



Comparative Analysis of Paint Drying Behavior Under Controlled Humidity: Influence of Formulation on Coating Performance

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This application note investigates the drying behavior of six paint formulations using Dynamic Vapor Sorption (DVS) to measure mass change over time under controlled relative humidity conditions. The coatings include standard water-based paints, functional water-based systems (gloss and sealer), an oil-based primer, and an acrylic stain/sealer, enabling comparison of different drying mechanisms. Comparison across humidity conditions reveals that differences between formulations become more apparent at higher relative humidity, where limitations in solvent transport dominate. Overall, the results demonstrate that drying performance is controlled by the interplay between evaporation, diffusion, chemical curing, and material interactions, highlighting the importance of both formulation and environmental conditions in determining coating behavior.

Introduction

Understanding the drying behaviour in paints is important across a wide range of industries, as it governs coating performance and durability by providing long term protection against corrosion and mechanical wear. The process determines how a liquid coating transforms into a solid film and governs properties such as adhesion, durability, and quality of surface coating.

The types of paints discussed in this application note are water based, functional water based and oil-based paints. The difference in their drying behaviour is determined by their film formation mechanism. This can occur either by physical drying, chemical curing, or a combination of both. Water based paints, for example acrylics, dry through water evaporation followed by polymer particle coalescence [1]. As water evaporates, particles pack together and merge into a continuous film. Environmental conditions such as humidity and temperature play an important role as both parameters govern the rate of evaporation.

For example, if exposed to high humidity, the drying process slows down and can result in an incomplete film formation [2]. Oil based paints use organic solvents and dry through a two-stage process: solvent evaporation followed by oxidative crosslinking [3]. After initial solvent evaporation, the binder reacts with oxygen to form a chemically cross-linked network. This makes drying less sensitive to humidity than water-based paints but more dependent on oxygen availability and temperature [3].

In this application note the process of paint drying is measured using the Dynamic Vapour Sorption (DVS) which is a gravimetric technique that monitors mass loss associated with solvent evaporation. These methods produce drying curves (moisture content versus time). Two important parameters for understanding and comparing paint drying behaviour are those that define how quickly and uniformly a coating forms.



Method

Six commercially available paint formulations from Kilz and Behr were selected to represent a range of coating chemistries and functions, including primers, topcoats, and sealing systems. The samples included a water-based primer (Paint A), an oil-based, alkyd, primer (Paint B), an acrylic flat paint and water-based primer (Paint C), an acrylic gloss enamel (Paint D), a primer/sealer (Paint E), and an acrylic stain/sealer (Paint F). This selection allowed for a comprehensive comparison between water-based and solvent-based systems, as well as coatings which are expected to exhibit different drying and diffusion behaviours.

Drying measurements were carried out using a Dynamic Vapor Sorption instrument to monitor mass change as a function of time under controlled environmental conditions. Experiments were conducted at a constant temperature of 25 °C with a carrier gas flow of 200 sccm air. Relative humidity was varied stepwise across 0%, 20%, 40%, 60%, 80%, and 95% RH to evaluate the effect of environmental conditions on drying kinetics. Paint samples were applied onto glass slides mounted on adhesive painter's tape to ensure consistent sample handling.

Each humidity step was maintained for a duration of 180 minutes, with extended measurements up to 720 minutes at 95% RH to monitor slower, diffusion-limited drying behaviour. Mass change was continuously recorded throughout the experiment, and drying was considered complete when the rate of mass change reached a steady-state ($dm/dt \approx 0.05$).

Result

The drying behavior of the six paints have been grouped together according to formulation type and functional behavior. Group 1 includes Paints A (primer) and C (flat coating), both water-based formulations. Group 2 includes Paints D (gloss) and E (sealer) which are functional water-based formulations. They have modified film properties to

produce either a high gloss film (Paint D) or act as a non-porous barrier/sealer (Paint E). Group 3 includes Paint B (oil) and F (stain/sealer), these are specialized paint systems where Paint B is an oil-based primer and Paint F is an acrylic stain/sealer.

