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Vapour Sorption Properties of Building Materials using Gravimetric Sorption Instrumentation - an Overview

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DVS Application Note 104

Dynamic Vapour Sorption (DVS) has long been used for investigating the interaction of water and organic vapours with solid materials. The versatility and impact of DVS has particular importance in the study of building materials. This overview application note summarises several examples of using DVS to study cements, wood, insulation, and other building materials.

Introduction

The interactions of water vapour (moisture) with solid materials have impact over a wide range of industries and materials including pharmaceuticals [1] foods [2,3], fuel cell membranes [4], and polymers [5]. In particular to building materials [6], moisture sorption has significant implications for cements [7], woods [8], insulation materials [9], and fibres [10]. Moisture damage is a significant factor limiting a building's lifespan [11]. As well, moisture infusion through a building's outer structure can have a significant effect on indoor air quality and air-conditioning loads [11]. The use of automated gravimetric vapour sorption instruments has become standard practice in many industries for investigating the vapour sorption properties of solid materials. This overview paper outlines how Dynamic Vapour Sorption (DVS) instruments can be used to investigate several different types of materials used in the building industry. Examples will be discussed from literature references and results generated by Surface Measurement Systems.

Method

A schematic of the DVS-Advantage instrument is shown in Figure 1. The instrument measures the uptake and loss of vapour gravimetrically using the SMS UltraBalance. The SMS UltraBalance comes in two configurations: (1) one gram capacity with a mass resolution of at least 0.1 μg and (2) four gram capacity with a mass resolution of at least 1.0 μg . The vapour partial pressure around the sample is generated by mixing saturated and dry carrier gas streams using electronic mass flow controllers. The DVS-Advantage instrument has the unique capability to actively measure and control the concentration of water and a wide range of organic vapours. This is accomplished by utilising a proprietary optical sensor which is specifically tuned for a wide range of solvents. This technology allows the instrument to measure and control organic vapour concentrations in real time. The DVS-Intrinsic instrument has similar balance configurations (1 gram or 4 gram capacity), but is designed for water vapour only.





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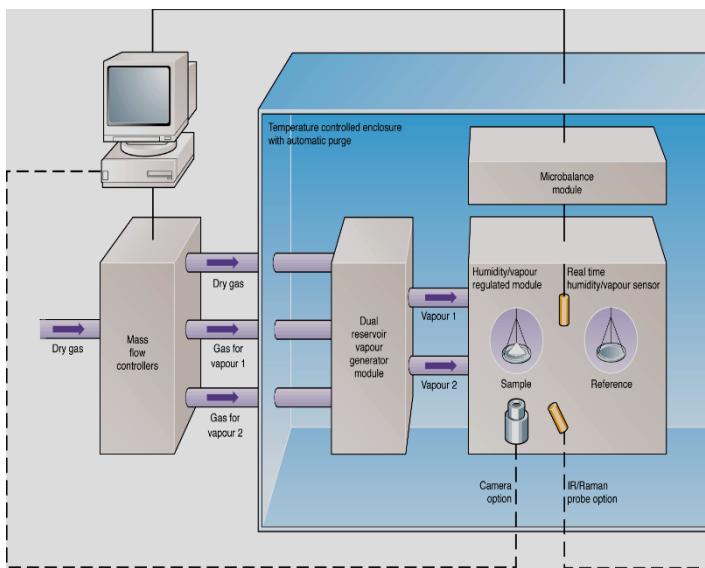


Figure 1. Schematic overview of the SMS DVS-Advantage instrument.

Results

Cements

Studying the moisture transport behaviour in porous building materials, like cements, is essential to improving their performance [11]. For these materials, vapour concentration and temperature are considered to be the principal driving principals in understanding moisture transfer. For concrete and reinforced concrete structures, degradation pathways, such as; carbonation, chloride or sulphate ingress, freezing and thawing cycles, and alkali-silica reaction, are all dependent on moisture [12,13]. For instance, there is a critical relative humidity range where carbonation is favoured, which is important for accelerated carbonation tests. Additionally, water has the ability to impair the mechanical durability of reinforced concrete structures. Also, hardened cement paste is known to be a dynamic system with regards to moisture content [14]. Further, water sorption isotherms have been used to study the hardening processes of cement [15]. Water sorption-desorption isotherms are essential parameters for durability evaluation and prediction [12]. For these reasons, water sorption studies on cements or cement components using

gravimetric sorption instrumentation has been used many researchers [14,15,16,17,18].

