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ULTRAVIOLET CONFORMAL COATING PROCESS DEVELOPMENT

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OVERVIEW

Ultraviolet (UV) curable coatings can be used to meet cost pressures and for improved coating performance when compared to other coating material. However, there are some unique process controls that need to be put in place to guaranty a well controlled process that does not require cleaning. This paper provides a review of a conformal coating process development for a coating using UV light to provide the cure mechanism.

A UV conformal coating line will usually consist of an In-feed conveyor, Coating applicator, Inspection station, UV Oven and an Out-feed conveyor. The UV oven and the coating applicator are the actual components in the line that require an understanding of the process mechanism and the effect that machine settings have on the process.

COATING PROCESS CONSIDERATIONS

Several machine factors work together during the coating process. There are many machine settings to consider when setting up the coater. Figure 1 shows [1, 2, 4] there are many factors that interact with each other. A discussion with the coating supplier and applicator manufacturer can be very helpful in removing some of these factors.

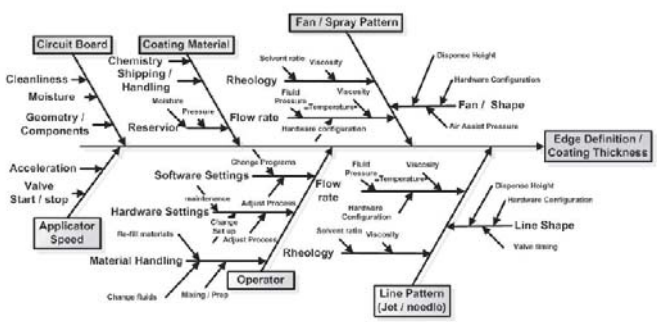


Figure 1 Coating Machine Factors
Courtesy of Astmtek)

One of these factors is valve opening. The valve opening affects the maximum amount of material that can flow out of the valve. If the valve is not open enough no amount of pressure can push enough material out to coat the assembly to the correct thickness. Once the valve setting is determined, it becomes a fixed setting. The same is usually true of pot pressure and incoming line pressure to the material pot. This pressure must also be controlled to reduce variation in the process.

Whether using a spray type nozzle or needle dispense head travel speed is one variable that has a large impact on coating thickness. Coating too fast will cause the coating to be thin and possibly have skips. Coat too slow and the coating will be too thick. Head speeds also affect line edge definition and contribute to overspray condition.

Line definition is also influenced by the distance from the surface that the coating is being sprayed. Figure 2 below clearly shows the effect of head speed using a spray nozzle. This effect becomes more noticeable as the distance from the surface increases. After a certain distance from surface, the line edge definition does not degrade and remains the same.

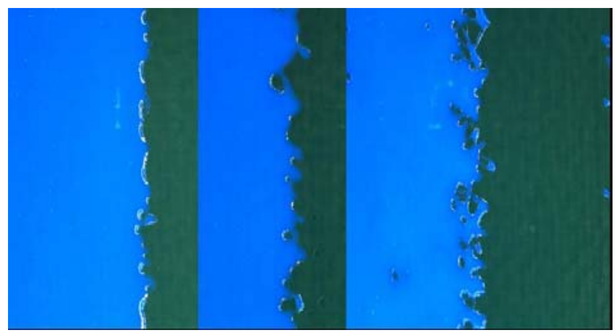


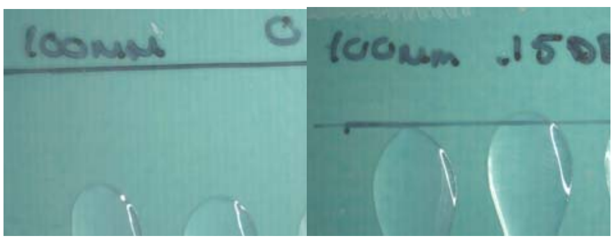
Figure 2 100mm, 200mm, 300mm respectively
(6mm Spacing off the Surface of the Assembly)

Overspray is coating in unintended areas. This condition can be minimized and there are many parameters that affect this condition. Work to determine the minimum keep out area has shown that 1.5 mm is achievable without taping or booting in places where there are no components. This tight of keep out area requires very precise control of the spray head and there are some process components that are not obvious that need to be reviewed and analyzed. Examples of these type of concerns for process development are does the applicator head act the same front to back vs. back to front and left to right vs. right to left . While it might be intuitive that the applicator should be the same in both directions it might not be and needs to be checked.

