# Paint Temperature Control Solves Finishing Defects

In spray painting operations, temperature-related variations can result in significant quality problems with film build, color match, surface finish, adhesion, etc. A global Tier-1 supplier of interior and exterior components to major automotive manufacturers was experiencing difficulty maintaining consistent finish quality on their painted parts. Working with their global paint manager and staff, Saint Clair Systems (SCS) set out to accurately quantify the impact of temperature on surface finish. Finish quality measurements were made with a BYK micro-wave-scan, which is well suited to the small, often curved parts painted for customers like Renault, VW and Audi, just to name a few. This provided an industry-accepted metric on which to base our analyses and conclusions. The goals and objectives set forth for this project were to:

- Quantify the relationship between paint temperature and surface finish at each step in the painting process;
- Demonstrate that controlling paint temperature at the nozzle can reduce the variation across a group of parts and increase first-pass yield;
- Define a temperature control system that can be installed on the existing robotic paint system with minimal down-time and limited interference with the paint path.

**FIGURE 1** | Viscosity vs. temperature for water.[1]

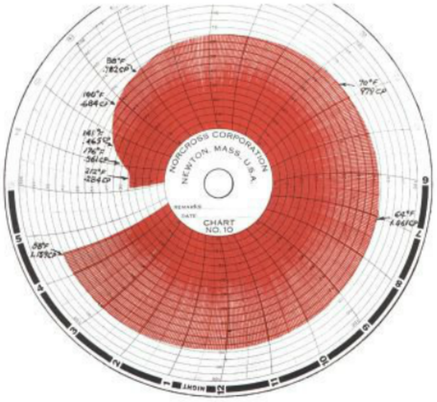
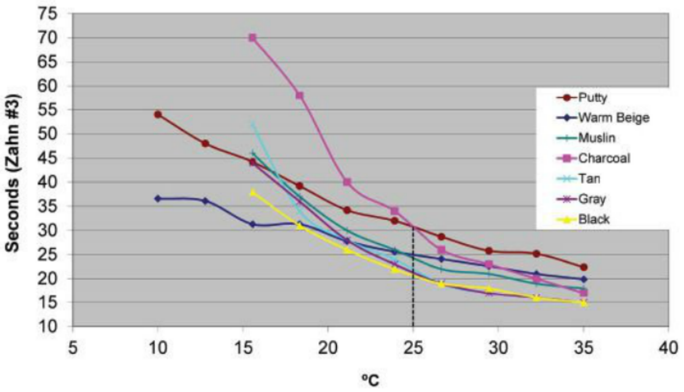


**FIGURE 2** | Paint viscosity vs. temperature by color.[2]



## The Basics

All liquids show some change in viscosity as a function of temperature. Figure 1, taken from a viscometer data sheet,[1] shows that even water goes through a viscosity change of nearly 2:1 between 10 °C and 40 °C.

Paints are no different. Figure 2 shows the viscosity/temperature curves for a selection of common, related paints used in spray painting operations. This shows the typical non-linear relationship associated with these materials over the normal ambient temperature range. It is worthwhile to note that this is shared with virtually all liquids and is a physical property, not a defect. As such, this is a parameter that can be exploited to improve the performance of the painting process.

In a spray delivery system, paint viscosity has a significant impact on system variables such as flow, pressure drop and atomization, and paint performance properties such as film build and flow out. Each of these has an impact on the final quality of the finish.