Figure 1 shows the drying behavior of Group 1 paint systems with both paints experiencing the characteristic two-stage drying behavior of water-based paints which proceeds via surface evaporation at a constant rate, followed by a decreasing-rate stage governed by solvent diffusion through the formation of the paint solid film. It has a strong dependence on relative humidity, consistent with a predominantly evaporation-driven mechanism of water-based paints [4]. At low RH (0–20%), both coatings show a rapid mass loss, indicating a high initial evaporation rate and efficient removal of water from the paint formulation. As humidity increases, the drying rate progressively decreases, with an even longer drying time at 80–95% RH. Paint A shows a slightly faster overall drying compared to Paint C with Paint A's mass decreasing gradually over ~700 minutes while Paint C plateaus earlier at ~150-200 minutes, suggesting Paint A achieves more complete drying. Dm/dt drying rate plots support this, where (at high RH) Paint A maintains a negative rate beyond 300 minutes gradually approaching equilibrium. Whereas Paint C stabilizes sooner but retains more solvent suggesting Paint A dries more effectively overall. This is due to its primer formulation, which may contain lower solids content or more volatile components, whereas flat coatings' higher binder and filler content slows solvent loss and delays drying [5].

Figure 2 shows the results from Group 2 paints which are also water based products however, show a difference in drying behavior compared to Group 1 paints due to their functional roles as a gloss (Paint D) and sealer (Paint E). Both paints exhibit an initial rapid mass loss consistent with evaporation-driven drying but their behavior at different relative humidities show some differences. In the mass change plots, Group 2 show more gradual drying curves at higher RH (80%-95%) suggesting increased solvent retention compared to Group 1. This is especially evident for Paint D,

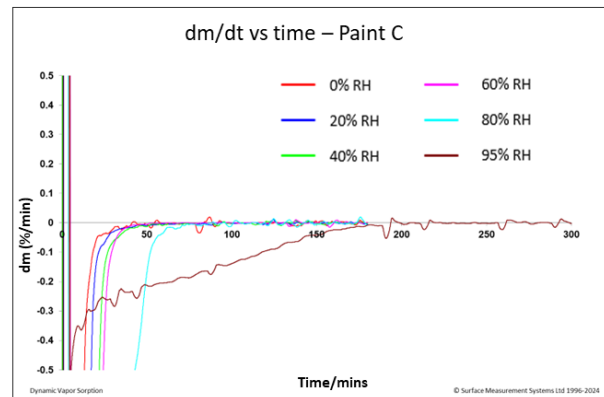
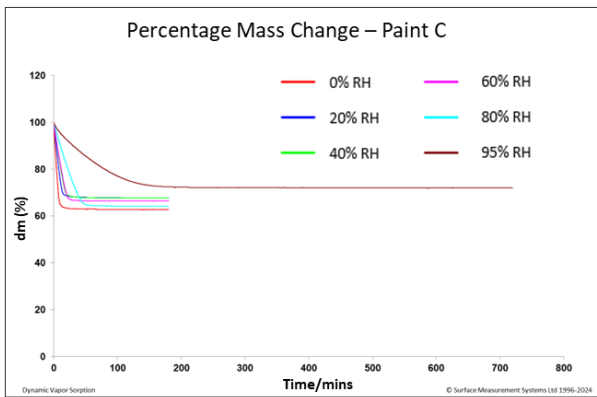
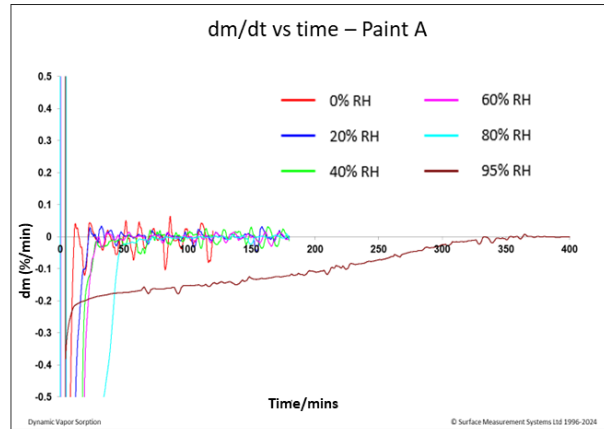
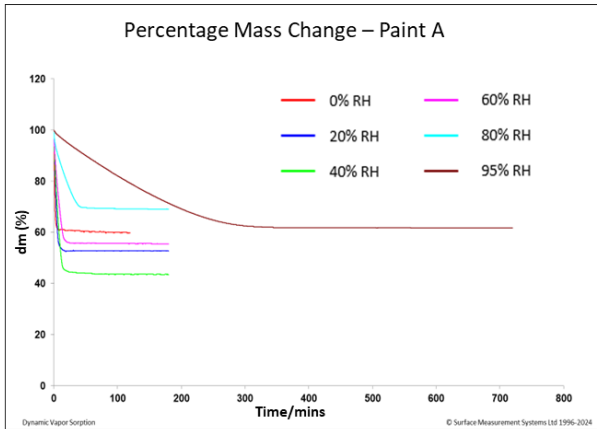