Control of stops and starts should also be checked. Applicator head design and mounting can play a significant role in line definition. Applicator heads that start and stop too fast could possibly have some amount of oscillation associated with them. This “ringing” can cause variation in line widths at the beginning and end of an application. This condition needs to be review with applicator vendor and mitigated. This could be as simple as changing as setting or as significant as "stiffening" the applicator head assembly.

Another process parameter that should be reviewed when setting up the process is Atomization pressure. Process testing and experimentation is required to fully optimize this parameter with all the others.

Valve turn on time and turn off time are also critical parameters and affect all application nozzles. Valve turn on time affects the actual start point of where the coating will begin. If there is no delay between when the valve opens and when the head moves there will be a gap from the expected target location to where the coating first touches the surface. Very fast head speeds can create large gaps between when the valve starts to move and when the coating actually touches the board. Figure 3 shows this effect using a needle dispense. The black line is the start location.



0.0 second delay 0.15 second delay

Figure 3 Different turn on times

This same effect also shows up for turn off time but in a different way. When discussing valve turn off it is sometimes easier to discuss it as a distance. One would say that the valve was turned off 2.0mm before the end of the line as an example. If one waits until the line ends to turn off the valve the coating material that has been dispensed out of the valve but has not touched the board (the coating material that is between gap of the nozzle and the board) will pool slightly. As the nozzle moves to the next position to dispense some carryover in the nozzle movement will result. A slight curve in the dispensed material and the coating thickness at the end of the dispense will be thicker, shown Figure 4.

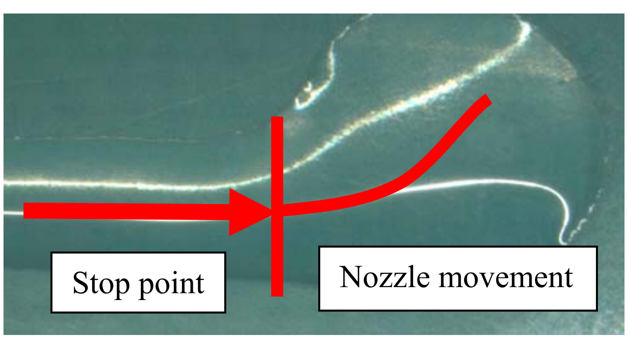


Figure 4 Improper valve turn off

Another consideration is distance from the surface of the board. Different distances will perform differently. The width that one line will coat should be determined. This will be different for different distances from the coating surface. As an example, 6.0 millimeters away from the coating surface will yield a different line width than 12.0 millimeters away from coating surface. This difference is not a direct relationship but proportional to the distance so different settings have to be checked. As an example a line sprayed 12mm away from the coating surface will not be twice the width of a line sprayed at 6mm away from the coated surface. Because of these variable line widths, different step distances or line spacing will be required. If the step to too large, the spray pattern will not cover the area needed. This condition should not be confused with de-wetting of the coating which looks exactly like the same phenomenon. This condition can be distinguished from de-wetting by the straight line that shows up in the coating compared to the random nature of actual de-wetting. In the de-wetting situation this is caused by lower surface energy than the coating requires.

SURFACE ENERGY DISCUSSION

UV cure materials are 100% solids so they have no solvents that will "pseudo" clean the boards like a water based coating. This means that the assemblies that are being coated must be as clean as possible or at least clean enough to "hold" the coating. In order for the coating to adhere to the surface there needs to be a certain amount of surface energy present to help adhesion. This can be checked by the use of Dyne Pens. Dyne Pens have an engineered fluid in them that mimics surface energy for the specified surface energy reading. To use a Dyne Pen mark an uninterrupted area of the surface to be coated, similar to using a "magic maker." If the surface energy of the surface is lower than the pen used the fluid will not wet out and a rough edge will be seen. If the assembly surface energy is higher than the fluid from the pen it will wet out and the line marked on the surface will have a smooth edge as shown in Figure 5.