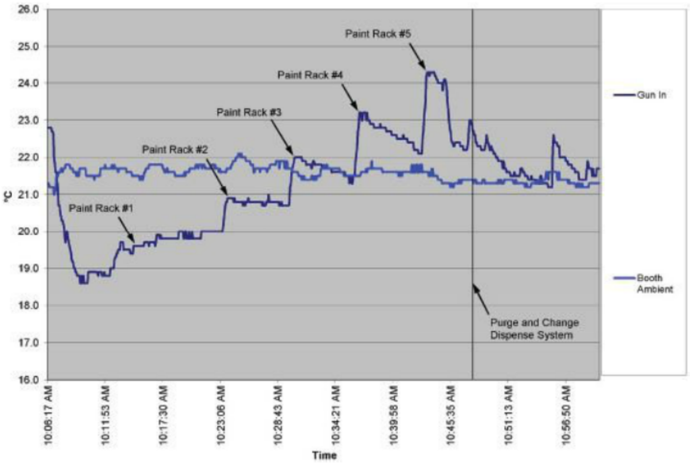
In the paint data sheet for a given formulation, the manufacturer provides a reference viscosity, often specified at 25 °C (77 °F). In Figure 2 we see that these colors, all of the same resin base type and formulated for the same operation, display a range of viscosities from 21 to 31 seconds at 25 °C (77 °F), and each varies differently as a function of temperature. Therefore, to obtain acceptable performance from each color, there must be either changes in the setup parameters of the spraying system for each color and at each ambient temperature, or the paint must be delivered to the gun at its optimal temperature every time it is sprayed. In fact, a similar project with a domestic

By **Michael R. Bonner**, Vice President of Engineering & Technology | Saint Clair Systems, Inc., Washington, MI

**FIGURE 3** | SCS' proprietary Re-Corable Coax Hose Assemblies in place on the 2K clearcoat robot.

**FIGURE 4** | AT-5900S TCU.

**FIGURE 5** | Clearcoat temperature testing data.



high-end automotive specialty vehicle and aftermarket supplier showed that their orange peel problems could be eliminated if their paint formulation was sprayed within a consistent 3 °F (2 °C) window. This, then, forms the foundation for modern paint temperature control.

## Temperature Control Equipment

Shown in Figure 3, SCS's patent-pending Re-Corable Coax Hose Assemblies provided the easiest method for retrofitting the robot while providing temperature control all the way to the point of dispense – the gun. This system surrounds the existing paint-carrying tube with a jacket that carries temperature-conditioned thermal transfer fluid, creating a flexible tube-in-tube heat exchanger. Available in configurations for both 1K and 2K paint systems, it is flexible enough to handle the motion of a robotic application and, because it fits around the existing paint tubing, it does not alter the existing paint path and, therefore, cleaning and color change practices can remain unchanged.

In conjunction with the Re-Corable Coax Hose System, SCS's AT-5900 TCU (Temperature Control Unit), shown in Figure 4, provided the ability to vary the temperature of the paint being sprayed while all other application parameters (flow, gun path, speed, etc.) were held constant. Together, this system could provide all of the heating and cooling necessary to accurately control the paint temperature and was installed in the 2K clearcoat booth in just two hours. In order to record the temperatures throughout the system, a series of fast-acting thermocouples was employed. These were coupled to a wireless transmitter system that relayed temperature data from inside the booth to a computer located outside the intrinsically safe painting area.

## The Effect of Clearcoat Temperature

Using the setup above, the first test was designed to determine the effect of clearcoat temperature on surface finish parameters. For this test, the basecoat was applied normally and the temperature of the clearcoat was varied, as shown in Figure 5.

Here we can see the change in temperature for each rack as it is being sprayed. This also shows that the system is capable of both changing the temperature of the clearcoat and maintaining it independent of the 22 °C (72 °F) ambient.

After curing, the parts were measured with a BYK micro-wave-scan unit and the data analyzed. For those of you unfamiliar with the BYK wave-scan system, it is a tool used to objectively analyze paint finish quality for two of the most important and troublesome criteria:

1) Orange Peel – Describing the leveling of the paint across the surface, it refers to a wavy appearance, often looking very much like the texture of the peel of an orange.

2) Distinctness of Image (DOI) – This describes the sharpness or clarity of an image reflected in the surface of the paint.

The waviness of automotive paints fall in the range of 0.1 mm to 30 mm in length. In addition to DOI, the micro-wave-scan measures both long-wave and short-wave variations. While the objective is to minimize these variations, a decrease in short wave value results in a more brilliant appearance, making longer waves more visible. Therefore, to optimize appearance, a “balance” between short wave and long wave leveling is essential.