Figure 1: Mass change versus time and corresponding drying rate (dm/dt) profiles for Group 1 paints: Paints A and C

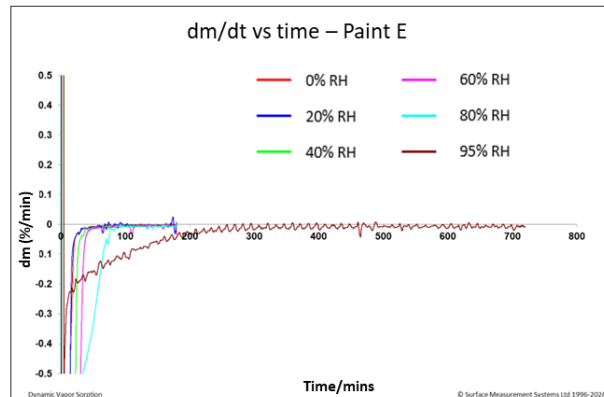
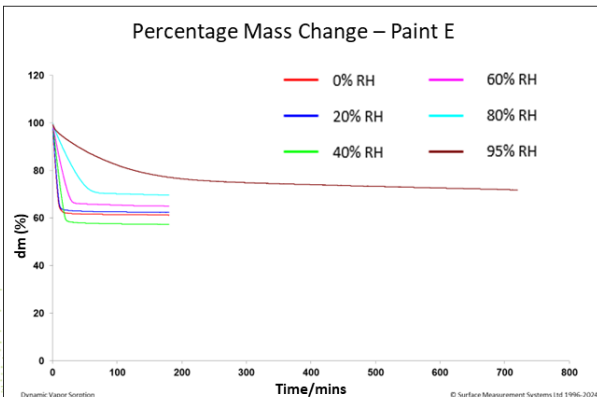
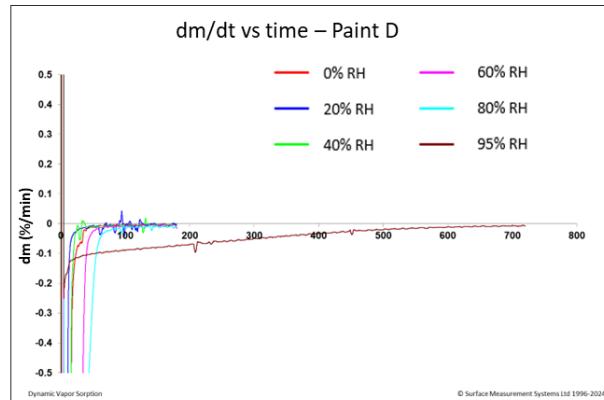
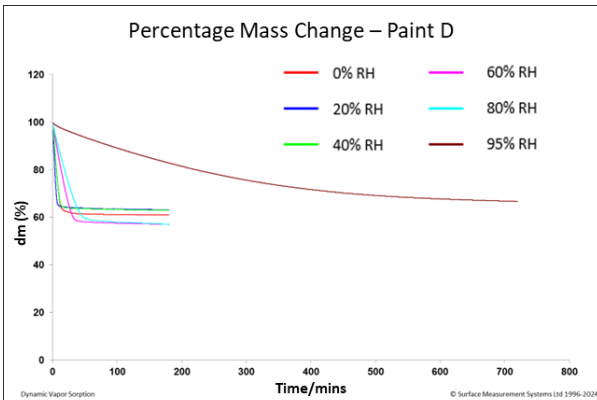


Figure 2: Mass change versus time and corresponding drying rate (dm/dt) profiles for Group 2 paints: Paints D and E

