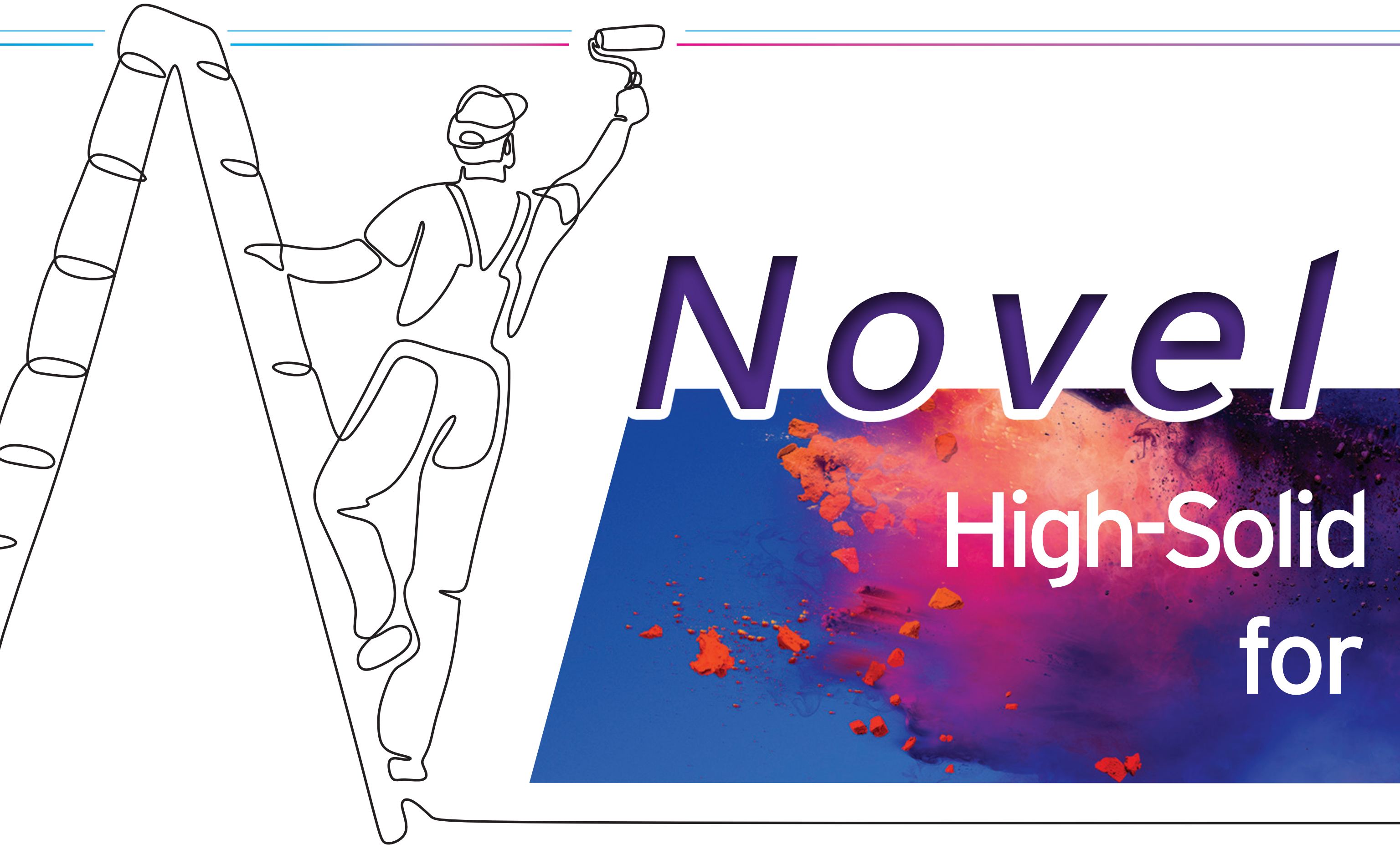


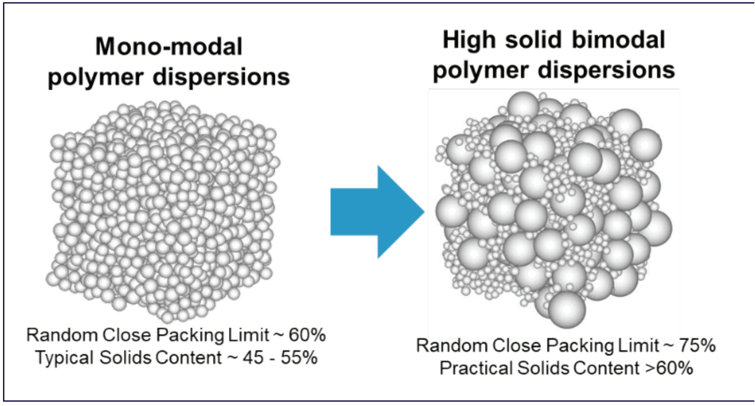
Novel High-Solid for

**By Michael Krayer
and Sean W. Bullis,
BASF Corporation, USA**

Over the past few decades, the performance of water-based architectural paint has consistently improved. However, latex polymer dispersions used in water-based coatings are typically limited to around 50 wt % polymer solids. This is because most polymer dispersions used for architectural coatings have a fairly narrow, single particle-size distribution (monodisperse), and when the monodisperse polymer particles approach their close packing limit, there is a sharp increase in viscosity at solids contents much beyond 50%.[1,2,3]

On the other hand, polymer dispersions with a bimodal particle-size distribution can achieve a significantly higher solids content due to the increased random close packing limit of polydisperse systems **(Figure 1)**.[3] BASF has extensive experience in developing and producing higher solid polymer dispersions, especially for pressure-sensitive adhesive applications, achieving solids content up to 70%. Recently, BASF has developed a 60 wt % polymer dispersion with a bimodal particle-size distribution for water-based architectural coating applications.

FIGURE 1
Comparison of the random close packing limit and practical solids content of monomodal versus bimodal polymer dispersions.



Compared to architectural paints formulated with conventional polymer dispersions, paints formulated with bimodal high-solid dispersions can achieve a higher solids content, resulting in an increased dry film thickness. For instance, in a paint formulation that uses a monodisperse latex binder, increasing the paint solids content beyond 50 wt % (or 40

Bimodal Polymer Dispersions Architectural Coatings

vol%) causes the formulation to quickly turn into a paste, making it unsuitable as a paint. However, paint formulations that use a bimodal high-solid latex can achieve solids contents of more than 60 wt % (or 50 vol%).

Furthermore, the rheological properties of paints formulated with high-solid dispersions allow for a more favorable balance between high-shear viscosity, sag resistance, and flow and leveling. A certain high-shear viscosity is typically desired to achieve the desired amount of paint applied. However, current high-shear rheology modifiers, used in conventional paint formulations, have a significant viscosity contribution to the mid- and low-shear regions **(see Figure 2)**. When targeting a desired high-shear viscosity by adding high-shear rheology modifiers, one quickly increases the mid- and low-shear viscosity beyond the desired points. The mid- and low-shear regions of paint are responsible for the sagging and

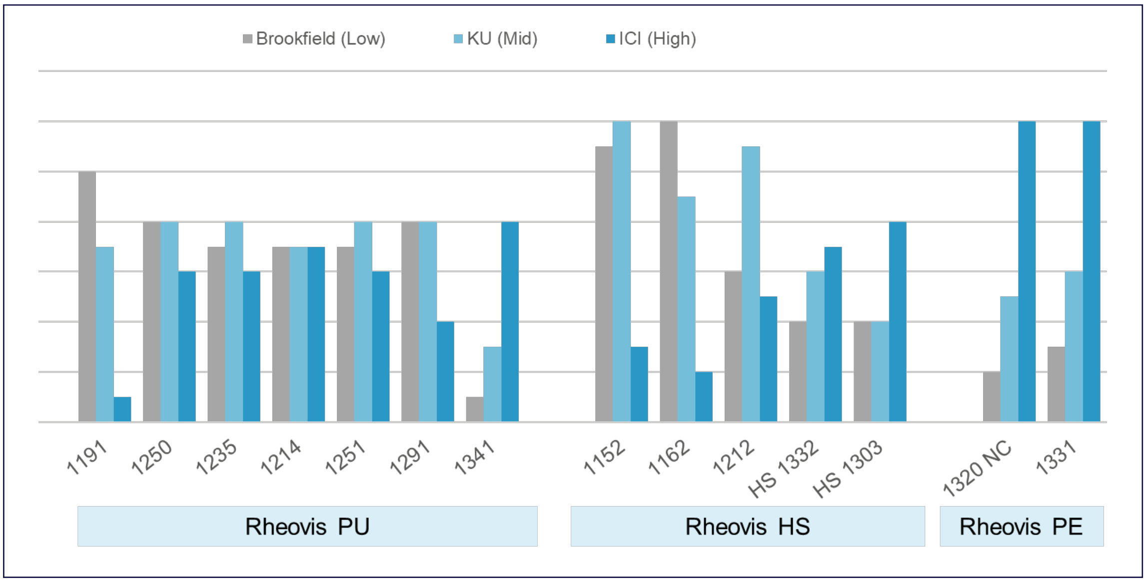
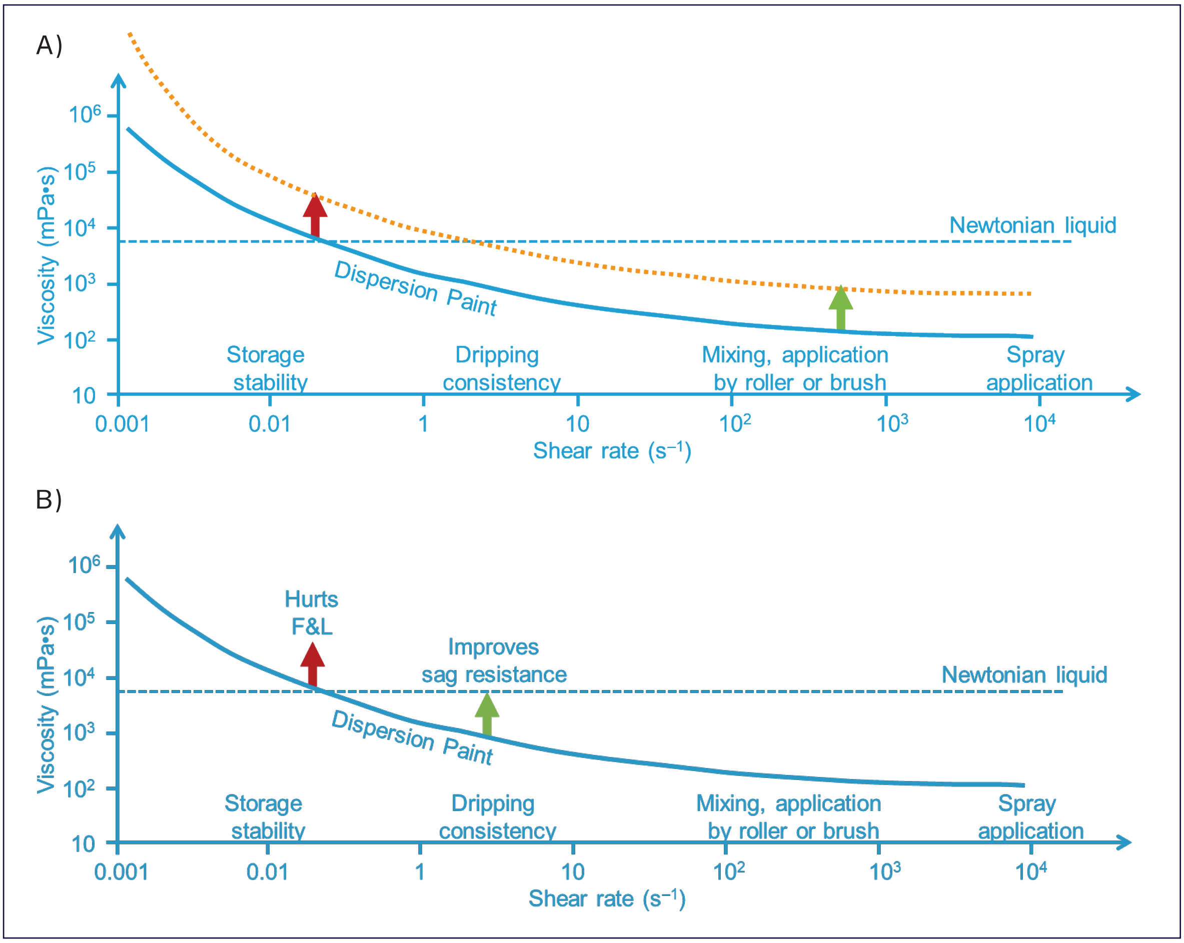