The longwave results are shown in Figure 6. From this graph it is easy to see that the optimal longwave results with this setup are achieved at about 21.0 °C (69.8 °F). The shortwave results are shown in Figure 7. Here we can see that the optimal shortwave results are achieved at about 23.2 °C (73.8 °F).

Looking at these two graphs, it can be observed that the scales on each are equivalent at three points of wave measurement and 6 °C (11 °F) of temperature variation (25 °C-19 °C = 6 °C). By placing both data on the same dual scale graph, which allows us to shift the two plots to coincide with one another, the optimal operating temperature can be quickly determined, as shown in Figure 8.

This shows that the best overall balance between longwave and shortwave performance is achieved with this setup at the intersection point of 22.2 °C (72 °F). This also demonstrates how temperature can be used to shift the performance as desired between the two. If it is desirable to optimize longwave performance over shortwave, the paint temperature can be lowered toward 21 °C (70 °F). Conversely, if it is desirable to optimize shortwave over longwave, the paint temperature can be raised toward 23 °C (73 °F). This control provides the ability to “fine tune” the process while keeping all other variables constant.

The last remaining parameter to be considered was distinctness of image (DOI). The results are shown in Figure 9. Here we can see that the optimal DOI results with this setup are achieved at just below 20 °C (68 °F) and just over 23 °C (73 °F). For these parts, the minimum value allowed is 86, so the DOI is acceptable at all values between 20 °C-24 °C (68 °F-75 °F) and, therefore, will remain in spec regardless of how the longwave and shortwave are optimized. This kind of fine tuning allows the best match to the rest of the vehicle to be consistently achieved.

Based on this analysis, a similar experiment was performed on the combination of basecoat and clearcoat to determine the degree of impact that each paint layer has on the overall finish.

## Combined Effect of Basecoat and Clearcoat Temperature

Similar to the clearcoat test discussed above, racks of parts were sprayed with basecoat setpoint temperatures incremented from 18 °C to 28 °C (64 °F-82 °F). Once painted and baked, the parts were pulled and inspected to determine the best finish. Because the gloss of the basecoat was below the threshold required for the micro-wave-scan unit, these were judged manually against standard ACT Appearance Test Panels. This analysis revealed that the best basecoat finish was achieved at 22 °C (71.6 °F). Multiple racks of parts were then painted with a stable basecoat setpoint temperature of 22 °C (71.6 °F). The temperature data collected during this run showed that the actual measured gun temperature was maintained at a consistent 21.3 °C (70.3 °F).

These were then sprayed with clearcoat at multiple setpoint temperatures from 20 °C to 28 °C (68 °F-82 °F) to confirm the effect of clearcoat temperature on finish

