

# Whitepaper

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# Physical Characterization: Surface Area and Porosity



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# Physical Characterization: Surface Area and Porosity

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## Introduction

Surface area and porosity are two important physical properties that impact the quality and utility of solid phase chemicals including agrochemicals, additives and pharmaceutical active ingredients. Differences in the surface area and porosity of particles within the material, which otherwise may have the same physical dimensions, can greatly influence its performance characteristics. Surface area and porosity play major roles in the purification, processing, blending of chemical products as well as product function, efficacy and stability.

Gas Adsorption analysis is commonly used for surface area and porosity measurements. This involves exposing solid materials to gases or vapors at a variety of conditions and evaluating either the weight uptake or the sample volume. Analysis of these data provides information regarding the physical characteristics of the solid including: skeletal density ( $\rho_s$ ), porosity, total pore volume (TOPV), and pore size distribution.

The Brunauer, Emmett and Teller (BET) technique is the most common method for determining the surface area of powders and porous materials. Nitrogen gas is generally employed as the probe molecule and is exposed to a solid under investigation at liquid nitrogen conditions (*i.e.* 77 K). The surface area of the solid is evaluated from the measured monolayer capacity and knowledge of the cross-sectional area of the molecule being used as a probe. For the case of nitrogen, the cross-sectional area is taken as  $16.2 \text{ \AA}^2$ /molecule.



### BET Surface Area Calculation

For the case of spherical, non-porous particles, the BET surface area is related to the particle diameter (D), or radius (R), and the skeletal density through (Rouquerol, F, *et al.*, 1999):

$$\text{BET} \left[ \frac{\text{m}^2}{\text{g}} \right] = \frac{4 \delta R^2}{3 \delta R^3 \bar{n}_s} = \frac{3}{\bar{n}_s R} = \frac{6}{\bar{n}_s D} \quad (1)$$

Skeletal density ( $\rho_s$ ) is the mass of the solid divided by the volume of the solid excluding open and closed pores. For a non-porous solid, the skeletal density is the same as the geometric or envelope density. The BET surface area, therefore, can be calculated from knowledge of the particle density and diameter or, conversely, the average particle diameter can be evaluated from the measured BET surface area and knowledge of the material density. For a porous material, or one that has an unsmooth surface, the BET surface area is generally appreciably larger than its non-porous analog.

### Pore Volume and Porosity

The porosity of pharmaceutical materials can impact processing and manufacturing. During the manufacturing process the density of these materials can change and are sometimes altered on purpose to enhance the handling properties of the solid materials (e.g., powder flow). Tablet porosity can affect the hardness, disintegration and dissolution of tablets and so understanding tablet porosity could be used to monitor the tabulating process. Some excipients are designed to have specific porosity to enhance product performance.

BET experiments are typically conducted to a relative pressure,  $P/P_0$ , of approximately 0.3 at 77 K, where  $P_0$  is the saturation pressure (Lowell, S. *et al.*, 2004). One can think of the relative pressure in terms of relative humidity, *i.e.*, the experiment is conducted to 30% of the saturation pressure of  $N_2$  at 77 K ( $\approx 230$  torr). At relative pressures above the point at which a  $N_2$  monolayer has formed on the solid, capillary condensation occurs within the pore structure of the material such that the smaller pores are filled more easily and consecutively larger pores are filled as pressure is increased. When the saturation point is approached, *i.e.*,  $P/P_0$  is approximately 1.0, the internal pore structure of the material contains condensed (liquid) nitrogen. The total pore volume can be calculated

### High Surface Area Materials: Nanoparticles

Nanoparticles are being incorporated into a wide range of products including drugs, personal care products, plant growth regulators, specialty additives, medical devices and nutritional products.