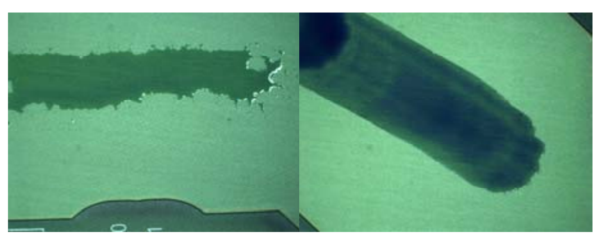


Figure 5 De-wetting and Wetting examples
Dyne pen results

Dyne pens are a good tool to get into the ball park but are very dependent on the person using them. This is why even with something as simple as dyne pen use you must provide training on how to use them correctly.

Because of this variability we have looked for a better method to qualify solder mask surface energy, something more definitive. Both peel and pull tests have been tried but to date have not been successful.

Manufacturing processes like reflow, wave solder and touchup add process "dirt." Testing has found that in general we see about a 6.0 to 8.0 dyne/cm decrease in surface energy.

Making certain that both the reflow and wave solder profiles are correct will help minimize the amount of process dirt left. Incorrect thermal profiles will not volatize some of the flux components and can cause de-wetting of the surface [1], so it is critical that all profiles are checked to make sure they meet the minimum manufacturer's requirements. Post-processing materials can also cause coating de-wetting. It is important that all materials used in post processing be checked for compatibility [4] with the coating. Production associates need to be trained and fully understand how to use and process these materials. An example of this would be post solder work where cored solder flux might not be volatized sufficiently, excess or left over flux residue not cleaned correctly. Certain RTV's, rework adhesives, spot soldermask pose problems, but correctly processed will pose no problems.

Most coating manufacturers indicate that the minimum required surface energy is 35.0 dyne/cm. So 35dynes/cm minimum energy plus the 8dynes/cm of process dirt equals 43 dynes/cm. Add 1 more dyne/cm for dyne pen tolerance and you get 44 dyne/cm. This means that incoming material should have a reading of 44.0 dynes/cm. The incoming surface energy requirement will be different for different manufacturing sites because it is based on average "process dirt" left on an assembly and how uniform processes are across all manufacturing sites. This requirement should be part of the Purchase Order requirements or the general fabrication requirements specification.

Even if the bare boards come in clean the process window is very small which means making sure that everything is correct is a must.

Attention to the smallest details are now required. As an example making sure that selective wave solder pallets are now cleaned and not trapping un-volatized flux is a good example of things to look for. Count the number of times the pallet goes through the process before cleaning it.

SOLDERMASK DISCUSSION

Surface energy is greatly influenced by soldermask. The type, application method and how it was processed are all important factors for high surface energies. According to most soldermask manufacturers all soldermasks should be able to easily achieve 48 dynes/cm or greater. For bare boards that are lower than the required surface energy the bare boards can be plasma cleaned.

Plasma cleaning is done by using plasma created by a high frequency electric field to ionize a gas. This "excited" gas collides with the surface of the boards and knocks off surface contaminates and creates a "tooth" on the solder mask. This is a common practice in the semiconductor industry but is not extensively used in the printed circuit board fabrication. This process is not always available from all fabricators and it is not inexpensive. To avoid the special process of plasma cleaning focus should be paid to the fabricators solder mask process steps. The typical list of process steps include but are not limited to mixing, pot life, pre-cleaning, coating, drying, exposure, developing, stripping and cure. Since all soldermasks, are different these steps will need to be checked/verified with the fabricator for each mask type and process that is used on bare boards. Low surface energy can be caused by a number of these factors but most soldermask suppliers agree that the biggest contributing factor is post cure. If the thermal profile for curing the soldermask is not correct, adequate cross-linking of the soldermask will not take place and there could be spots in the soldermask where contamination can stay and this will be a cause for coating de-wetting and loss of adhesion.