Figure 2 shows the dehydration kinetics (a.) and resulting desorption isotherm (b.) for a cement paste sample at 25 °C. The isotherm in Figure 2b shows evidence of dehydration occurring in several steps. There is rapid mass loss above 90% RH, most likely due to loss of loosely bound water. There is gradual mass loss between 90% and 40% RH followed by a sharper mass loss at 30% RH, which may be due to loss of internal or hydrated water. There is another sharp drop in mass as the sample is fully dried at 0% RH.

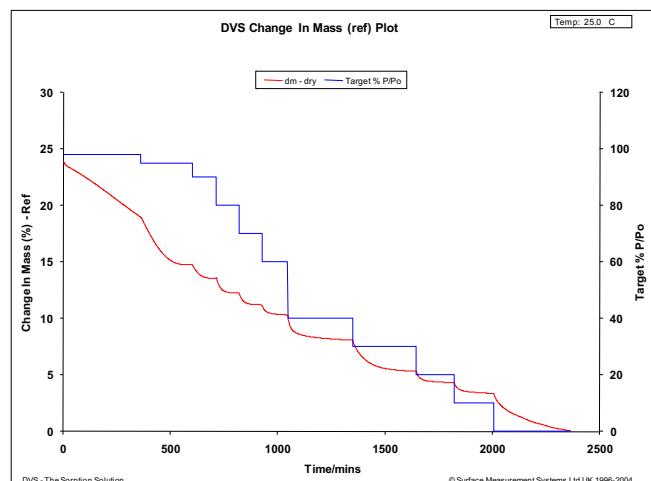


Figure 2(a).

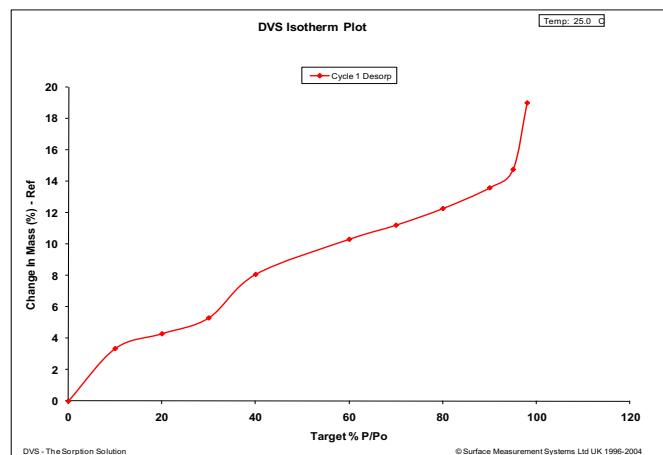


Figure 2(b).

Figure 2. Drying kinetics (a.) and desorption isotherm (b.) for a cement paste sample at 25.0 °C.



The sorption kinetics for two different cement samples has been studied previously in SMS Application Note 09. In this study two different dry cement powders were exposed to 95% RH at 40 °C and the mass was monitored over time (see Figure 3). The Cement 1 sample rapidly increases in mass initially, followed by a more gradual increase over time. In contrast, the Cement 2 sample shows a very small mass increase initially, followed by a large increase in mass after nearly 24 hours of exposure to 95% RH conditions. Therefore, the Cement 2 sample might have a longer storage lifetime compared to the Cement 1 sample. These two simple studies illustrate how gravimetric moisture sorption experiments can be used to study cement-based materials. Experiments could be expanded to include a wide range of samples (i.e. cement components, wood-cement composites, synthetic cements) and a wide range of conditions (up to 85 °C with the correct instrument configuration).

