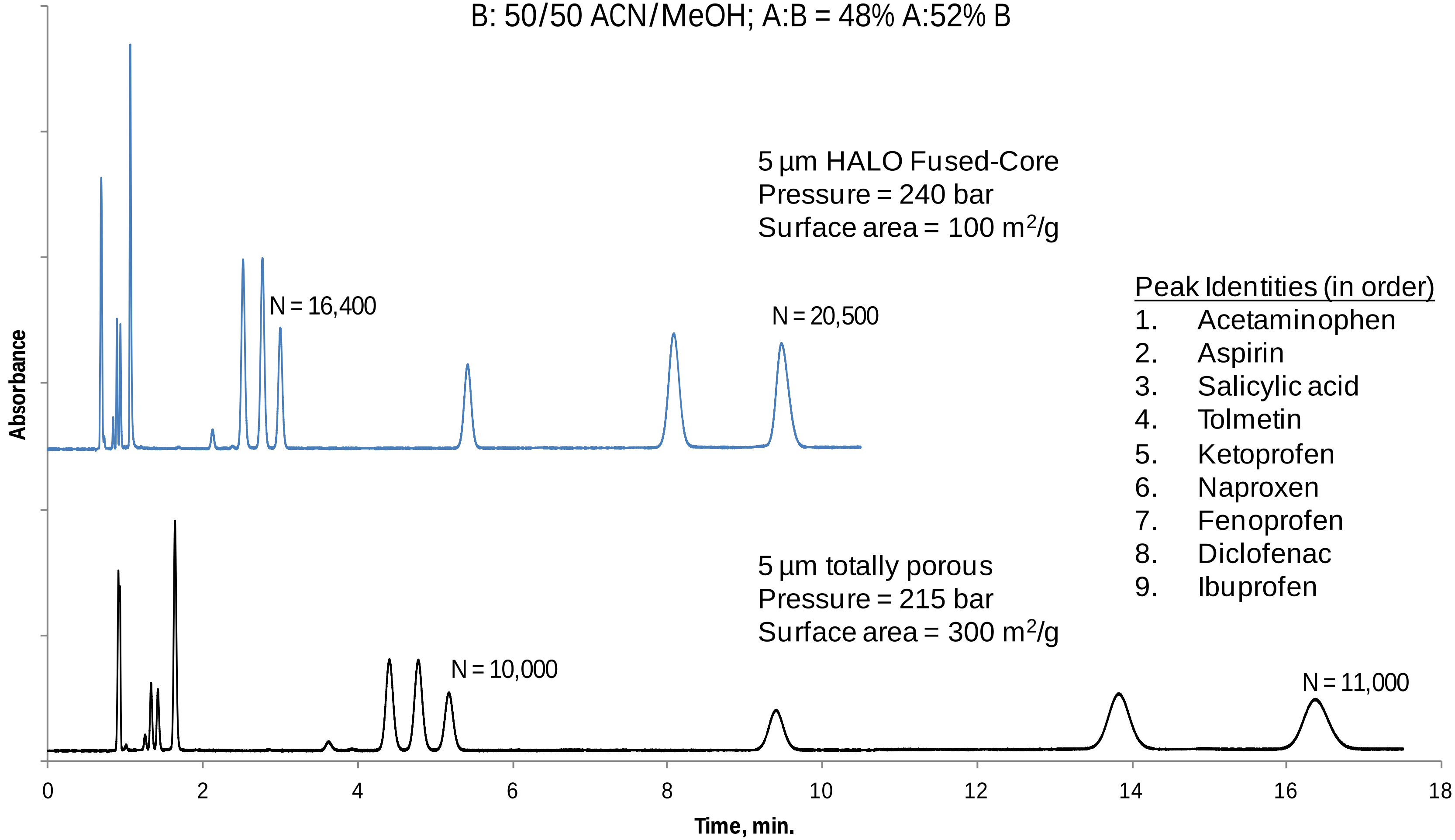


Peak identities (in order): hydroquinone, resorcinol, catechol, phenol, 4-nitrophenol, 4,4'-biphenol, 2-chlorophenol, 4-chlorophenol, 2,2'-biphenol, 2,6 –dichlorophenol, 2,4-dichlorophenol

Faster separation and sharper peaks using fused-core particles.

5 µm HALO Fused-core vs. 5 µm Totally Porous: NSAIDs

Columns: 4.6 x 150 mm Instrument: Shimadzu Prominence UFLC XR
Flow rate: 2.0 mL/min, Injection Volume: 2 µL,
Detection: 254 nm; Temperature = 35 °C
Mobile Phase: A: 20 mM pH 2.5 Potassium Phosphate
B: 50/50 ACN/MeOH; A:B = 48% A:52% B



Nearly 2X improved efficiency at equivalent pressure.

Conclusions

- Reduced plate heights of 5 μm fused-core particles: smaller than smaller fused-core particles.
  - More homogenously packed beds with larger particles?
- Thinner shell for the fused-core particles: flatter van Deemter plot.
  - especially evident for larger molecular weight solutes.
- Sample Loading: thinner shells = reduced surface area and therefore reduced loading and retention
- Plates/pressure: 5 μm fused-core particle has more than double the plates/pressure of 5 μm totally porous particles.
  - 4 times better than 3 μm particles.
- 5 μm fused-core particles can provide faster, more efficient separations compared to 3 μm and 5 μm totally porous particles.