FIGURE 2
Examples of Brookfield (low-shear), KU (mid-shear), and ICI (high-shear) viscosity contributions of various BASF rheology modifiers used in conventional paint formulations.

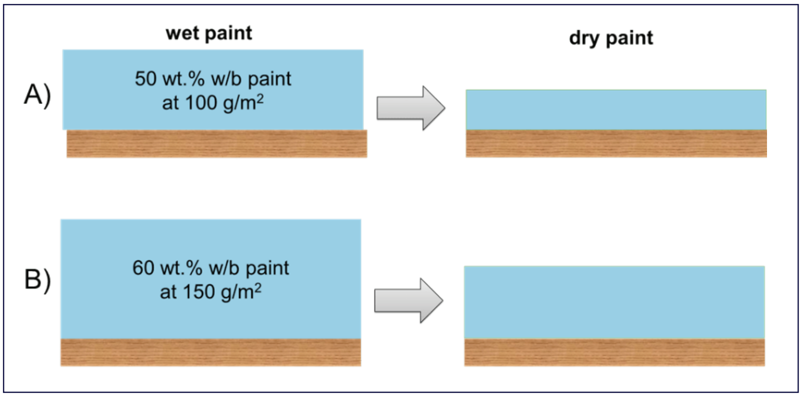
FIGURE 3
Illustration of different shear rates and applications associated with them.
A) Increasing high-shear viscosity typically has an undesirable impact on mid- and low-shear viscosity.
B) Mid- and low-shear rheology need to be balanced for optimum sag resistance and flow and leveling.



flow and leveling behavior of the paint. While a certain mid-shear rheology is desirable to prevent sagging, the optimal flow and leveling is achieved when the low-shear viscosity is kept low **(Figure 3)**. Compared to paint formulated with a monodisperse latex, bimodal latex systems have a lower low- and mid-shear viscosity response when high-shear rheology modifiers are added. Therefore, they allow for higher high-shear viscosities while being able to achieve the desired mid- and low-shear viscosities. In other words, bimodal latex binders allow for the formulation of paints with a more Newtonian rheology profile.

By combining a higher paint solids content, resulting in thicker dry films by itself, with a favorable rheology profile that enhances paint transfer and increases both wet and dry film thickness, the resulting thicker films can significantly improve hiding **(Figure 4)**.

FIGURE 4
Illustration of dry film thickness of a A) conventional architectural paint vs. B) architectural paint formulated with high-solid polymer dispersions.



These value propositions have been thoroughly explored and demonstrated by our team in Europe and were published in the *European Coatings Journal* earlier in 2023.[4] However, the development and formulation work in Europe focused primarily on brush application to mimic application properties of solventborne alkyd wood and trim paints. In this report, we focus on exploring the same value propositions for roller application in the North American market. Our objective is to demonstrate that bimodal high-solid polymer dispersions can be formulated in paint to improve application feel and one-coat-hide properties when applied with a roller to a vertical wall.

Results and Discussion

Brush vs. Roller Application

To understand why the learnings from formulating for brush application are not directly applicable to roller application, it is worth highlighting the significant differences between the two application methods **(Figure 5)**. Firstly, the painting speed for brush application is significantly slower. Secondly, the spread rate and, therefore, the thickness of applying a paint with a brush or roller will be different and depend on factors such as how much pressure is applied, and the material composition, texture, and thickness of the brush or roller cover. Of course, the paint itself also guides the painter in how to apply it. The height applied by a roller is typically lower because thick layers of paint cause the roller to push paint in front of it and shear it up until a certain, lower wet layer thickness is achieved. As a result, the painter instinctively applies more force to get the roller rolling.

From the painting velocity and the coating thickness, the shear rate that is being applied to the paint can be calculated by dividing the velocity by the height, as in **Equation (1).** For the two examples shown in **Figure 5**, this results in a shear rate of about 3,500 s^{-1} for brush application and about 10,000 s^{-1} for roller applications. Additionally, applying a paint with a roller results in an elongational shear orthogonal to the substrate, brought on by the angular velocity of the roller, which does not exist in brush application.

EQUATION 1
Shear rate is defined as velocity divided by shear gap/height.

$$\boxed{Shear\ rate: \dot{\gamma} = \frac{v}{h}}$$

Ideally, paint formulators should take these differences into account when formulating a paint primarily intended for application using either a brush or a roller. And, indeed, some paint brands have significantly different rheology profiles for various sheens. For instance, **Figure 6** shows the distinctly different rheology curves of a semigloss and satin paints from the same commercial paint line. The intended effect of these specific rheology profiles becomes apparent when applying each paint with either a brush or a roller.

Subjectively, the semigloss paint applies better with a brush than with a roller,

FIGURE 5
Differences in shear rate between A) brush and B) roller application.

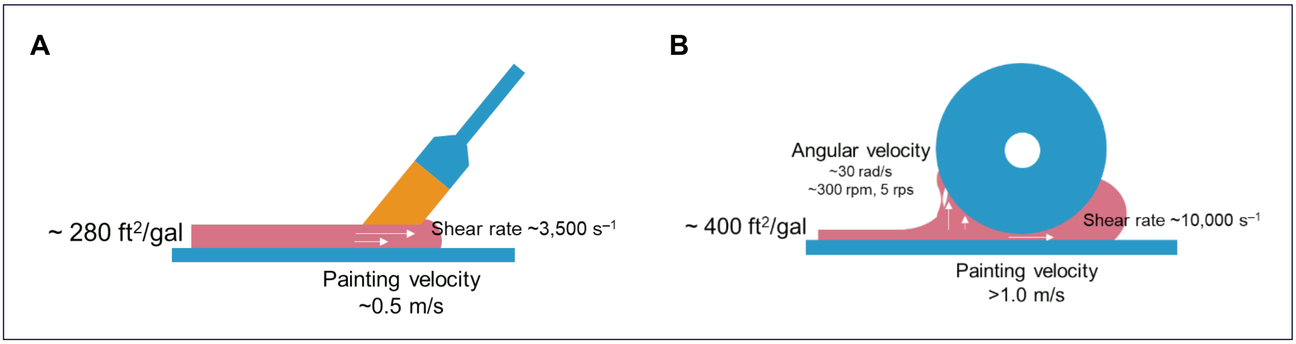
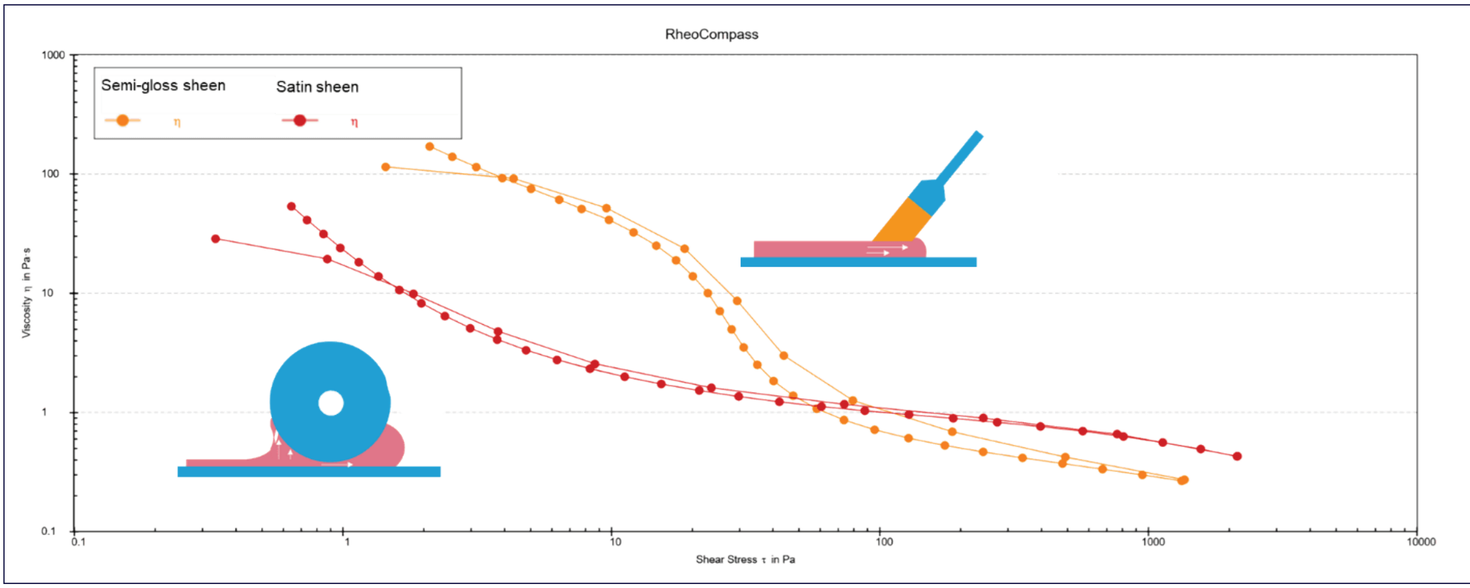


FIGURE 6
Rheology profiles (viscosity vs. shear stress) of semi-gloss (orange –) and satin (red –)from the same commercial paint line.



while the Satin paint applies much better with a roller than with a brush. During brush application, the satin paint seemed too “watery,” and when more paint was applied to achieve good coverage and hiding, the paint started sagging. In this regard, the semigloss performed much better, which can be attributed to the higher mid-shear viscosity.