**FIGURE 6** | Longwave vs. temperature.

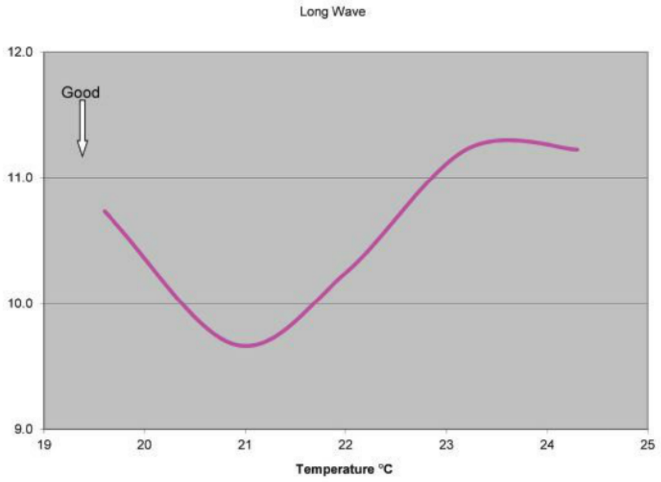


**FIGURE 7** | Shortwave vs. temperature.

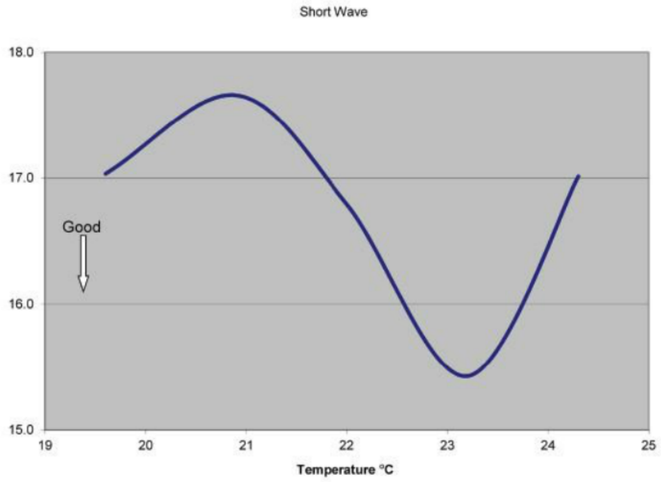


**FIGURE 8** | Determining the optimal operating temperature.

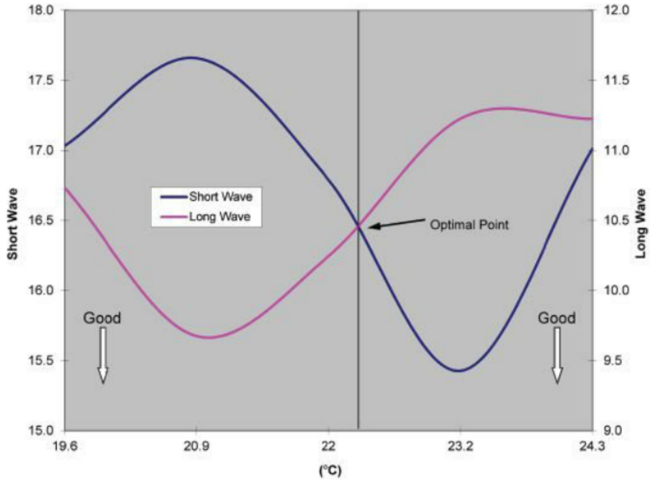


**FIGURE 9** | DOI vs. temperature.

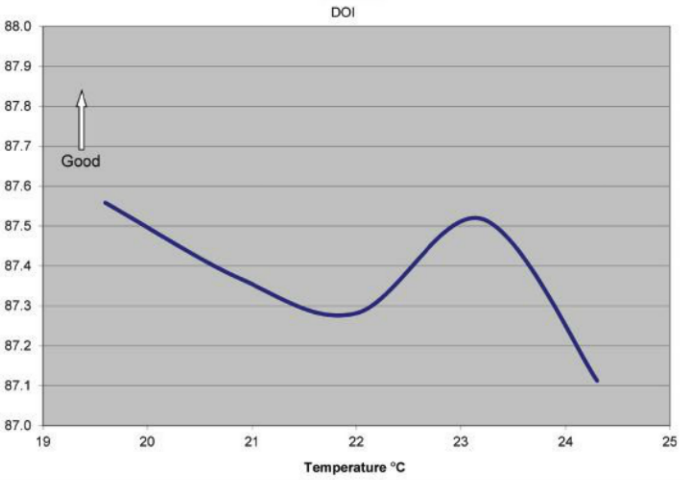
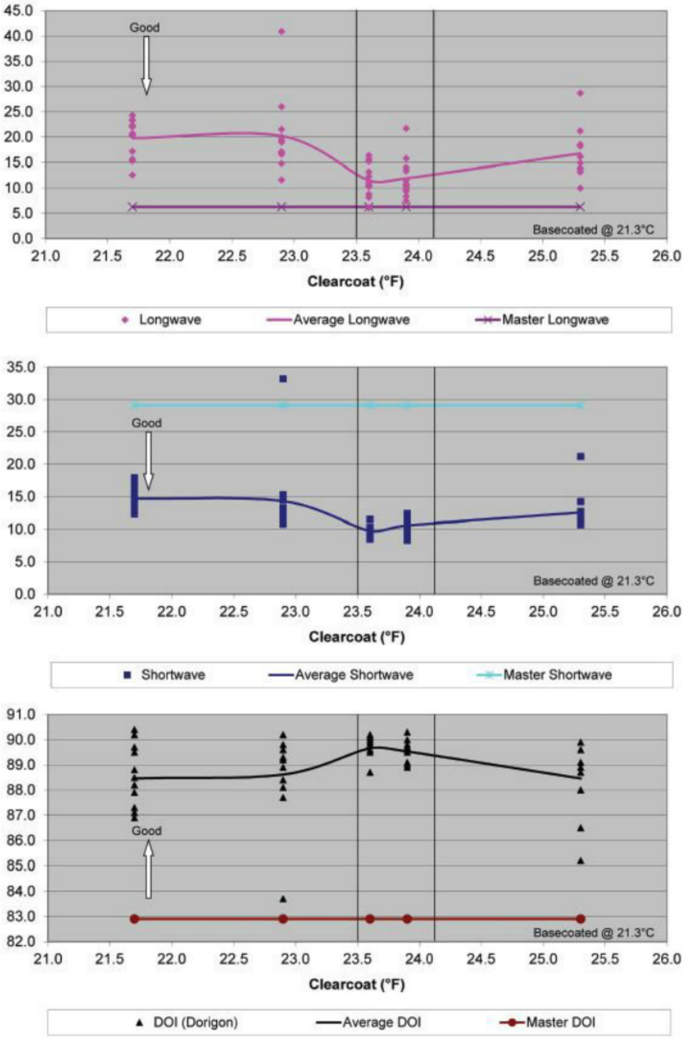