High surface area systems can be attained either by fabricating small particles or clusters where the surface-to-volume ratio of each particle is high, or by creating materials where the void surface area (pores) is high compared to the amount of bulk support material. Small particles such as nanoparticles have a high surface-to-volume ratio potentially resulting in increased surface reactivity, increased rate of dissolution, altered bioavailability and most importantly, a changed toxicity profile. Linsinger *et al.* of the Joint Research Council published a report in 2012 entitled '*Requirements on Measurements for the Implementation of the EC Definition of the Term Nanomaterial*'. In this comprehensive report Linsinger *et al.* conclude that according to the definition set forth by the EU, specific surface area by BET surface area measurements can be used to positively classify a material as a *nanomaterial*. BET surface area measurements may also be highly relevant when considering the toxicological aspects of novel materials.

by assuming that the density of liquid nitrogen (LIN) in the pores is the same as that of bulk LIN, such that:

$$TOPV \left[ \frac{\text{cm}^3}{\text{g}} \right] = \text{Max Loading} \left[ \frac{\text{cm}^3 \text{STP}}{\text{g}} \right] \times \left[ \frac{1 \text{ mole}}{22,414 \text{ cm}^3 \text{STP}} \right] \times \text{MW} \left[ \frac{\text{g}}{\text{mole}} \right] \times \frac{1}{\rho_L} \left[ \frac{\text{cm}^3}{\text{g}} \right] \quad (2)$$

Here, MW and  $\rho_L$  are the molecular weight and density of the probe molecule being used, which for  $N_2$  adsorbed at 77 K have values of 28.01 g/mol and 0.807 g/cm<sup>3</sup>, respectively.

Figure 1 depicts a typical 77 K  $N_2$  sorption isotherm with both adsorption and desorption branches of the isotherm measured. The hysteresis seen between the adsorption (lower) and desorption (upper) curves indicates the existence of mesoporosity (pores in the range of 20-500 Å) and provides information regarding the connectivity of the porous network. A detailed discussion of this phenomenon is provided by Gregg, S.J. *et al.*, 1982. Also, illustrated in Figure 1 are the regimes of the isotherm which are examined to evaluate the BET and the TOPV. Since the surface area is gauged by monolayer coverage of  $N_2$  on the surface, it follows that the initial part of isotherm is used for this analysis. In contrast, since the TOPV is evaluated by the maximum amount of condensed  $N_2$ , the latter part of the isotherm is examined for this calculation.  $N_2$  sorption is suitable to characterize materials with pores within the range of ~20 Å to below ~1500 Å (0.15 µm). For materials containing larger pores, mercury porosimetry is the preferred experimental technique and spans the pore range from ~35 Å to ~200 µm.

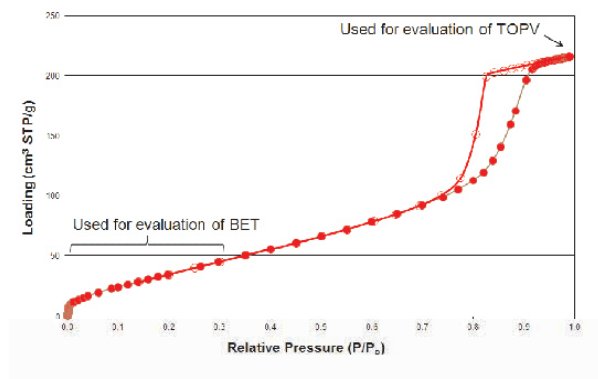


Figure 1 – Typical  $N_2$  adsorption/desorption isotherm measured at 77 K. Closed circles represent adsorption while open circles represent desorption.