On the contrary, during roller application, the satin paint with lower low- and mid-shear viscosity and slightly higher high-shear viscosity applied easier with less effort, while still achieving good coverage. Meanwhile, the semigloss seemed too “thick” and was difficult to apply. The roller picked paint back off the surface when back-rolling the same area again and left a more pronounced stipple pattern. These observations are not surprising considering that semigloss paint is more commonly brushed onto smaller areas like trim, whereas a paint with a lower gloss, such as satin, is typically roller-applied to larger surfaces like an entire door panel or a wall.

Practical Approach to Optimization Rheology of Architectural Paints

To develop an architectural paint that is better suited for roller application, providing a smooth application feel and efficient one-coat coverage, we followed a similar methodology to our European colleagues who formulated a paint for brush application.[4] The steps involved are outlined in **Figure** 7 and include:

1) Formulating a simplified base paint with minimal or no addition of thickener or rheology modifier. This also means excluding attapulgite clay or cellulosic thickeners. If the viscosity is too low for effective pigment grinding, a small amount of rheology modifier can be added to the grind to achieve the desired viscosity.

2.1) Applying various commercially available benchmark paints to evaluate their application performance when applied with a roller. The detailed description of the application setup is provided below.

2.2) Measuring the flow curves of both the benchmarking paints and the base paint.

3.1) Comparing the rheology curves of the benchmarking paints and the base paint.

3.2) Deciding on the type and amount of rheology modifier to be added to the base paint to achieve the desired rheology profile.

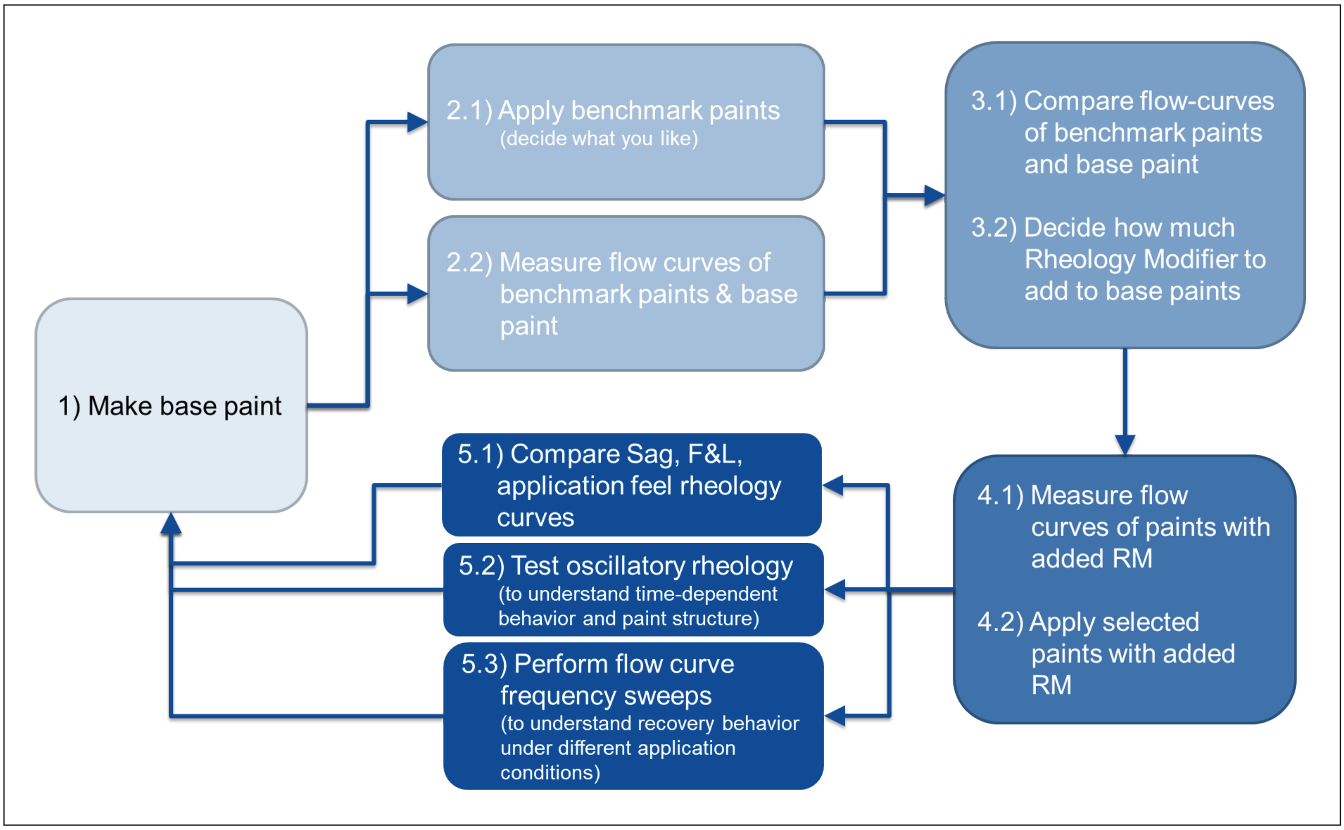
4.1) Re-measuring the rheology curve.

4.2) Applying the base paint with the added rheology modifiers to determine if the desired rheology profile and application properties have been achieved.

Additional steps can be taken to compare the measured sag and flow and leveling with the predicted values (5.1), conducting oscillatory (3iTT) tests to understand time-dependent behaviors and paint structure (gel- vs. non-gel forming paints) (5.2), or performing frequency sweeps to understand the recovery behavior under different application conditions (5.3).

Note: In this study and formulation optimization, we did not investigate the gel-forming behavior in more detail.

FIGURE 7
Standard procedure for formulating an architectural paint with optimal rheology properties.



Base paint formulation

The initial base paint formulation is shown in **Table 1** and contained 250 lbs/100 gal rutile TiO_2, and a small amount of a high-shear associative polyether thickener (1% w/w) and low-shear associative polyurethane thickener (0.15% w/w) resulting in a 24% pigment volume concentration (PVC), 56 wt % and 41 vol% solids content. To demonstrate the different rheology responses of latex polymer dispersions with different particle sizes and particle-size distributions, this base paint formula was used to formulate paint samples with three different latex polymer dispersions (Latex ***A***, Latex ***B***, and Latex ***C)*** at constant PVC and paint solids content with increasing amounts (1–4% w/w) of the high-shear rheology modifier.

Latex A is a ~60 wt % latex polymer dispersion with a novel bimodal particle-size distribution. In contrast, Latex B is a 50 wt % latex with a small narrow monomodal particle-size distribution at ~120 nm, and Latex C has a high-solids content (60 wt %) but with a large broad particle-size distribution ~250 nm **(Figure 8)**. The shear stress

TABLE 1

Initial Base Paint Formulation Containing Latex Polymer Dispersions with Different Particle Sizes and Particle-Size Distributions

	Latex A	**Latex B**	**Latex C**
Latex solids content	61%	50%	60%
Latex particle size (nm)	80/300	120	250
Description			
Water	150.8	122	152.3
Propylene Glycol	15	15	15
Dispex® CX 4231[i]	10	10	10
FoamStar® ED 2522[i]	4	4	4
Ammonium hydroxide	2	2	2
Rheovis® PE 1330[i] (1-4% w/w)	10 - 40	10 - 40	10 - 40
Kronos 2310[ii]	250	250	250
ASP G90[iii]	30	30	30
Loxanol® CA 5310[i]	12	12	12
Latex A	420		
Latex B		512.4	
Latex C			427
FoamStar SI 2210 NC[i]	2.3	2.3	2.3
Rheovis PU 1191[i]	1.5	1.5	1.5
Water adj. based on thickener loading	60.4–92.4	0–28.8	53.9–83.9
Total	1000	1000	1000
% PVC	24	24	24
% Weight Solids	56	56	56
% Volume Solids	41	41	41

