The Theory and Advantages of Solid-Core Particles

Solid-Core (also known as superficially porous (SPP) or fused-core®) particles have become widely utilised in liquid chromatography (LC) separations over the last decade and can offer distinct advantages compared to traditional fully porous particles (FPP). In particular, they are able to offer column performance similar to smaller sized fully porous particles at significantly lower back pressures. This short article discusses the concepts and theory behind solid-core technology and the advantages that it can offer.

Solid-Core Particles

The majority of modern LC phases are manufactured from fully porous spherical silica particles. Solid-core particles have an alternative particle morphology, which consists of a partially porous shell surrounding a non-porous solid silica core (Figure 1). The concept of solid-core particles is well established [1,2], but has gained prominence in recent years. The ability to generate higher efficiencies than comparably sized fully porous particles makes their use highly attractive, allowing higher resolution and/or faster separations to be obtained. It has been shown that columns packed with 2.5-2.7 µm solid-core particles are able to generate theoretical plate values comparable to 1.7 µm fully porous particles, with the advantage of significantly lower back pressure. As a result, columns packed with 2.5 or 5 µm solid-core particles are compatible with standard 400 bar HPLC systems and can be used to increase separation efficiency and drive improvements in sample throughput. This makes solid-core particles an interesting option for increasing separation efficiency, without the need to utilise Ultra High Performance LC (UHPLC) equipment and sub-2 micron particles.

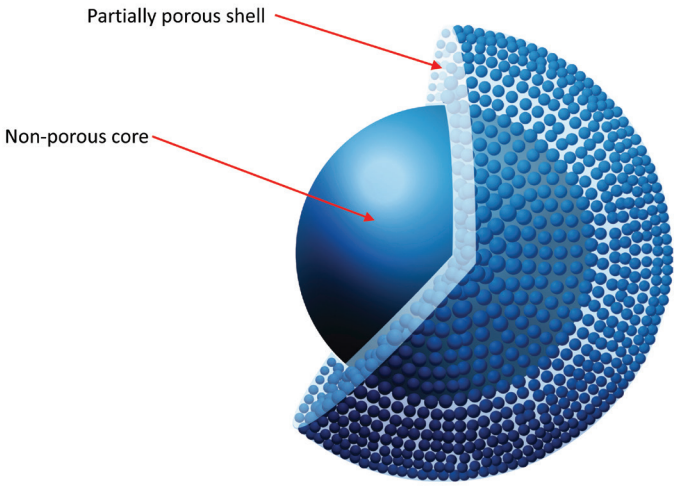


Figure 1: Structure of a solid-core particle.

Why Are Solid-Core Particles More Efficient?

The performance advantages of solid-core particles, relative to their fully porous equivalents, can be understood by considering the van Deemter equation [3] and its three composite terms:

$$HETP = A + \frac{B}{u} + C.u$$

A = Eddy diffusion (analyte paths, packing, wall effects)

B/u = Analyte longitudinal / axial diffusion

C.u = Analyte mass transfer between stationary & mobile phases

It was previously widely stated that improved mass transfer (i.e. the C-term) was responsible for the higher performance of solid-core particles; however, more recent studies have shown that for small molecules (<500 Da), this contributes less than expected and that it is reductions in both the A and B-terms that are primarily responsible [4-6]. The reduction in Eddy-diffusion (A-term) provides the largest contribution to the improved efficiency, potentially due to a more homogenously packed bed for columns packed with solid-core particles [6]. A reduced B-term contribution also improves performance as the presence of a solid-core reduces longitudinal diffusion of the analyte band.

Improved Chromatographic Performance

Two options are typically considered to improve the efficiency of a separation and therefore the resolution achieved between peak pairs. Firstly, column length can be increased to increase the efficiency of the column. This results in a proportional increase in run time and back pressure. The second option is to reduce the particle size of the fully porous packing material. Using this approach, the column length can be reduced to obtain a faster analysis whilst still maintaining separation efficiency. However, this will result in a significant increase in backpressure and is therefore not possible on many HPLC instruments, due to pressure limitations, and therefore requires the use of UHPLC instrumentation. For many laboratories, the capital investment in UHPLC, with associated service costs plus staff training, may not be a

good option. In these cases, the use of solid-core particles may offer a solution.