PROCESS MONITORING

Once the final parameters of the coating process are solidified a thickness check needs to be done and monitored. This is done using a thickness gauge of some type. The traditional method used in the past is a wet thickness gauge. The wet thickness gauge has a set of steps in it that have been machined or stamped out in some material at specific measurements. Each step represents a different thickness. This gauge is then set in the wet coating that was just sprayed on the board surface. As the gauge is set into the wet coating the steps are then reviewed and the step that doesn't have a gap between it and the coating is determined as being how thick the coating is. The problem, in the case of solvent based materials, is that as the solvent is driven off, it will shrink and then the exact coating is not known. Contrast that to an eddy current meter that checks thickness of a cured coating based on an eddy current derived between the coating and a metal surface directly below the surface. Eddy current measurement provides a direct reading that indicates the coating thickness. No need for cross sections and micrographs. One thing to note with either method is that all coating materials have a viscosity to them.

When two spray lines overlap there is a small rise. The amount on this rise has to be controlled by using the correct line spacing. Too little of a step and the coating will be too thick, too much of a step and the coating will be too thin. Too much of a step could also have gaps in the coating and could potential lead to adhesion and or cohesion loss to the board surface or the material itself.

Figure 6 shows this small rise using in house data collected for thickness measurements, note the outliers in the data.

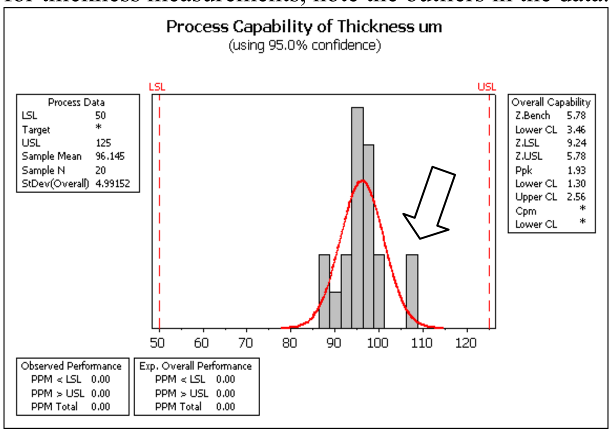


Figure 6 Thickness Capability

This outlier data causes the process sigma for coating thickness to be 5.78 sigma. Removing this outlier data improves the sigma level to 8.17. This "overlap" if not understood can manifest itself as an out of control process if the thickness requirements are very tight.

Using the parameters that we just discussed, head speed, distance from the surface and line spacing we can create a linear regression that can predict the coating thickness shown in Figure 7.

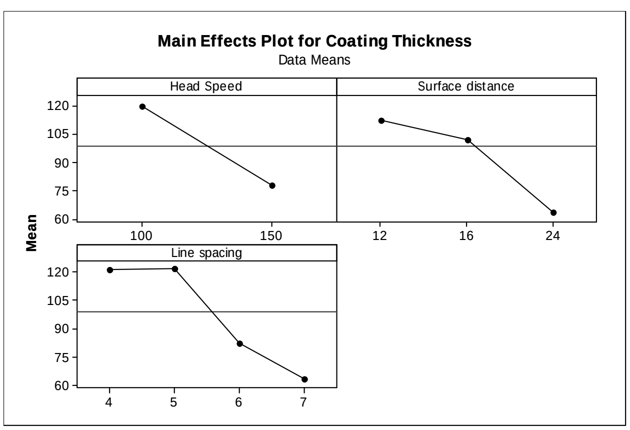


Figure 7 Main Effects for Coating Thickness

Linear regression for Coating Thickness (um):

Coating Thickness = 263 - 0.647 Head Speed + 1.33 Surface distance - 19.6 Line spacing

S = 12.0706 R-Sq = 83.7% R-Sq(adj) = 83.6%

The high R-sq number (83.7%) means that the data fits the model well but there is 16.3% error that cannot be explained using the parameters in the above equation.

Other causes of variation in coating thickness not accounted for are board bow, fixture rails that are not parallel and the clips that hold board assemblies in the fixture that are not parallel and can be seen in Figure 8.