**FIGURE 10** | Variable clearcoat temperature testing.



quality with a consistent basecoat. The results of this trial are shown in Figure 10. Here, data points for all parts are plotted at each temperature such that the actual deviation can be observed. The average line is also plotted to show where the mean of the data falls at each temperature. To provide a comparison to the finish goal, the micro-wave-scan readings from the Master Part, approved by the end customer, are also shown. These three frames reveal that all three parameters are optimized in the same temperature range – 23.5 °C-24.0 °C (74.3 °F-75.2 °F). Not only did this achieve the optimal average value in each category, it also produced the lowest variation (tightest groupings). This is extremely important in that lower variation relates to greater first-pass yield. In addition, the DOI and shortwave are significantly better than the Master, and the average of the longwave is only five points off the Master reading. This is in keeping with the data from the first test, which showed that this temperature range would optimize shortwave performance over longwave. All of this suggests optimal performance with a basecoat spray temperature at 21.3 °C (70.3 °F) is achieved with a clearcoat spray temperature between 23.5 °C-24.0 °C (74.3 °F-75.2 °F).

## Conclusion

From this testing, it is clear that the temperature of the paint at the nozzle has a significant, measureable impact on surface finish and that each layer (basecoat, clearcoat, etc.) plays a role in the appearance of the final part. Furthermore, the effects of temperature are both controllable and repeatable, which suggests that we can turn temperature from an adversary in our quest for quality into a tool we can actively use to improve our process outcomes.

The system supplied for the purpose of running these experiments demonstrated that temperature control can be quickly and easily added to an existing spray system with minimal downtime and without interfering with the paint path, robot programming, cleaning procedures and the like.

Over the course of this experiment, it was determined that an increase in first-pass yield of just 5% (a very conservative estimate based on this data), would result in an ROI for the temperature control system of months as opposed to years. Furthermore, any increase in first-pass yield reduces scrap and frees production time that would otherwise be dedicated to rework and/or the additional production volumes necessary to satisfy customer requirements. This translates to shorter leadtimes, fewer customer rejects and an overall stronger relationship, with a simultaneous increase in throughput, which translates directly to an increase in capacity to support additional business. This provides the opportunity for revenue growth with no increase in cost, which further shortens the ROI equation. In every way, this is a fast, sure improvement path with a short-term ROI and a long-term benefit.

Temperature control systems for both spray booths were subsequently purchased and installed. ■

## References

[1] Water Temperature vs. Viscosity data provided courtesy of Norcross Corporation.

[2] Paint Viscosity vs. Temperature data provided courtesy of Sherwin-Williams Corporation.