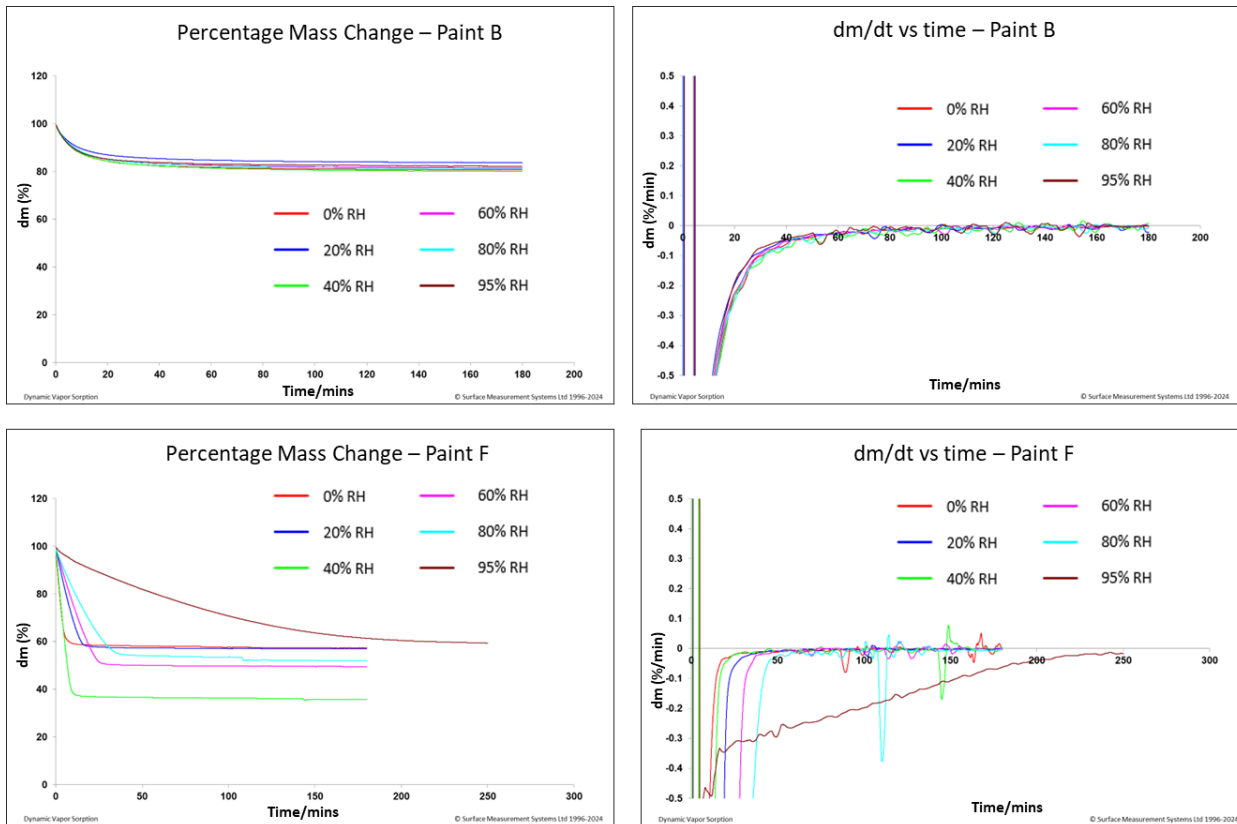


Figure 3. Mass change versus time and corresponding drying rate (dm/dt) profiles for Group 3 paints: Paints B and F

Where the 95% RH curve shows a prolonged, slow decrease over the full experimental duration, suggesting slower drying times. The dm/dt plots for both coatings support the mass change plots showing the drying rate transitions from an initial evaporation-controlled regime to a prolonged diffusion-limited stage, with the 95% RH curves remaining negative over time, particularly for Paint D. This behavior is consistent with their functional roles: the gloss enamel (Paint D) forms a denser, less permeable surface layer, while the primer/sealer (Paint E) is designed to limit porosity and moisture movement [6]. As a result, both coatings show a slower drying behavior than standard water-based systems particularly when exposed to high humidity.

Figure 3 shows Group 3 paints which represent two non-standard drying mechanisms. Paint B, an oil-based primer, shows very little dependence on RH with similar mass loss profiles observed across all humidity conditions. The mass rapidly decreases

within the first 40 minutes and then stabilizes at RH 80–85%, with dm/dt approaching zero quickly and consistently for all RH stages. This suggests that, drying is governed by oxidative curing of the alkyd binder. After initial solvent loss, the formation of a crosslinked network proceeds via reaction with atmospheric oxygen, making the process less sensitive to humidity showing typical behavior of oil-based paints [3]. In contrast, Paint F, an acrylic stain/sealer, shows a strong dependence on humidity, like water-based paint formulation but with longer drying times. The mass change plots show significant solvent loss at low RH but at high RH (95%), drying is gradual over time with no sharp plateau. This is confirmed by the dm/dt plot which shows slow drying with ongoing moisture diffusion. This behavior is characteristic of substrate effects, which are common in acrylic stain and sealer formulations. In these systems, the coating interacts strongly with the material being coated, penetrating into it rather than forming a purely surface-bound film [7]. The lower viscosity of the