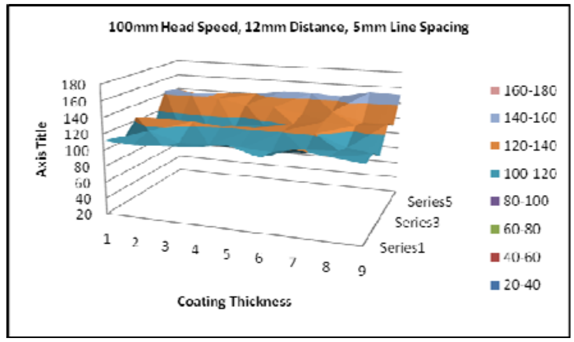


Figure 8 Fixture, Board Bow and Holding Clips

Board bow is nothing new to any electronics assembler but adding the need for flat boards for conformal coating is one more detail that requires attention and again points to the need to have solid thermal profiles that meet the reflow and wave needs but does not create bowed assemblies.

Once we identified these sources of variation we did not go back and qualify the exact contribution of each source but we were comfortable that these sources explained most of the 16.3% error.

UV OVEN CONSIDERATIONS

UV curable materials have a wide process window. This wide process window means that a broad range of conveyor speeds can be used. This is very important for high through put of assemblies. However, there is also another reason. Printed Circuit Board Assemblies (PCBAs) with tall components get very close to the UV light source. In some cases UV light sources can produce up to 200-watts/inch of bulb length.

The damaged sleeving on this capacitor body shown in Figure 9 was not the result from thermal excess. A thermal profile was taken and indicated that the temperature at the top of the capacitor was only 86ºC. This temperature is lower than would be expected in normal wave soldering processes. The source of damage for this capacitor is from the UV energy itself. This damage could have two mechanisms. The tearing of the sleeving is right where component identification was stamped into the sleeving and could have produced a weak spot in the sleeving. The other possible mechanism is the component color itself. Sleeve tearing on Black, Dark Blue, and Brown parts could not be duplicated.

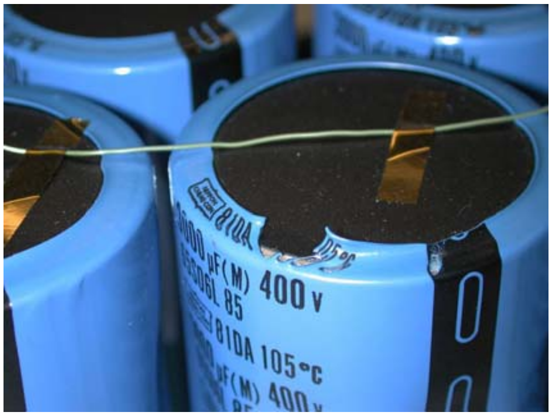


Figure 9 Damaged sleeving

In these cases, higher conveyor speed can be used to eliminate component damage from UV light. High conveyor speeds while desirable need to be properly vetted to assure that the appropriate amount of UV light is exposing the coating so it cures properly. If it is not possible to increase conveyor speed then a simple mitigation strategy for this is to cover these parts with aluminum foil or some type of machined cover. Additionally conformal coating material can be selected that has a secondary cure mechanism that uses atmospheric moisture.

UV coating manufacturers specify exposure times and rates at specific UV light wavelengths to achieve the best cure. UV light is typically broken up into 4 wave length bands, UVA, UVB, UVC, and UVV. A device called a radiometer, shown in Figure 10, is used to collect UV light parameters and provide feedback on the process UV light output from the light source. It is now generally acknowledged that there are two measurements that need to be monitored. These two parameters are Irradiance (Watts/cm^2) and dose (joules/cm^2) [5]. Irradiance is the power or intensity of the UV energy, delivered to a surface per unit area [6]. Dose is the total energy delivered per unit area. Both of these parameters work in tandem to produce the cure characteristics that are required for the coating in question.

The front of the radiometer has the operator interface and the back has a small mirrored window that collects the light output.

Front Back

Figure 10 Radiometer Example

Radiometers are very sensitive. A slight change in position will result in changes in the readings. It is highly recommended that some type of tooling is used to make certain that the radiometer window is in the same location every time. As an example a fingerprint was found on the mirrored window that was causing a change in the reading. Variation in technique will cause changes in the readings. One operator lets the conveyor take the fixture/ radiometer into the oven and another operator pushed the fixture/ radiometer into the oven part-way to speed the process up. In this case the total exposure time will vary. To minimize this, create a procedure that tells exactly how to send the fixture/radiometer through the UV oven and then train to that procedure.