Since  $N_2$  condenses in the pores of the solid, TOPV has units of cm<sup>3</sup> of void space per gram of solid. Skeletal density, on the other hand, represents the density of the solid portion of the material and therefore has units of grams of solid per cm<sup>3</sup> of solid. Skeletal density is typically evaluated by helium pycnometry experiments and represents the true solid density of a material when there is no closed porosity. A comparison of TOPV and  $\rho_s$  enables one to evaluate the porosity of a material, since:

$$\text{Porosity} = \frac{\text{cm}^3 \text{void}}{\text{cm}^3 \text{solid} + \text{cm}^3 \text{void}} = \frac{TOPV}{\frac{1}{\rho_s} + TOPV} \quad (3)$$

Porosity reveals the total fraction of void space within a material but does not address the size of the voids or their distribution. Traditional pore size distribution analysis is performed by capillary condensation experiments such as  $N_2$  sorption and the application of various forms of the Kelvin equation which relates the average pore size filled at a particular relative pressure.

Figure 2 illustrates an  $N_2$  isotherm with a well-defined pore structure. The sharp rise in the loading at low values of  $P/P_0$  indicates a high surface area (see Figure 1 for comparison), the abrupt loading transition within the  $P/P_0$  range of 0.3-0.4 reveals a unimodal pore size and the absence of hysteresis suggests the existence of macropores since unrestricted monolayer-multilayer adsorption occurs at high  $P/P_0$ . The inset to Figure 2 shows the pore size distribution from a modified Kelvin analysis using a BJH thickness curve (Rouquerol, F., *et al.*, 1999).

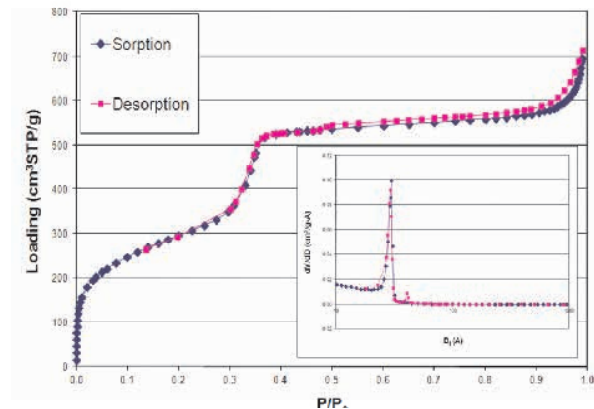


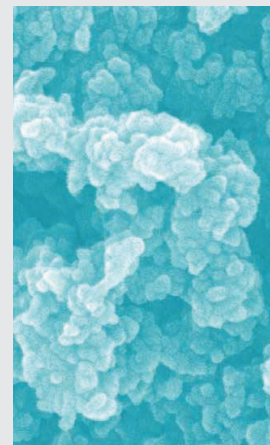
Figure 2 – Typical  $N_2$  adsorption/desorption isotherm measured at 77 K. Inset is the pore size distribution evaluated from analysis of the isotherm.

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**Controlled Release Polymer Formulations**

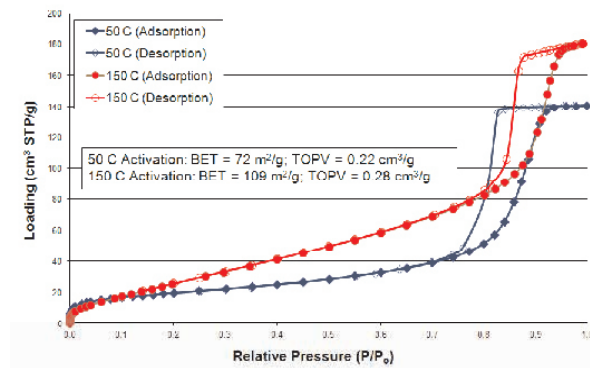
Polymeric encapsulation systems have been developed for controlled release of active species across many chemical applications. Insecticide formulations, for example, have been developed with the aim to improve efficacy of the insecticide whilst achieving a reduction in environmental contamination and human exposure through a controlled release matrix. Encapsulated biostimulant products have been developed to improve product stability and control the release of plant nutrients over time.