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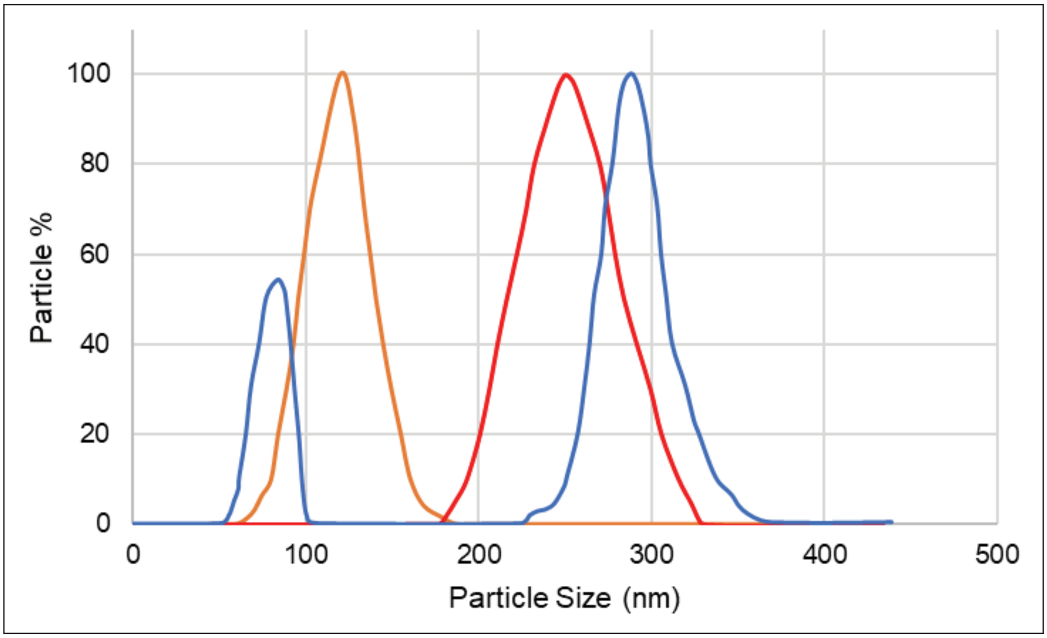
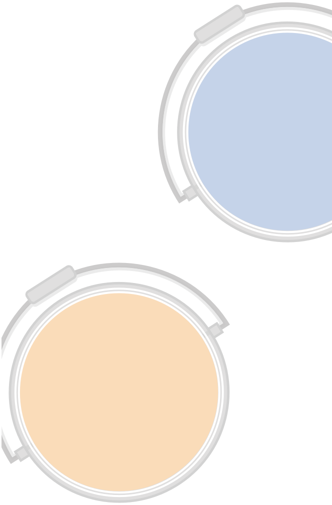
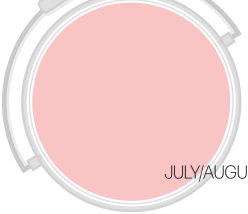
FIGURE 8

Particle-size weight distribution overlaid data.

Latex A (blue bimodal), Latex B (orange small monomodal), Latex C (red large broad).







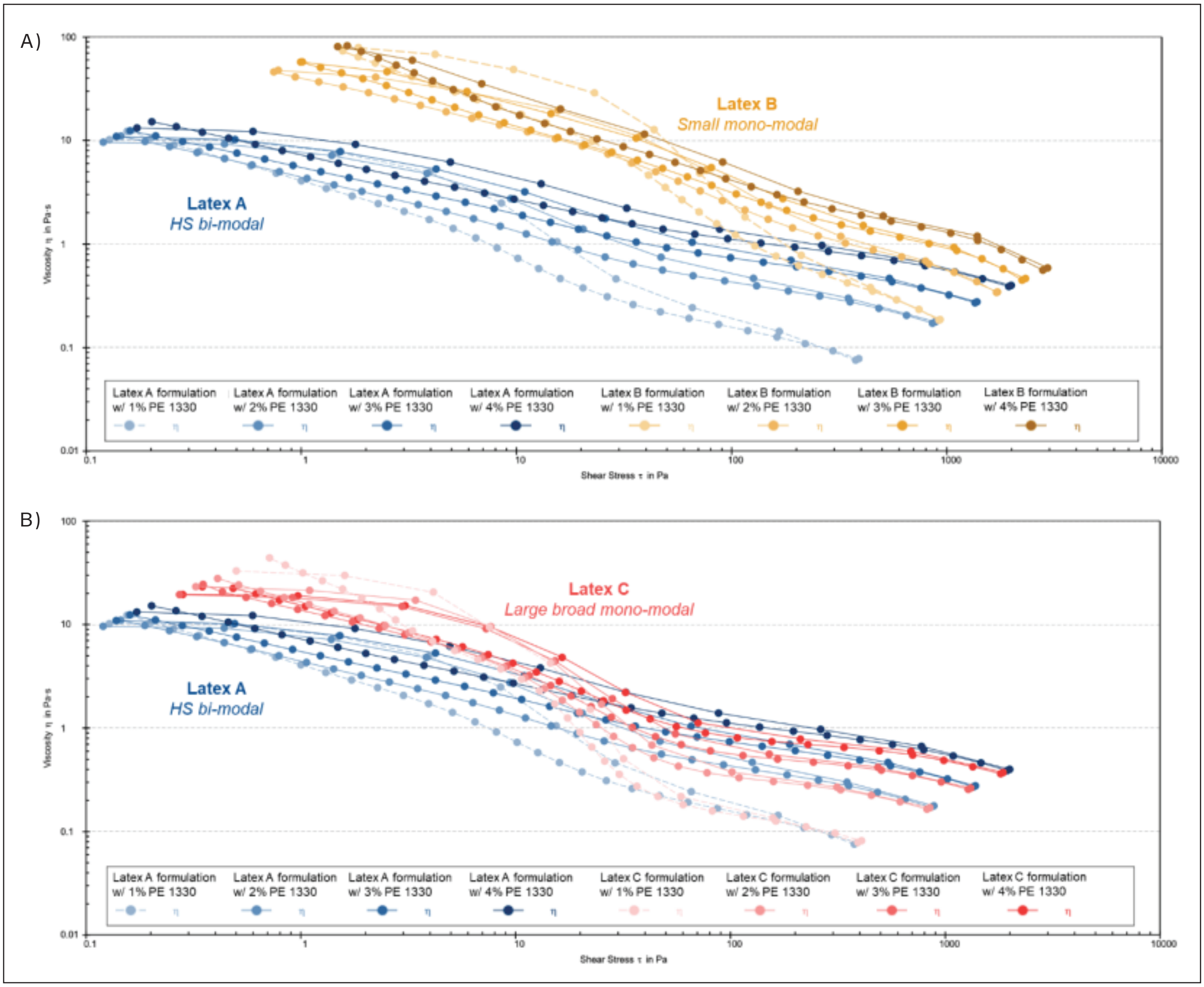
versus viscosity flow curves are shown in **Figure 9** and nicely demonstrate the unique rheology properties when formulating with a bimodal high-solid latex. When the high-shear rheology modifier is increased from 1% to 4% in the Latex A formulations, the highest high-shear viscosity point (measured at a shear rate of 5,000 s^{-1}) increases as intended from <0.1 Pa·s to ~0.4 Pa·s, while the low-shear viscosity stays relatively low between 9 and 15 Pa·s. In contrast, the formulations with Latex B have a much higher low-shear viscosity response when adding the high-shear rheology modifier. For example, the Latex B formulations with 2 and 3% Rheovis PE 1330 display similar high-shear viscosity to the sample with 4% Rheovis PE 1330 in the Latex A formulation (0.3–0.4 Pa·s), but have a low-shear viscosity that is much higher at 60–80 Pa·s. The formulations with Latex C show less low-shear viscosity response than the formulations with Latex B, but still higher than the Latex A.

*Note: In these measurements conducted on an Anton Paar Rheometer using Rheocompass software, the shear rate was controlled from 0.01 s^{-1} to 5,000 s^{-1} and then back to 0.01 s^{-1}. The torque, which represents the shear stress, was measured and the resulting calculated viscosity ($\eta = \tau / \gamma$, viscosity = shear stress ÷ shear) rate was plotted against the shear stress. The flow curves in **Figure 9** display the relationship between shear stress and viscosity, rather than shear rate, since shear stress is more easily related to application properties such as sag resistance and flow and leveling.*

Note: The flow curves show shear stress versus viscosity rather than shear rate, since the shear stress is more easily related to application properties such as sag resistance and flow and leveling.

The reason for the high-solid bimodal system giving a more Newtonian rheology response is not well understood. However, it can be hypothesized that the lower low-shear rheology response with Latex A is due to the inherently better particle packing of a bimodal system compared to monomodal systems. Meanwhile, the high-shear rheology response with the associative thickener is likely dictated by the total surface area of the latex particles. **Table 2** shows the calculation of total latex surface area based on the base paint formulations. A clear trend is observed in which Latex B has the highest surface area and the largest high-shear viscosity response, while Latex A and Latex C have similar total surface areas and, therefore, similar high-shear viscosity responses. In fact, the surface area of Latex B is roughly twice that of Latex A or Latex C, while the

FIGURE 9
Shear stress vs. viscosity flow curves of base paint formulation with increasing amounts of high shear rheology modifier Rheovis PE 1330. A) Formulations containing Latex A (blue bimodal) show less low-shear viscosity response and are more Newtonian compared to Latex B (orange small monomodal), and B) Formulations containing Latex A (blue bimodal) show less low-shear viscosity response and are more Newtonian compared to Latex C (red large broad monomodal).



high-shear viscosity is also approximately twice as high for the Latex B formulations compared to the other two.

A second base paint formulation was prepared to increase the solids content of the paint to 63 wt % and 50 vol% by adding 310 lbs/100 gal rutile TiO_2 and removing some water from the formulation **(Table 3)**. This formulation also contained a small amount of high-shear associative polyether thickener (1% w/w) and low-shear associative polyurethane thickener (0.10% w/w), and the same high-shear rheology modifier ladder study was done as above. Generally, the rheological trends between Latex A, Latex B, and Latex C were the same, with Latex A displaying the most Newtonian rheology behavior, i.e. displaying lower impact on the low- and mid-shear regions compared to the other two latexes. **Figure 10** only shows the rheology curves with 1% Rheovis PE 1330 and 0.10% Rheovis PU 1192 added since the higher amounts of PE 1330 in the Latex B formulations presented significant issues in preparing the formulation and taking measurements due to the high viscosities. This observation alone nicely demonstrates the limits of formulating at higher paint solids content with small monomodal particle-size latex dispersions.

Note: The flow curves show shear stress versus viscosity rather than shear rate because the shear stress is more easily related to application properties such as sag resistance and flow and leveling.