Figure 2 shows a comparison of the van Deemter plots obtained for 2.5 and 5 µm solid-core particles and fully porous equivalents. By comparing the 5 µm solid-core and 5 µm fully porous particles, a dramatically lower height equivalent to a theoretical plate (HETP) value is obtained. This directly equates to a significant increase in column efficiency. Figure 3 demonstrates that this performance gain is delivered at approximately the same back pressure as the fully porous equivalent. Columns packed with 5 µm solid-core particles can therefore be utilised on any standard HPLC system to improve chromatographic performance over traditional 5 µm fully porous particles, without encountering back pressure issues (Figure 4). In this example, the run time is also significantly reduced due to solid-core particles having a lower porosity and therefore lower surface area for analyte interaction and hence being less retentive. Due to the narrower peaks and smaller peak volumes, sensitivity also increases markedly.

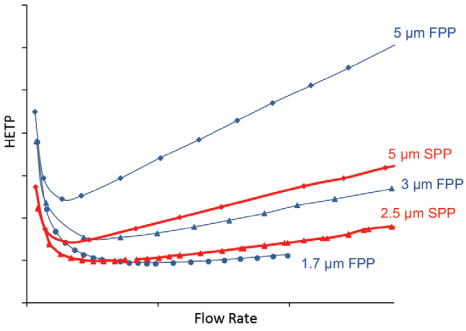


Figure 2: Comparison of van Deemter curves for solid-core particles and fully porous particles.

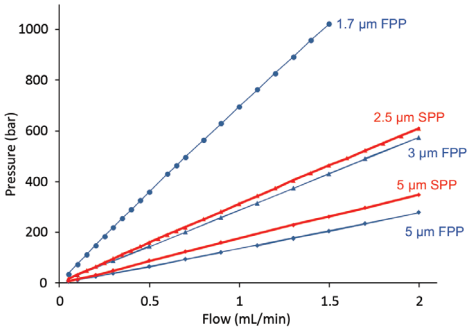


Figure 3: Plot of flow rate vs total backpressure for 50 x 2.1 mm columns packed with solid-core and fully porous particles.

Similarly, Figure 2 shows that 2.5 µm solid-core particles can deliver significantly higher performance than a 3 µm FPP and is similar to the performance of a fully porous 1.7 µm UHPLC particle. However, as shown by Figure 3, this increased performance is obtained at more modest pressures. The higher efficiencies of solid-core particles mean that shorter column lengths can be used, leading to reduced run times and improvements in laboratory efficiency.

For existing methods, provided that the stationary phase characteristics are similar, it may be feasible to migrate separations from fully porous to solid core particles. Figure 5 shows how a column packed with 2.5 µm solid-core particles can be utilised to provide a large increase in performance at HPLC pressures. In this example, the USP method for Naproxen was translated from a 5 µm fully porous column to a shorter column packed with 2.5 µm solid-core particles. The column ID and flow rate are kept constant, whilst the injection volume has been scaled down to the dead volume of the new, shorter column (please refer to references 7 and 8 for further details regarding method translation). Despite the shorter column length, an increase of 81% in efficiency and 55% in resolution was obtained. In addition, solid-core particles also have a higher optimum linear velocity and flatter van Deemter curve. This means that a higher flow rate could potentially be utilised to further reduce the run times without observing a significant drop off in efficiency.