The particle size of these polymer excipient can greatly influence release performance in the hydrophilic matrix. Where the particle size is small the system will have a greater surface area relative to equivalent weights of samples with larger particle size. A larger surface area provides a better polymer-water contact, thus enhancing the rate of polymer hydration and release of active. A good understanding of both particle size and surface area will assist with product formulation development.



**Sample Activation**

Sample preparation (or activation) prior to sorption analysis is a key aspect of material characterization. To perform a meaningful analysis the material should be in a state that is representative of how it will be used and pretreated accordingly. It is necessary to remove gas and vapors which may have adsorbed onto the surface from the ambient air. If this is not done, the surface area result can be low and non-reproducible since an indeterminate amount of the surface will be covered with these materials. This step must be done whilst making every effort not to change the original surface of the sample. Activation consists of heating a sample under conditions of dynamic vacuum or purging with an inert gas to remove adsorbed, volatile compounds from the surface. Isotherms and, consequently, BET and pore size distribution results can be greatly influenced by sample preparation since the pore structure can be collapsed upon too stringent activation or insufficiently cleaned (leaving the internal pore structure partially blocked) upon too mild a conditioning. High temperature activation, therefore, can either increase or decrease the porosity. Caution must be used when heating some common pharmaceutical excipients because melting, dehydration, sintering, and decomposition are processes that can drastically alter the surface properties of the sample. An example of the appreciable effect that pretreatment can have on the material structure is provided in Figure 3.



**Figure 3 – N<sub>2</sub> isotherms measured at 77 K. This is an example of a higher temperature sample activation leading to enhanced cleaning of a material and, consequently, a higher surface area and total pore volume.**

**Conclusion**

Understanding the physical properties such as surface area or porosity of solid phase chemicals is key to successful product and process development. Gas adsorption analysis is one of the most commonly used techniques for surface area and porosity measurements for these materials.

## Intertek Physical Characterization Expertise

Intertek provides expert surface area expertise via BET approaches at both R&D level or to GLP / cGMP if required.

Available from our laboratories in Europe and the US, Intertek have regularly applied gas adsorption approaches, over the years, to a range of sample types.

Physical characterization expertise provides data to assist with formulation or process development, regulatory submission data, QC testing, GMP lot release and manufacturing troubleshooting.

The wider Intertek physical characterization capabilities include microscopy (SEM, EDX, TEM and LM), X-Ray Powder Diffraction, (XRPD), thermal analysis (DSC and TGA) and particle size technology:

- Surface area & porosity
- Particulate size, distribution and shape
- Zeta potential
- Powder flow characteristics
- Polymorph analysis
- Microstructure analysis e.g. encapsulation
- Thermal properties
- Physico-chemical properties

## Contact details

For more information on please contact Intertek. our experts would be delighted to answer your questions.

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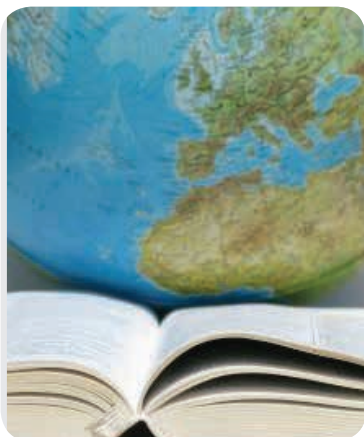
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## References

- Gregg, S.J. and Sing, K.S.W., "Adsorption, Surface Area and Porosity, 2nd Edition", Academic Press Inc., San Diego (1982).
- Lowell, S., Shields, J.E., Thomas, M.A. and Thommes, M., "Characterization of Porous Solids and Powders: Surface Area, Pore Size and Density", Kluwer Academic Publishers, The Netherlands (2004).
- Rouquerol, F., Rouquerol, J., and Sing, K., "Adsorption by Powders & Porous Solids", Academic Press, London (1999).
- Sing, K., "The use of nitrogen adsorption for the characterization of porous materials", Colloids and Surfaces A: Physicochem. Eng. Aspects, 187-188 (2001), 3-9.



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