TABLE 2
Latex Polymer Surface Area Calculation Based on Formulas in Table 1

	Latex A	Latex B	Latex C
Latex solids content	61%	50%	60%
Particle size 1 (nm)	80	120	250
Particle size 2 (nm)	300	–	–
Surface area total (m2/kg formulation)	**6,533**	**12,810**	**6,149**
Formulation viscosity @ 5,000 1/s (Pa·s) w/ 2% PE 1330 loading	0.177	0.341	0.167

TABLE 3
Base Paint Formulation with Higher Paint Solids Content Containing Latex Polymer Dispersions with Different Particle Sizes and Particle-Size Distributions

	Latex A	Latex B	Latex C
Latex solids content	61%	50%	60%
Latex particle size (nm)	80/300	120	250
Description			
Water	68	12.3	68
Propylene Glycol	18	18	18
Loxanol® CA 5310[i]	15	15	15
Dispex® CX 4231[i]	10	10	10
FoamStar® ED 2522[i]	4	4	4
Acticide MBS[iv]	2	2	2
Ammonium hydroxide	1.6	1.6	1.6
Kronos 2310[ii]	310	310	310
Deuteron MK[v]	10	10	10
Rheovis® PE 1330[i] (1-4% w/w)	10 - 40	10 - 40	10 - 40
Rheovis® PE 1192[i]	1	1	1
Water adj.	46 - 76	0 - 24.3	38 - 68
Latex A	488		
Latex B		595.4	
Latex C			496.1
FoamStar SI 2210 NC[i]	8	8	8
Total	1021.6	1021.6	1021.6
% PVC	22	22	22
% Weight Solids	63	63	63
% Volume Solids	50	50	50

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FIGURE 10
Shear stress vs. viscosity flow curves of base paint formulation with 1% high-shear associative polyether thickener. A) Formulations containing Latex A (blue bimodal) show less low-shear viscosity response and are more Newtonian compared to Latex B (orange small monomodal) and Latex C (red large broad monomodal).

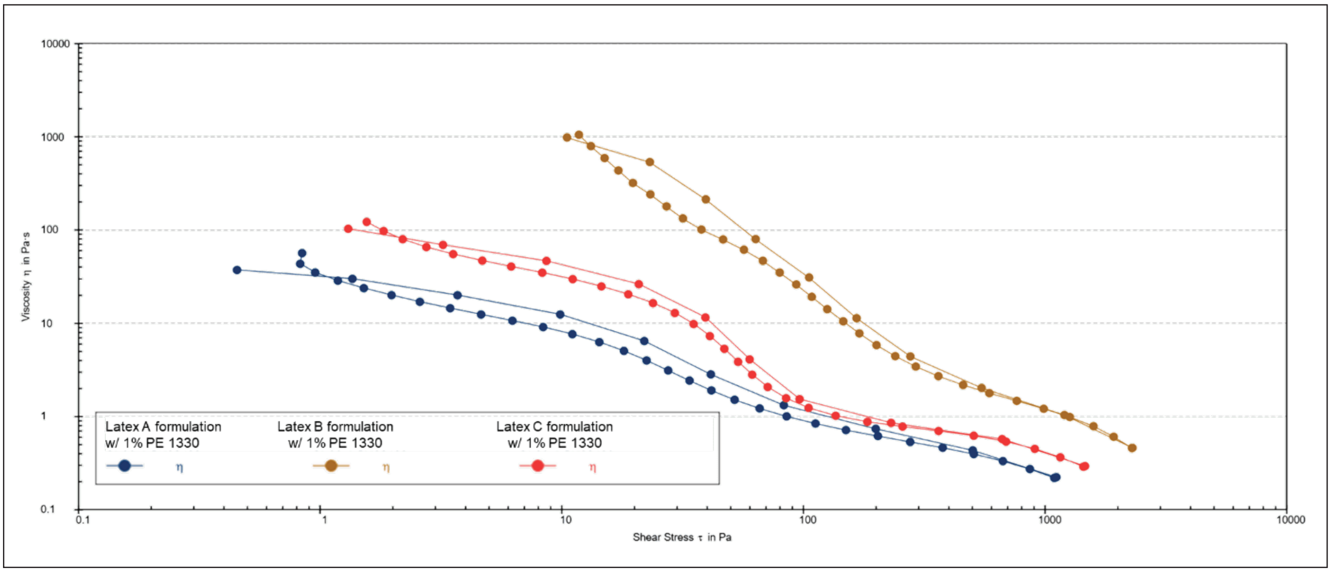

FIGURE 11
Spreading rate curves to determine maximum TiO_2 loading before scattering intensity is diminished by TiO_2 crowding.

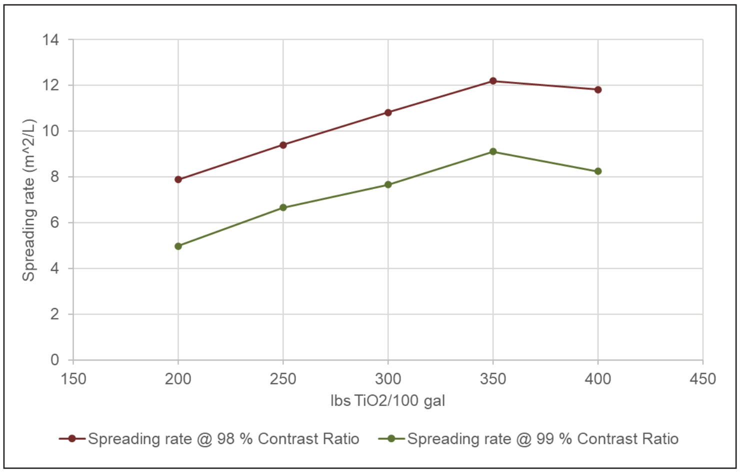

TABLE 4
Final Base Paint Formulation

Grind	
Water	98.0
Propylene glycol	18.0
Loxanol CA 5310[i]	15.0
Dispex CX 4231[i]	10.0
FoamStar ED 2522[i]	4.0
Acticide BW20[iv]	2.0
Ammonium hydroxide	1.6
Kronos 2310[ii]	350.0
Deuteron MK[v]	10.0
Letdown	
Rheovis PE 1330[i]	7.5
Water	10.0
Latex A	488.0
FoamStar SI 2210[i]	8.0
Total Weight	1022.1
% PVC	25
% Weight Solids	66
% Volume Solids	51

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To optimize the formulation for the best hiding performance, we aimed to increase the TiO_2 content of the formulation shown in **Table 3** as much as possible before the scattering intensity is diminished by TiO_2 crowding.[5] Therefore, our first step was to determine the dispersant demand for the pigment dispersant and rutile TiO_2 used in the formulations above. This was followed by measuring the spreading rate of formulations containing 200–400 lbs/100 gal of rutile TiO_2 and corresponding amount of dispersant. The dispersant demand for dispersing Kronos 2310 with Dispex CX 4231 was found to be 2.75% w/w, and the maximum TiO_2 loading was determined to be approximately 350 lbs/100 gal **(Figure 11).**

The final base paint formulation is shown in **Table 4**.

Applying Benchmark Paints

To determine a favorable rheology profile and hiding performance for roller application, a variety of commercial benchmarking paints were applied to a pre-primed 2x4 ft section of a 4x4 ft drywall with a gray contrast strip in the middle, using a 4-inch-wide, 1.5-inch core roller with a 3/8-inch nap woven roller cover. A general setup of the rollout is shown in **Picture 1.**

Each commercial paint was applied by two people, and the paint loading, application, spreadability, spatter/dripping, wet hide, dry hide, sag resistance, flow and leveling, and overall uniformity were subjectively rated on a scale of 1–5. The amount of paint applied was measured to give an overall impression of the paint. The results are summarized in **Table 5**.

Although Painter A consistently applied less paint to the 2x4 ft section compared to Painter B, the overall trends in the favorability ranking and amount of paint applied are consistent, with the Commercial Paints ***A*** and ***B*** (highlighted in ***gray*** and ***black***, respectively) ranking the highest.

Generally, the paints with more paint applied were preferred over the paints with less paint applied, which is consistent with previous consumer marketing studies.[6]

Note: All paints used were semigloss white base with no additional color added, although most seemed to have a slight tint. Commercial Paint A had a more noticeable color, which likely contributed to its better hiding performance compared to the Commercial Paint B. Also, we chose to use a semigloss sheen for consistency, as determining a favorable rheology profile should be independent of the sheen. This profile can later be applied to lower sheens such as satin, eggshell, or flat.

PICTURE 1
General application setup for determining roller application performance.

Comparing Rheology Profiles of Benchmark Paints and Commercial Paints and Determining Desired Rheology Package

Figure 12 displays the rheology curves of the two most preferred commercial paints, Commercial ***A*** and ***B***, compared to two less preferred paints, Commercial ***K*** and ***L***. Overall, Commercial Paint ***K*** exhibits lower viscosity in the low-, mid-, and high-shear regions, resulting in a more "slippery" feel, lower paint transfer, lower sag resistance, but good flow and leveling. Conversely, Commercial Paint ***L*** has significantly higher viscosity in the low- and high-shear regions, leading to a more "sticky" paint with poor flow and leveling performance, but better sag resistance. Both Commercial Paints ***A*** and ***B*** have similar rheology curves, with a viscosity profile falling between that of Commercial Paints ***K*** and ***L***. The mid- and high-shear viscosities are high enough to prevent a "slippery" feel, but not excessively "sticky"; they also allow for sufficient paint transfer. Additionally, the low-shear regions strike a good balance between sag resistance and flow and leveling. The measured flow and leveling and sag resistance values are listed in **Table 6** and correspond quite well to the anticipated values from the rheology curves.

Commercial Paint ***A*** appears to achieve an overall balance quite effectively, which is why it was selected as the target rheology profile.

TABLE 5
Commercial Paint Ranking. Ranking from 1–5 (1: Worst, 5: Best)

Paint	Painter	Load	Application	Spread Ability	Spatter/ Drip	Wet Hide	Dry Hide	Sag/Flow Level	Overall Uniformity	**Total Score**	Amount Applied (g)
Commercial A	**A**	5	5	5	4	5	5	4	5	38	57.8
Commercial B		4	5	5	3	4	4	3	4	32	58
Commercial C		4	4	3	5	4	3	4	4	31	50.4
Commercial D		4	4	4	3	4	4	4	4	31	51.6
Commercial E		4	4	4	4	3	3	3	4	29	48.1
Commercial F		4	4	5	4	3	3	3	3	29	52.8
Commercial G		3	3	3	3	4	3	4	3	26	44.1
Commercial H		3	3	3	3	3	3	4	3	25	47.9
Commercial I		4	3	3	3	3	3	3	3	25	48.4
Commercial J		3	3	3	4	4	1	3	3	24	48
Commercial K		2	3	5	2	2	2	4	3	23	45.9
Commercial L		3	3	3	3	1	1	3	2	19	40.8
Commercial A	**B**	4	4	4	4	5	5	5	4.5	35.5	96
Commercial B		5	3	3	4	5	4	5	3.5	32.5	95
Commercial F		4	4	4	4	3	3	5	5	32	68
Commercial G		4	3.5	3.5	3	4.5	4	5	4	31.5	81.3
Commercial C		4	4	3	4	3	3	4	4	29	83.5
Commercial J		4	4	4	4	3	1	4	5	29	77.3
Commercial L		4	3	3	4	3	2	5	4.5	28.5	74.2
Commercial I		4	4	4	3	3	3	3	4	28	79.6
Commercial H		3	4	4	2	3	2	4	5	27	56.1
Commercial K		2	5	5	1	2	2	4	5	26	54.9

FIGURE 12
Comparison of rheology flow curves between Commercial Paint *A* (gray –), Commercial Paint *B* (black –), Commercial Paint *K* (green –), and Commercial Paint *L* (red –).