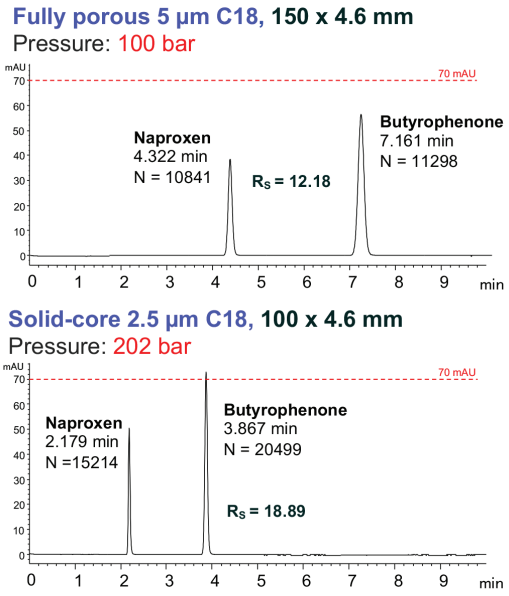
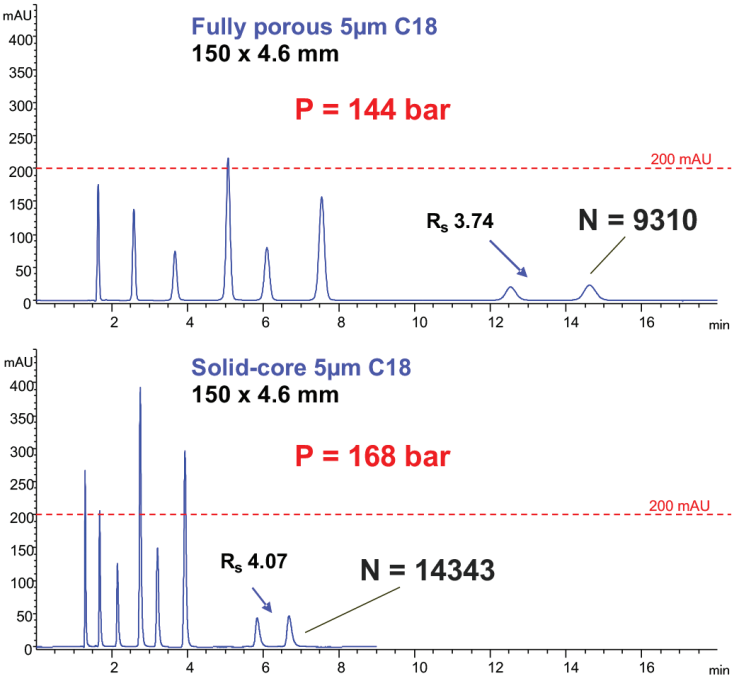


Figure 5: USP method for Naproxen run on a fully porous C18 column and solid-core C18 column. Columns: Avantor® ACE® 5 C18, 150 x 4.6 mm (top), Avantor® ACE® UltraCore 2.5 SuperC18 (bottom). Mobile Phase: H_2O with 2% glacial acetic acid/MeCN (50:50 v/v); Flow Rate: 1.2 mL/min; Temperature: Ambient (22°C); Injection: 20 µL (150 x 4.6 mm), 11.6 µL (100 x 4.6 mm); Detection: UV, 254 nm.



Mobile Phase:	A: 0.1% formic acid in H_2O
	B: 0.1% formic acid in MeCN
Gradient:	20-70 %B in 20 minutes
Flow Rate:	1.0 mL/min
Injection:	10 µL
Temperature:	40 °C
Detection:	UV, 254 nm
Sample:	1. Aspirin, 2. Phenacetin,
	3. Sulindac, 4. Tolmetin,
	5. Naproxen, 6. Nimesulide,
	7. Flurbiprofen, 8. Diclofenac,
	9. Phenylbutazone,
	10. Meclofenamic acid

Figure 4: Separation of antihistamines on a fully porous Avantor® ACE® Excel 5 SuperC18 and solid-core Avantor® ACE® UltraCore 5 SuperC18.

The universal applicability of solid-core particles also means that they can be used to acheive rapid separations similar to those obtained using sub-2 micron fully porous UHPLC particles. In Figure 6, the use of the solid-core technology with MS detection provides a rapid separation of a range of clinically-useful catecholamines and metanephrines in urine. Selective detection was achieved for the individual analytes by MRM using a triple quadrupole mass spectrometer. The exceptional separation efficiency of the solid-core column provides excellent resolution for a rapid 1.1 minute gradient and a total gradient cycle time of just 4.5 minutes.

Conclusion

This short article has highlighted how columns packed with solid-core particles deliver higher efficiencies and faster analyses than equivalent fully porous particles, without the disadvantage of high backpressure. Solid-core particles can therefore be used in a variety of laboratory settings to help drive reductions in analytical run times and increase laboratory efficiency.