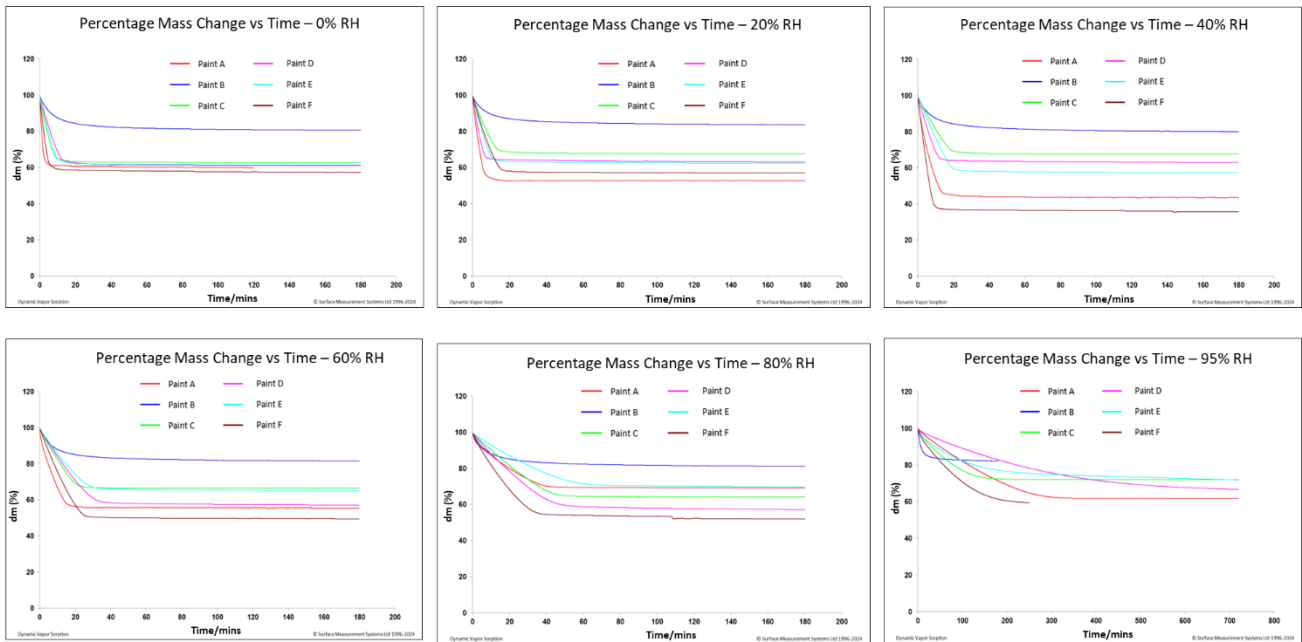


Figure 4: Mass change versus time for all paint formulations grouped by relative humidity (0–95% RH)

formulation allows it to soak into materials, resulting in a portion of the solvent being absorbed below the surface rather than evaporating directly. As a result, the drying process becomes more complex, involving both surface evaporation and internal diffusion within the substrate its being painted on. This is consistent with the behavior observed for Paint F, where the drying profiles are more gradual and variable, reflecting the combined influence of evaporation and solvent transport within the material.

An alternative way to interpret the drying behavior of all paint formulations is to compare them at different relative humidities shown in Figure 4. At low RH (0%), the drying profiles of all paints are similar, suggesting that under evaporation-driving conditions, the differences between paint formulations are less significant and solvent removal is efficient across all paints although the underlying drying mechanism may differ between water based and oil-based formulations. As humidity increases (20%, 30% and 40%) the differences become clearer. At the highest humidity levels (80% and 95%), the differences are even more significant. Paint B remains largely unchanged, confirming its curing-dominated

behavior, while Paints D and E show the greatest retention of solvent, and Paint F exhibits a more gradual, slower drying profile.

Conclusion

The DVS has shown to be a comprehensive tool to demonstrate that paint drying behavior is governed by formulation and interaction with relative humidity. Standard water-based coatings show evaporation driven drying with clean transition to diffusion limited behavior while functional coatings such as gloss and sealing systems experience slower drying due to slow solvent diffusion within the coating. In contrast, the oil-based paint shows that drying is largely independent of humidity, reflecting the dominance of oxidative curing. The acrylic sealer formulation shows more complex behavior due to internal solvent interactions. Collectively, these results show that drying performance is determined by the balance between evaporation, diffusion, chemical curing, and formulation properties which govern the efficiency of film formation under varying humidity conditions.



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