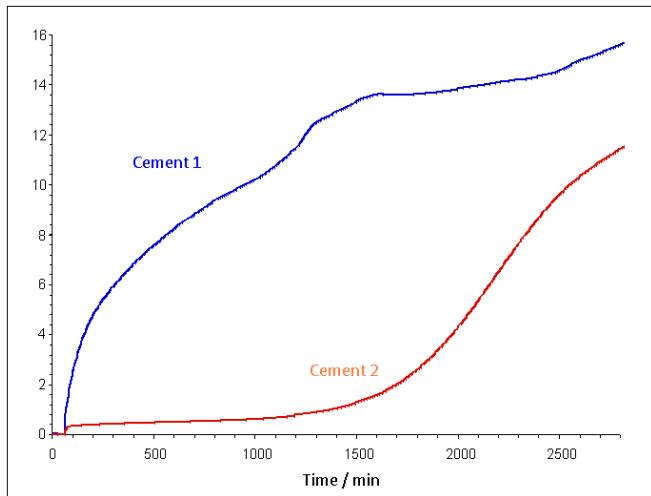


Figure 3. Moisture sorption kinetics for two dry cement powders at 40.0 °C.

Wood and Wood Composites

Moisture control and measurement are also critical parameters for wood and wood composites. For instance, moisture plays a key role in the fungal degradation and weathering of wood-plastic composites [19]. Moisture content change and moisture distribution can cause cupping of boards [20]. Additionally, oriented

strandboard is hydroscopic and is dimensionally unstable when exposed to high humidity conditions, leading to a loss of mechanical properties and aesthetic quality [21]. Sorbed water molecules on the surface of wood also affect the rate of photochemical degradation [22]. Moisture sorption behaviour and diffusion processes are also of interest for evaluating drying kinetics [23].

For several reasons, including those listed above, moisture sorption uptake, kinetics, and distribution have been the focus of numerous research papers on wood and wood-based composites [19,20,21,22,23,24,25]. In one such study, the hysteresis between sorption and desorption isotherms was related to wood stability: the narrower the hysteresis, the more stable the wood sample was to fluctuating humidities [26]. In another study, water vapour diffusion coefficients were found to be a function of wood species, wood grain direction, wood age, and tree ring location. Earlywood had higher sorption rates and diffusion coefficients than latewood. Similarly, outer tree rings had higher sorption rates and diffusion coefficients than inner tree ring locations [23]. Wax and resin loadings in oriented strandboard showed an inverse relationship with water vapour sorption (i.e. higher loadings lead to decreased water sorption capacity). Further, wax loading had a more significant impact on water sorption properties than resin loading [21].

Figure 4 displays representative water sorption isotherms for sawdust (Figure 4a) and a solid piece of wood (Figure 4b) measured at 25 °C. These isotherms illustrate the versatility of the DVS to measure wood samples in different geometries: sawdust, chunks, films, fibres, or slabs. These different geometries can be used to determine moisture sorption kinetics and diffusion coefficients (see SMS Application Notes 7, 12, 16, and 30) in addition to the equilibrium isotherm values.

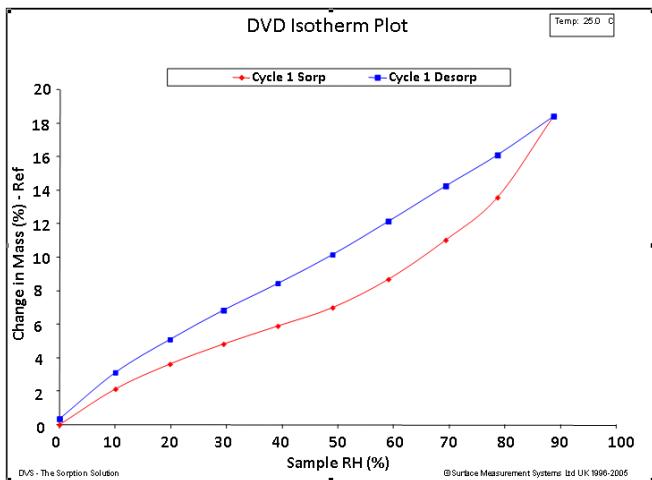


Figure 4 (a)

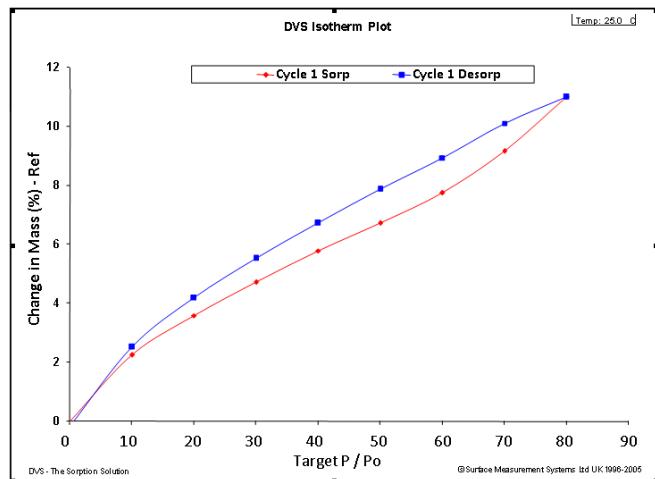


Figure 4 (b.)