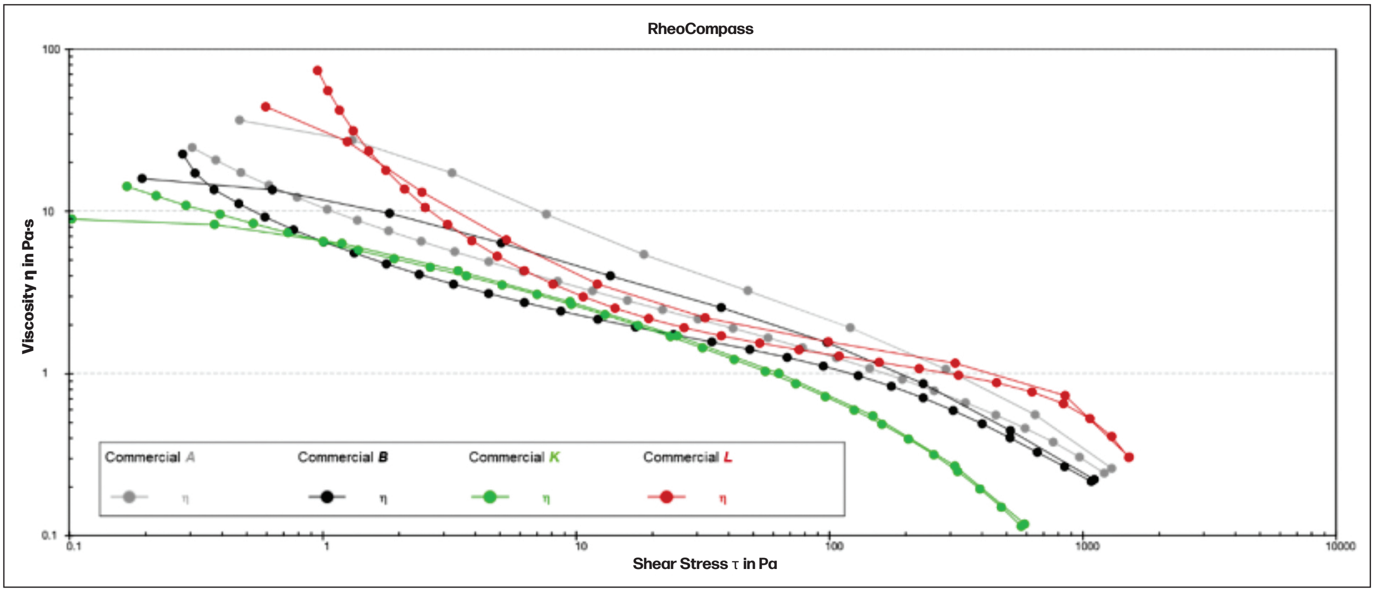


TABLE 6
Measured Leneta Flow and Leveling (ASTM D4062) and Sag Resistance of the Two Most Preferred Commercial Paints, Commercial Paints *A* and *B*, Compared with the Two Less Preferred Paints, Commercial Paints *K* and *L*

	Leneta F&L	**Sag Resistance** (mils)
Commercial L	4	16
Commercial A	7	14
Commercial B	7	12
Commercial K	9	10

Figure 13 shows the rheology flow curve of Commercial Paint *A* in comparison to the Latex A and Latex B formulations from **Table 1** and **Figure 9**, containing 1% high-shear associative polyether thickener. These curves highlight that a rheology profile similar to that of Commercial Paint *A*, given the paint solids content, cannot be achieved when using a small monomodal particle size latex dispersion, since the low- and mid-shear viscosity levels are already higher than the desired range. On the other hand, formulating with a bimodal high-solid latex provides an opportunity to increase the low-, mid-, and high-shear regions to achieve the desired rheology profile.

Next, to achieve the desired rheology profile in the experimental formulations with Latex A, various rheology modifiers were systematically added to the final base formulation from **Table 4**. The rheology modifiers and their combinations are presented in **Table** 7, which primarily consists of mid-shear associative polyurethane thickeners (Rheovis PU 1215, 1235, and 1291) at 0–0.2 wt %, along with one low-shear, non-associative acrylic thickener (Rheovis AS 1180) to provide some pseudoplasticity at 0–0.1 wt %. Out of all the combinations tested, Samples 13 and 20 most closely matched the rheology profile of Commercial Paint *A* **(Figure 14).** Sample 13 (BASF-13) had a final rheology package comprising 0.75 wt % Rheovis PE 1330, 0.1 wt % Rheovis PU 1235, and 0.05 wt % Rheovis AS 1180. On the other hand, Sample 20 (BASF-20) consisted of 0.75 wt % Rheovis PE 1330 and 0.15 wt % Rheovis PU 1291 in its final rheology package. Further, Samples 13 and 20 were chosen, because Sample 13 had some thixotropic character (more gradual time dependent rebuilt of viscosity) due to the addition of the alkali swellable Rheovis AS 1180, in contrast to Sample 20 displaying a much quicker viscosity recovery.

It is also worth highlighting at this point again that the experimental BASF paints with Latex A are not only able to achieve a similar rheology profile to Commercial Paints A and B, but are also able to achieve a significantly higher paint solids content at 50% volume solids compared to 38% and 40% for Commercial Paints A and B, respectively **(Table 8).**

FIGURE 13
Comparison of rheology flow curves for Commercial Paint *A*, and Latex A and Latex B formulations with 1% Rheovis PE 1330. Commercial Paint *A* (gray –), formulation containing Latex A (blue – bimodal), and formulation Latex B (orange – small monomodal).

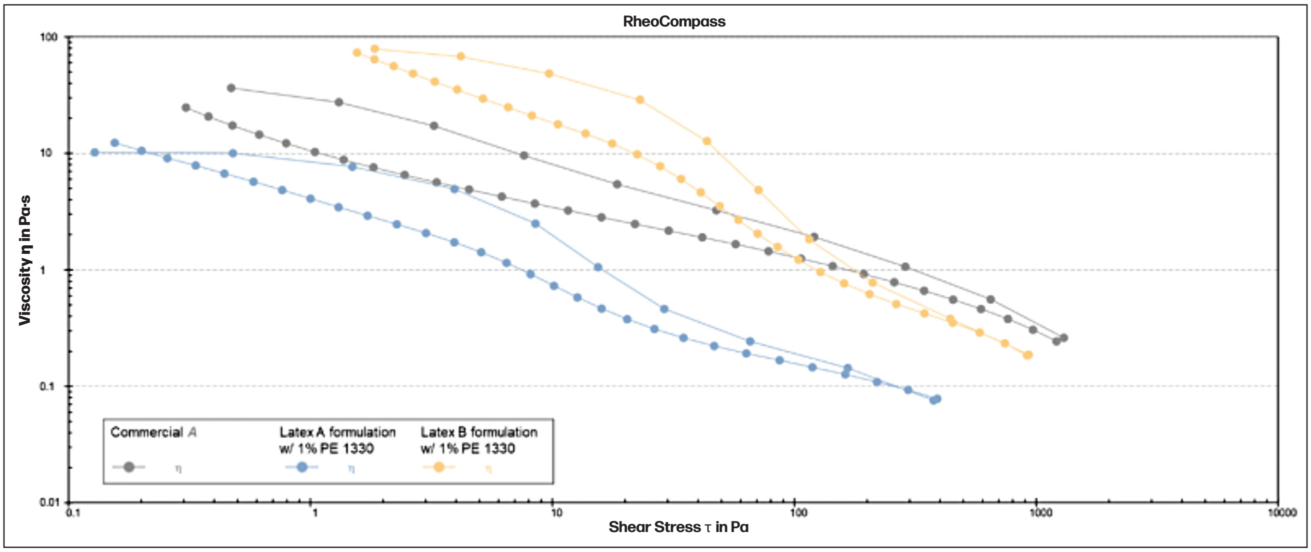
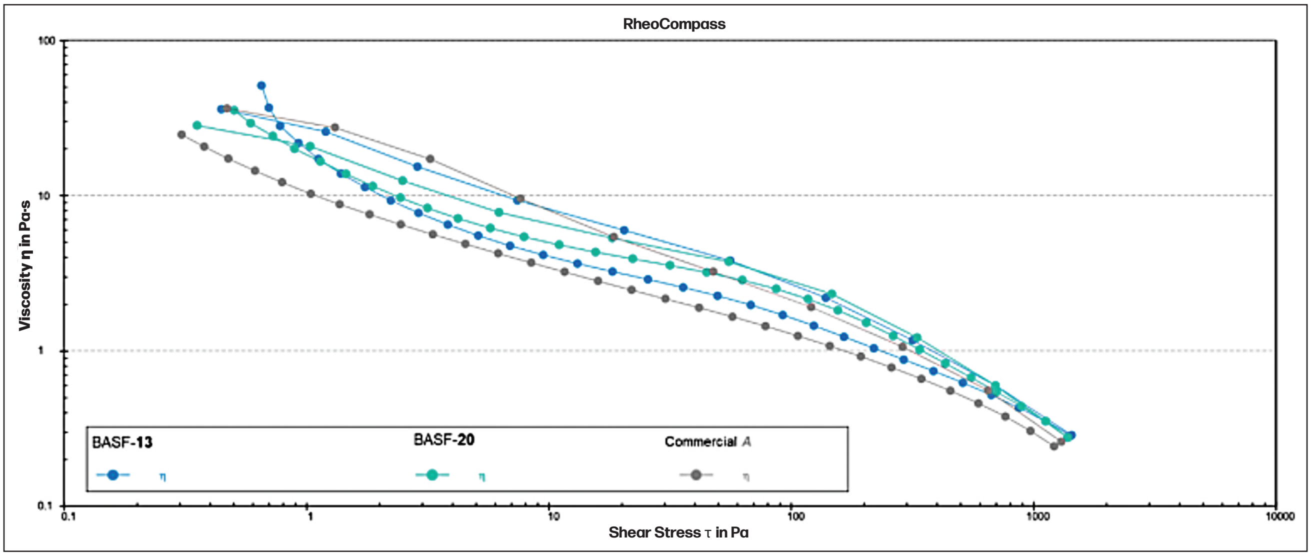


FIGURE 14
Rheology flow curves of high-solid experimental paint formulations BASF-13 and BASF-20 containing bimodal Latex A, compared to Commercial Paint *A*. Commercial Paint *A* (gray –), BASF-13 (blue –), and formulation BASF-20 (teal –).