References

1. CG. Horvath, BA. Preiss, SR. Lipsky, Anal. Chem., 39 (1967) 1422-1428

2. JJ. Kirkland, Anal. Chem. 41 (1969) 218-220

3. Avantor® ACE® Knowledge Note AKN0010: Chromatographic Band Broadening and the van Deemter Equation (accessed at https://uk.vwr.com/cms/ace_knowledge_notes)

4. G. Guiochon, F. Gritti, J. Chromatogr. A, 1218 (2011) 1915-1938

5. F.Gritti, G. Guiochon, LCGC N. America, 30 (2012) 586-595

6. S. Fekete, D. Guillarme, MW. Dong, LCGC N. America, 32 (2014) 420-433

7. Avantor® ACE® Knowledge Note AKN0023: Gradient Method Translation Using the ACE LC Translator (accessed at https://uk.vwr.com/cms/ace_knowledge_notes)

8. P. Petersson, MR. Euerby, MA. James, LCGC Europe, 28 (2015) 310-320

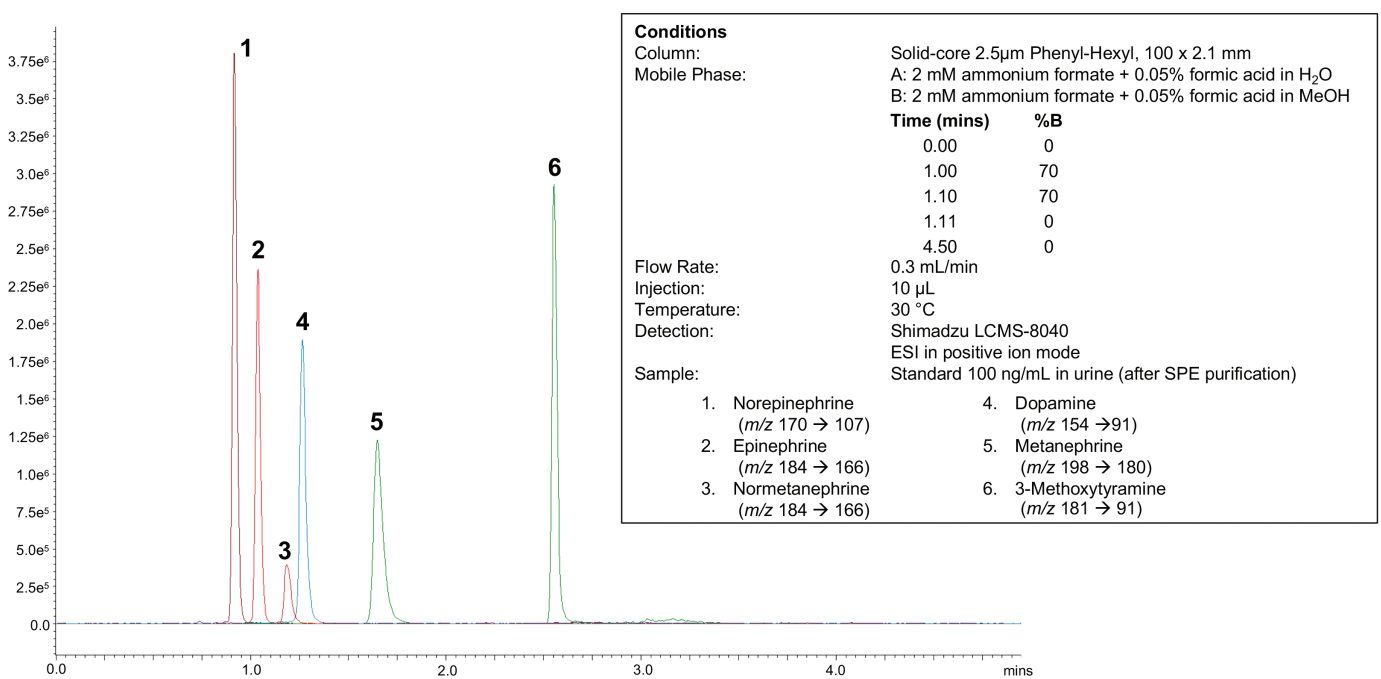


Figure 6: LC-MS^n determination of catecholamines and metanephrines in spiked urine using an Avantor® ACE® UltraCore SuperPhenylHexyl 2.5 µm column. Reproduced with permission of Shimadzu, France.