Figure 4. Water sorption (red) and desorption (blue) isotherms at 25 °C measured on sawdust (a.) and a solid wood sample (b.).

Insulation, Fibres, and Textiles

Moisture sorption also has implications for interior and exterior insulation and interior fabrics, fibres, and foams. Several researchers have addressed this area in recent studies [27,28,29,30,31,32]. In fact, the moisture sorption properties of textile fabrics and foams have been studied extensively by the Lund Institute of Technology [33,34,35]. Moisture properties of textile fabrics are dependent on many factors including: fibre type, spin and twist of the yarn, fabric weight, and weaving technique [36]. Water vapour management is critical for these materials as it

can affect moisture buffering, microbial growth, indoor air quality, and long-term material performance. Moisture buffering of internal building surfaces can be critical for health aspects (i.e. mould growth, control of dust mites, and chemical emissions from building materials) and hygrothermal management of building environment [35].

As outlined above, measuring water vapour sorption characteristics for insulation, fibres, foams, and textiles is important for building construction. The DVS instrument is well-suited for these materials. Figure 5a displays the water sorption properties for two carbon cloth samples. The red line is for a plain carbon cloth, while the green line is for a bilayer carbon cloth impregnated with particulate carbon. The plain sample shows a very low uptake, indicating the surface is very hydrophobic. The maximum uptake at 95% RH is less than 0.01 wt %. Despite the low uptake, the sensitivity and excellent baseline stability of the SMS UltraBalance allow accurate isotherm measurement. The bilayer sample shows a much higher uptake and a hysteresis typical for mesoporous materials (see SMS Application Notes 37 and 38). This is due to the presence of carbon powder, which is porous and has a significantly higher water sorption capacity. DVS is able to clearly differentiate these two otherwise similar samples. Figure 5b displays the water sorption properties of a glass fibre. The sample uptakes water readily during the sorption phase, increasing by almost 1 wt % at 95% RH. However, during the desorption phase, water removal is much slower as the sample retains almost 0.4 wt % of water at the end of the desorption isotherm. This water retention is due to the strong affinity for water to the fibre surface. Over time, this long-term water retention could lead to microbial growth or reduced performance for fibres in insulation applications.

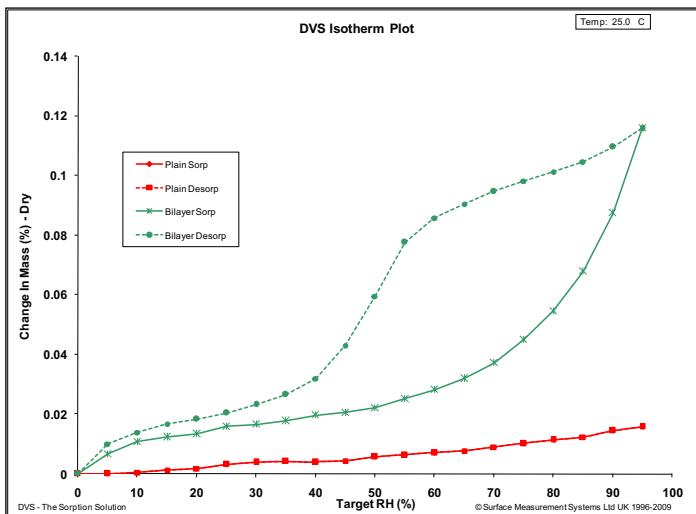


Figure 5 (a.)