Application Study of High-Solid Paints vs. Commercial Paints

To test the application and hiding properties of the two experimental high-solid formulations, BASF-13 and BASF-20, a double-blind application study was conducted. The study included a panel of eight participants who compared the experimental paints to commercial paints including Commercial Paints ***B***, ***K***, and ***L***. The rheology flow curves of each paint used in the study are shown in **Figure 15**. Commercial Paint ***A*** was not included in this study because it has a significant tint, making it an unfair hiding comparison to the other commercial white-base paints, which have much less color, or the experimental BASF-13 and -20 samples, which are pure white-base with no additional tint added.

The study setup was similar to the roll-outs of the commercial paints mentioned above. The participants applied each paint using a 4-inch-wide, 1.5-inch core roller with a 3/8-inch nap woven roller cover. The paints were applied to a pre-primed 2x4 ft section of a 4x4 ft drywall with a gray contrast strip in the middle. For consistency, Commercial Paint ***L*** was applied on the left side of the 4x4 ft board each time as a reference control. The other commercial paints

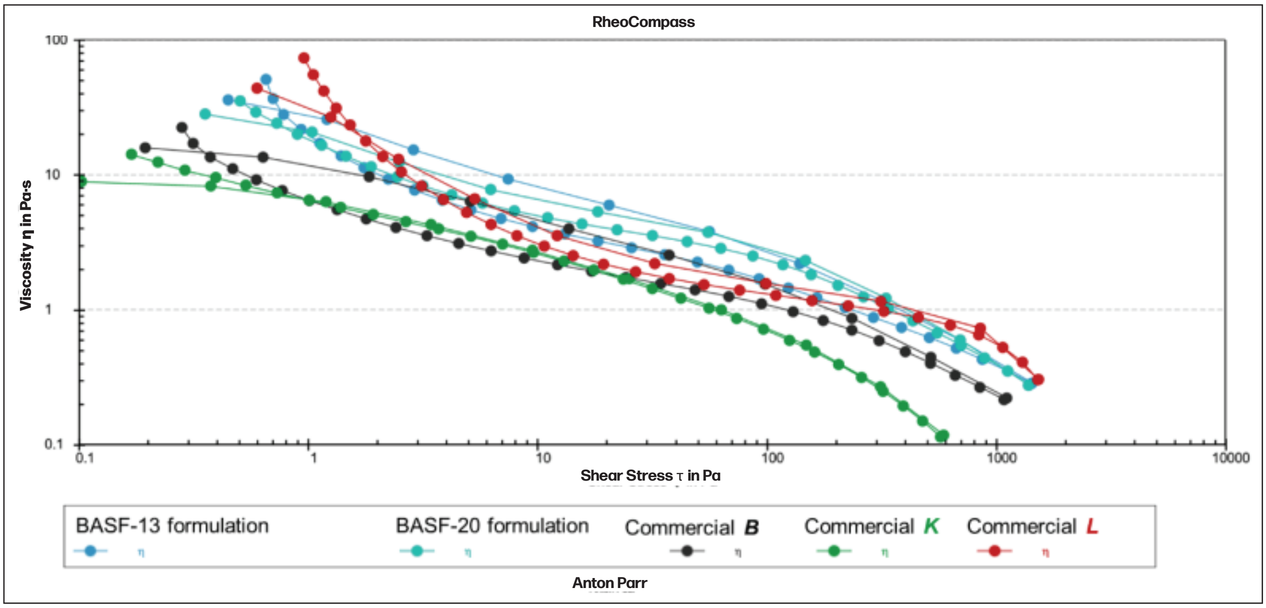
TABLE 7
Weight Percentage (wt %) of Rheology Modifiers In the Base Paint Formulation

	Rheology modifier				
Sample	**PE 1330**	**PU 1215**	**PU 1235**	**PU 1291**	**AS 1180**
Base formulation	0.75				
1	0.75	0.1			
2	0.75	0.15			
3	0.75	0.2			
4	0.75	0.1			0.05
5	0.75	0.15			0.05
6	0.75	0.2			0.05
7	0.75	0.1			0.1
8	0.75	0.15			0.1
9	0.75	0.2			0.1
10	0.75		0.1		
11	0.75		0.15		
12	0.75		0.2		
13	0.75		0.1		0.05
14	0.75		0.15		0.05
15	0.75		0.2		0.05
16	0.75		0.1		0.1
17	0.75		0.15		0.1
18	0.75		0.2		0.1
19	0.75			0.1	
20	0.75			0.15	
21	0.75			0.2	
22	0.75			0.1	0.05
23	0.75			0.15	0.05
24	0.75			0.2	0.05
25	0.75			0.1	0.1
26	0.75			0.15	0.1
27	0.75			0.2	0.1

TABLE 8
Solids Content of BASF Paint Formulations with Latex A vs. Commercial Paints

	Commercial Paint *L*	**Commercial Paint *B***	**Commercial Paint *K***	**Commercial Paint *A***	***BASF 13***	***BASF 20***
solids v%	33%	40%	37%	38%	50%	50%
solids wt %	46%	54%	52%	53%	63%	63%

FIGURE 15
Rheology flow curves of paints used in the application study, comparing the experimental high-solid formulations BASF-13 (blue –) and BASF-20 (teal –) with Commercial Paint B (black –), Commercial Paint K (green –), and Commercial Paint L (red –).



and the BASF paint formulations with Latex A were randomized among the participants and applied on the right side of the board **(see Picture 2)**.

In addition to measuring the amount of paint applied and the opacity of the final dry film, we also recorded participants' impressions on how the paint loaded onto the roller, its spreadability, application feel, subjective wet and dry hiding, sag resistance, flow and leveling, overall uniformity, and a final force-ranking of the paints, based on the application feel, hiding performance, and overall appearance of the dry coating (1: best, 5: worst). **Figures 16** and **17** show that there was significant difference in the amount of paint applied between each paint, with painters consistently applying more paint with the high-solids Latex A formulations and tending to prefer them over the commercial paints. The average amounts of paint applied for each paint type, along with the coverage (in sq ft/gal), are listed in **Table 9**. The table demonstrates that even at the highest average amount of paint applied for BASF-13 (79 grams per 2x4 ft), the spread rate is still well above the desired minimum spread rate of around 400 sq ft/gal, as recommended by most

PICTURE 2
Example of results from a double-blind roll-out study for one participant.

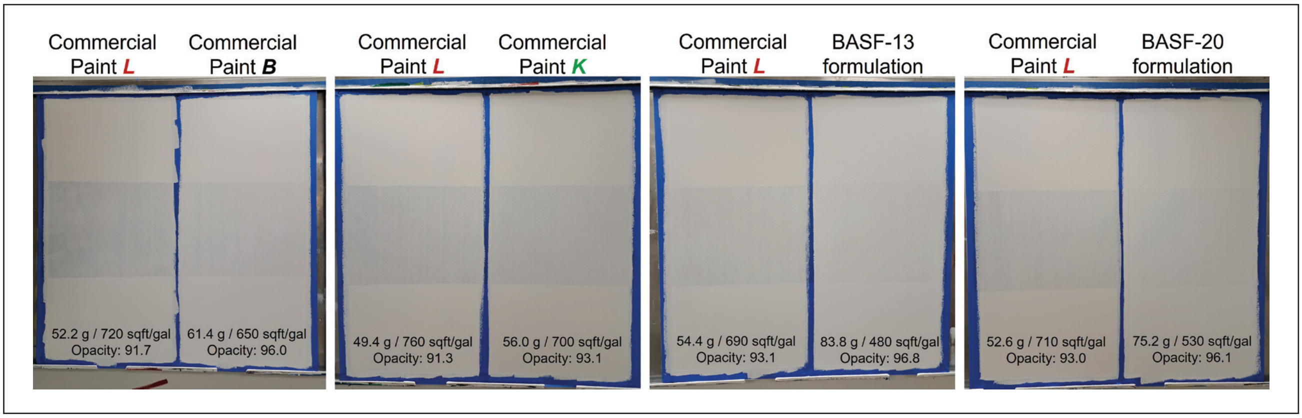


FIGURE 16
Comparison of the amount of paint applied and final ranking (1: Best, 5: Worst) by a panel of eight participants for commercial paints and experimental BASF paint formulations with Latex A.

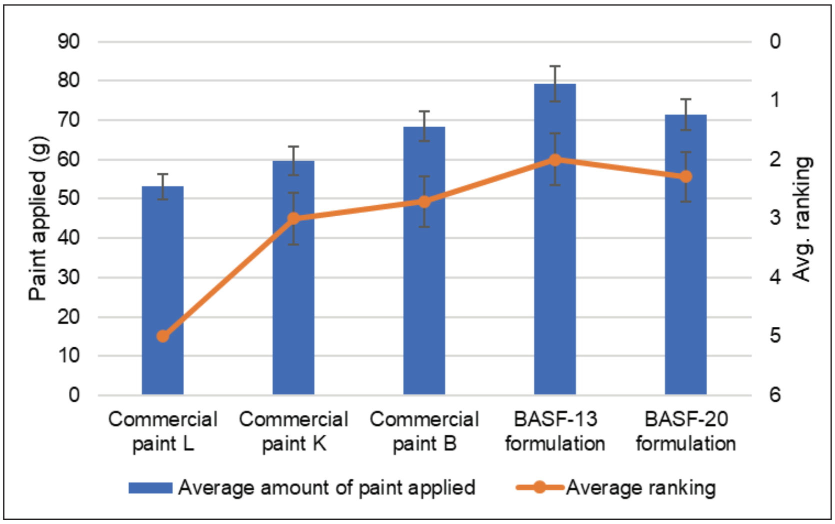
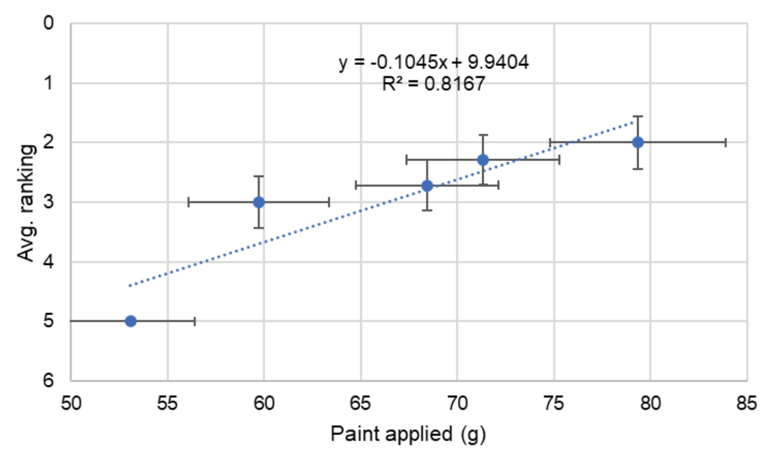


FIGURE 17
Average ranking (1:Best, 5: Worst) versus amount of paint applied by a panel of eight participants for commercial paints and experimental BASF paint formulations with Latex A.



paint producers. Additionally, even when the highest amount of paint (almost 90 g) was applied, the coverage achieved was still around 450 sq ft/gal.