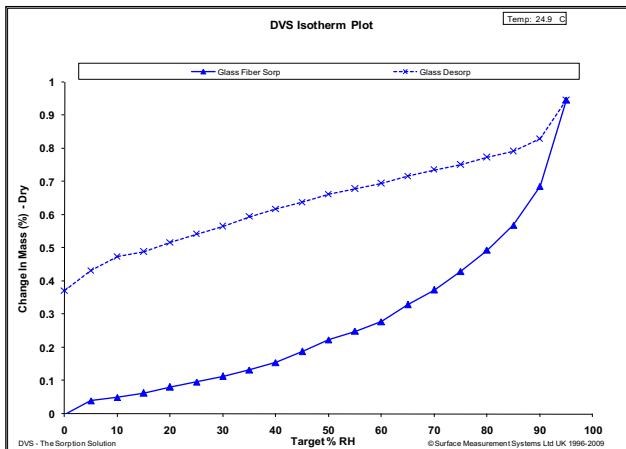


Figure 5 (b.)

Figure 5. Water sorption isotherms for two carbon cloth samples (a.) and glass fibres (b.).

Asphalts

Water sorption/diffusion properties are critical to the performance of roofing components. Not only is it important to study how liquid water permeates roofing materials, but also the drying rate of a wet roof or the ability of internal moisture to escape from a roofing assembly is of interest. In a recent study, the water permeance of different roofing materials showed differences between #15 asphalt roofing felt and #30 asphalt roofing felt [37]. Not only does the material affect the moisture resistance of roofing materials, but also the age of the materials. This is particularly a problem for water-based coatings, as water

sensitive stabilizers and additives can leach out over time [37].

Additionally, debonding of asphalt from the aggregates due to displacement by water is a well-known phenomenon for roadway materials [38]. The extent of moisture damage depends on internal structure distribution and the quality and type of materials used in the asphalt mixture [39]. Further, the hydrophilicity of filler material can affect the physicochemical properties of the asphalt filler [40]. For these reasons, it is not only important to study the moisture sorption properties of roadway materials, but also the surface chemistry of the components, as the interfacial adhesion is dominated by the materials' surface energy [41]. The DVS-Advantage instrument is equipped to measure both water and organic vapour sorption isotherms, making it ideal to study surface energetics of minerals (see SMS Application Notes 17 and 43). Figure 6 displays the dispersive and specific surface energy components for several aggregate samples measured by DVS. For these samples, the total surface energy was dominated by dispersive interactions. If the samples are ranked by their total surface energy the following sequence is obtained: Basalt >Augite> Calcite > Quartz >Feldspars~Granite. With exception to Quartz (generally has poor affinity to asphalt), this trend agrees in general with the empirical observation that these aggregates show a similar order of affinity to the most common asphalt binders. The Quartz sample may differ from expectation due to variances in impurity levels or geographic location which will affect the surface energy.

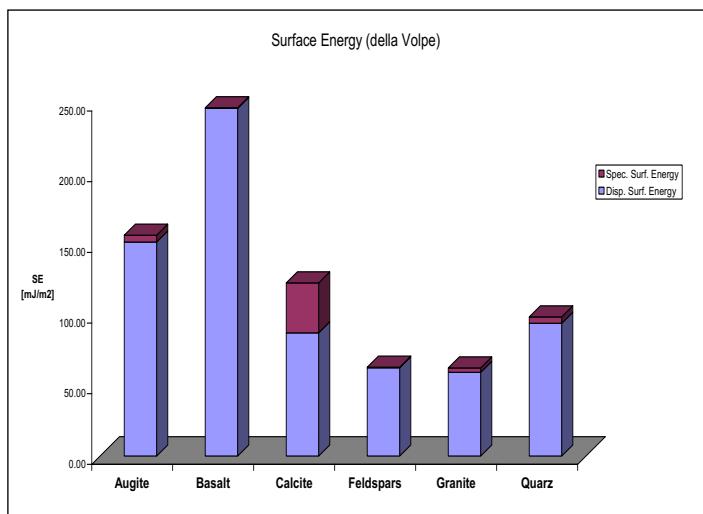


Figure 6. Dispersive and specific surface energies of the different aggregate samples.

Other Building Material Applications

The DVS could also be used in several other building material applications. For instance, the moisture sorption properties of gypsum board and plasters have received interest in recent years [42,43]. The main thrust of this research is for limiting microbial growth and the ability of these materials to act as hydroscopic buffers. The water sorption behaviour of paints can be important, because differences in moisture can cause deformations in the coating and substrate [44,45].