Furthermore, **Figures 18–20** demonstrate that increased amounts of paint application result in higher opacity (i.e., better hiding) and an improved painter

TABLE 9
Average Application Amounts and Corresponding Coverage Rates

	Density (WPG, lb/gal)	Mass (g)	Coverage (sq ft per gal)
Commercial Paint ***L***	10.4	53	709
Commercial Paint ***B***	11.1	68	592
Commercial Paint ***K***	10.7	60	650
BASF-13 formulation	11.1	79	510
BASF-20 formulation	11.1	71	567

FIGURE 18
Correlation of the amount of paint applied by a panel of eight participants and dry film opacity.

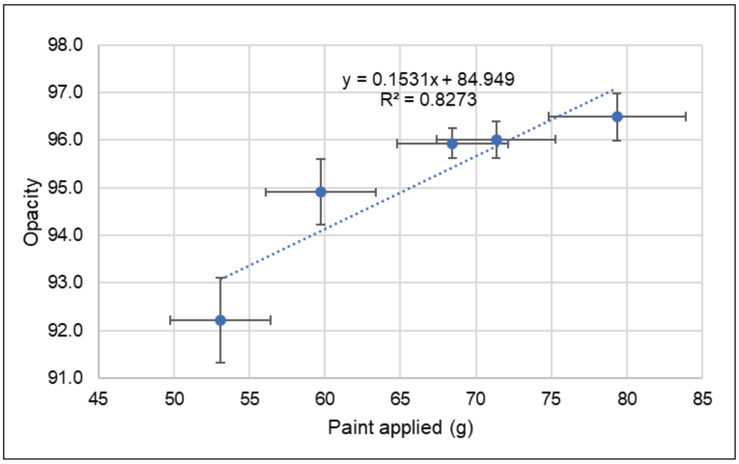
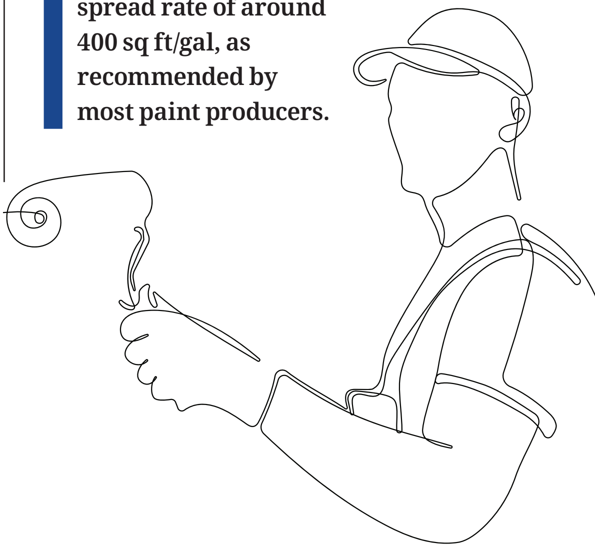


Table 9 demonstrates that even at the highest average amount of paint applied for BASF-13 (79 grams per 2x4 ft), the spread rate is still well above the desired minimum spread rate of around 400 sq ft/gal, as recommended by most paint producers.



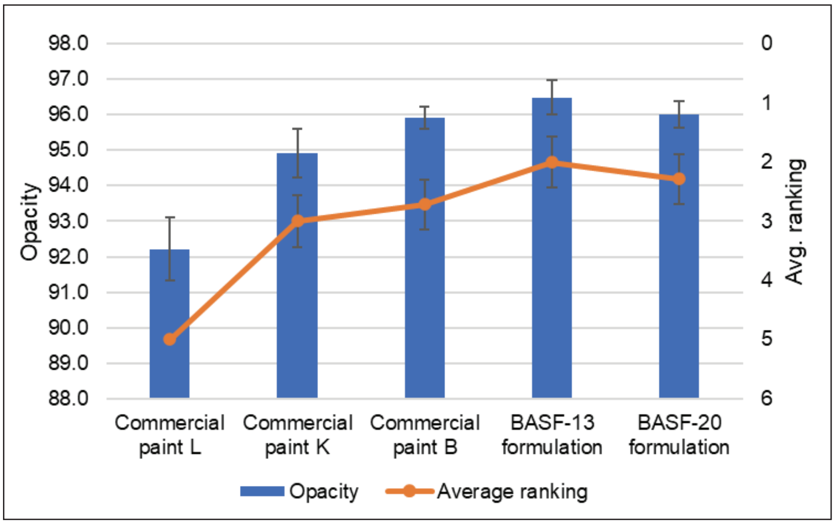


FIGURE 19
Comparison of dry film opacity and final ranking (1: Best, 5: Worst) by a panel of eight participants for commercial paints and experimental BASF paint formulations with Latex A.

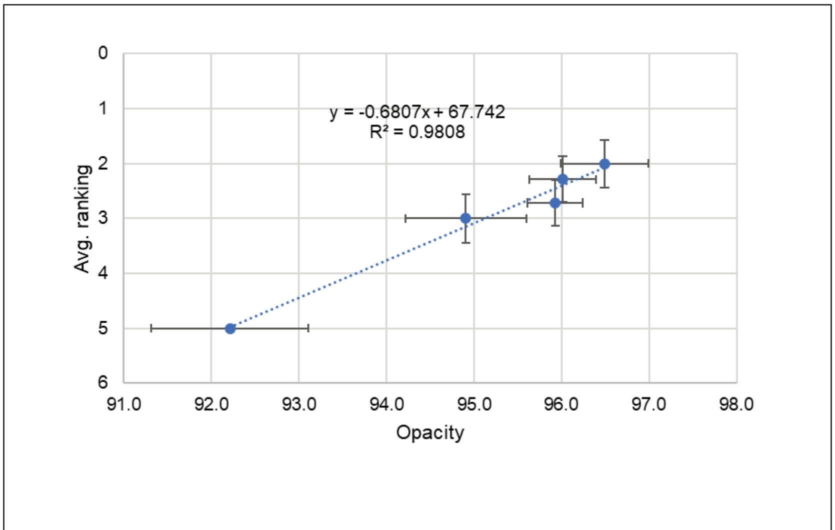


FIGURE 20
Average ranking (1: Best, 5: Worst) vs. the opacity of the final dry film by a panel of eight participants for commercial paints and experimental BASF paint formulations with Latex A.

TABLE 10
Summary of Common Verbatims Recorded for Each Paint by a Panel of Eight Participants

Commercial Paint ***L*** ○ Sticky ○ Thick paint doesn't spread as well ○ Does not cover well ○ When back-rolling: Am I making it better or worse?	Commercial Paint ***K*** ○ Slicker ○ Able to load more paint ○ Too slick and not enough drag. So slick, good grief ○ Too much paint on the wall, roller is floating on top ○ Glides nicely/easy ○ Spread well ○ Feels very slippery ○ Good wet hide	Commercial Paint ***B*** ○ Easy to load ○ Better control how much paint is on the roller ○ Smooth ○ Paint stretches further ○ Ammonia odor ○ Nice to roll ○ Spreads well ○ Good wet hide
BASF-13 formulation ○ I like how it loads on the roller ○ Easier to load the desired amount of paint ○ Feels good although it's thicker ○ Spreads well for how thick it is ○ Thick, but is loads up and spreads really well ○ Not worried about over applying ○ Able to add more unconsciously ○ Good wet hide ○ Happy medium	**BASF-20 formulation** ○ Loads pretty good ○ Good transfer ○ Nice spread, glides but not slippery ○ Can achieve optimal hide quicker ○ Can't really see the gray stripe anymore ○ Smooth ○ Although more drag, not more stipple ○ One coat ... I believe it	

experience. Lastly, **Table 10** highlights some common verbatims recorded for each paint, further confirming that the experimental paints formulated with the high-solid Latex A enable a favorable painting experience with better hiding performance.

Conclusions and Lessons Learned

The results in this work show that a high-solid bimodal latex polymer dispersion can enable 1) formulation of high-solid paints with volume solids >50%, and 2) achieve a rheology profile that enables more paint transfer, i.e. higher wet film thickness when applying the paint via roller application, while also striking a good balance between sag resistance (sufficient viscosity in the low-mid-shear region) and flow and leveling performance (low enough viscosity in the very low-shear region). While either one of these might be achieved independently using other formulation techniques, combining both high paint solids content with a thicker wet film allows for improved one-coat hide performance, which should ultimately result in an improved painting experience and fewer end-consumer complaints.

Future polymer development work in North America will focus on further enhancing other crucial dry film properties, including stain resistance and scrub resistance. By incorporating high-solids and a bimodal particle-size distribution into a latex specifically designed for the North American market, with good stain resistance and scrub resistance, we aim to capitalize not only on the favorable application and hiding properties achievable through correct formulation, but also to offer improved durability and longevity. This holistic approach ensures an overall enhanced consumer experience, providing paints that not only perform exceptionally during application but also maintain their quality and appearance over time. ❊

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Michael Krayer, *senior scientist & global technology manager at BASF Corporation; Dispersions & Resins North America: Email: michael.krayer@basf.com.*