The ability to use other vapours besides water allows the DVS-Advantage to be used for some unique building material applications. For instance, the DVS-Advantage could be used to determine the rainfastness and retention behaviour of herbicides and pesticides to concrete, asphalt, and other hard surfaces [46,47]. Organic vapour capability could also be utilized to study the ability for various interior building materials to act as sinks for different volatile organic components (VOC's) released by other materials [48,49,50].

The DVS-Advantage instrument also has the ability to couple *in-situ* video microscopy and spectroscopy (Raman and/or Near-IR) with the gravimetric sorption measurements (see SMS

Application Notes 10 and 46). The video microscopy allows for the investigation of vapour-induced colour change, swelling, or phase change. The *in-situ* spectroscopic measurements can elucidate more subtle structural changes in the material (i.e. polymer rearrangement, hydrate formation, polymorph identification, or hydrogen bonding). To illustrate, Figure 7 shows the gravimetric water sorption (Figure 7a) and Raman spectra (Figure 7b) for a microcrystalline cellulose (MCC) sample at 25 °C. MCC is not expected to form a crystalline hydrate or undergo any polymorphic transformation when exposed to increasing humidity. However, there are clear differences in the Raman spectra as the humidity is increased. MCC does experience a significant amount of bulk water absorption as humidity is increased. Therefore, the changes observed in Figure 7b could be due to increased hydrogen bonding, decrease in void spaces, or other structural rearrangements.

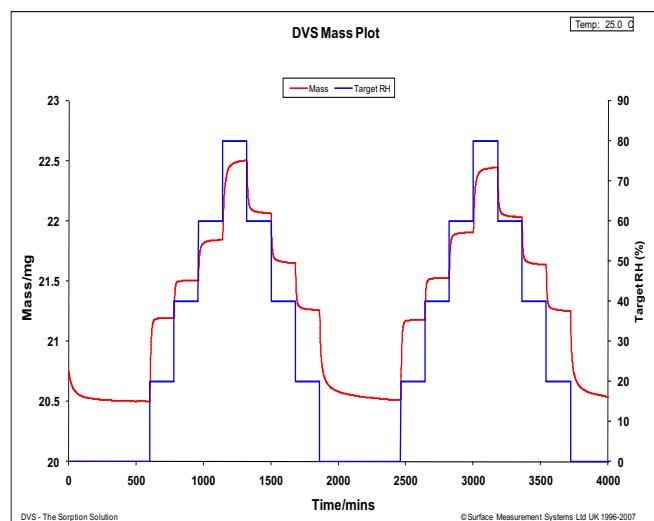


Figure 7 (a.)

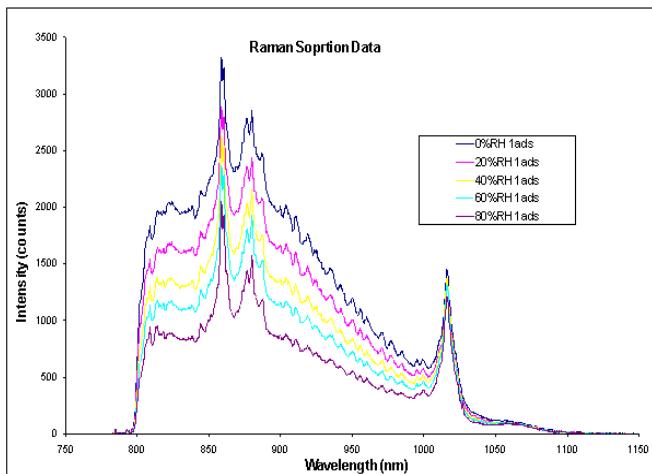


Figure 7 (b.)

Figure 7. DVS water sorption results (a.) and in-situ Raman spectra (b.) for MCC at 25 °C.

Conclusion

Utilizing the functionality of DVS instrumentation for the study of building materials allows the vapour sorption characteristics to be studied on wood, paint, insulation, cement, asphalt, and textiles. Water sorption on these materials can be vital in understanding and controlling mould growth, material stability, inter-material adhesion, and exterior weathering. Organic vapour sorption studies allow the study of material surface energetics, VOC sorption capacity, and herbicide/insecticide retention behaviour. This overview application note only summarizes a handful of these applications, but hopefully illustrates how DVS technology could be applied to a wide range of building-related materials and problems.



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