Over time UV light sources change; they age [1], and the UV lamps sag. Every month the UV lamps need be rotated 180 degrees. This is why it is very important that before starting a UV process that characterization of the UV light output is performed. This allows referencing back to the initial data to see if something had changed.

UV light output is highest from the center of the lamp and tapers off at the ends. In some cases UV light sources are back to back because the process width requires more than just one bulb width. A 20-inch wide process might be made up of two 10-inch lamps end-to-end. The red line in Fig. 11 represents the light output from the bulbs. When this type of arrangement occurs, it is important to check more than just one location in the process, especially during UV light process characterization.

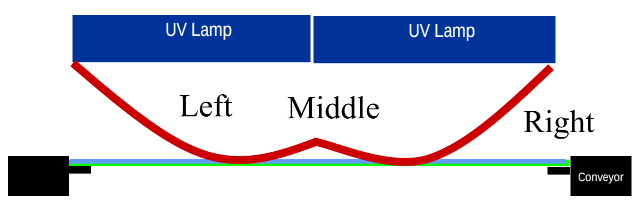


Figure 11 End to End lamps UV output

If just checking the process middle or middle of the UV lamps you could get a false sense of the process output.

Figure 11 illustrates that two lamp ends together have more output than a single lamp end and the middle of the lamp has the maximum output. Figure 12 shows these differences.

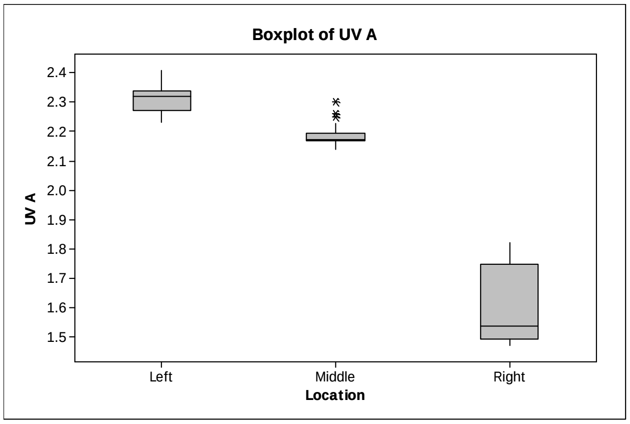


Figure 12 Differences between left, process middle, and right at 1.5 meters/minute

Using the manufacturer's specification of 1.38 – 2.40 joules/cm^2 as the process window, process data collected from either the middle of the lamp or the two lamp ends indicate that the coating material is cured. However the right end of the process might not be fully cured or could potentially still be wet. This shows why it is important to check more than just one spot of conveyor width for UV light output to optimize the conveyor speed.

These parameters are very easy to obtain. Adjusting the conveyor speed from low to high will provide the values that can be tied back to the coating data sheet and provide the absolute maximum process speeds.

For some UV processes, the distance between the conveyor and the lamps is relatively large, as mentioned earlier with the tall components. In these cases, the lamp energy at the surface of the assembly will fall off by the square of the distance. This equation is for light that falls perpendicular to the surface of the assembly. Where "I" represents the lamp energy and "d" is the distance from the light source.

$$E = \frac{I}{d^2}$$

Large spacing between the conveyor and UV lamps causes some light energy to be lost. In these cases reflectors at the ends of the lamps can be used as a mitigation strategy to improve the lamp output at the ends.

Figure 13 shows this strategy. The improvement shown is exaggerated for explanation purposes.

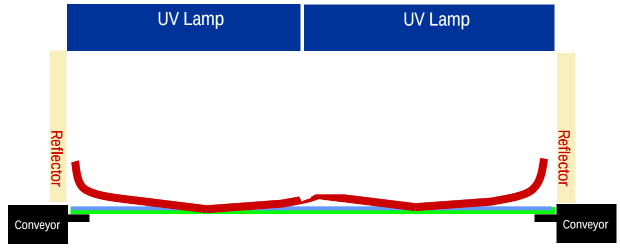


Figure 13 Reflector example

The light energy returned from the reflector will greater that 95% but never 100%. However the radiometer will not measure the reflected light in the same manner as light entering perpendicular through the exposure window. The actual amount of energy captured is

$$E_c = E_l * \cos\theta * R_e$$

where E_c = Energy Captured, E_l = Lamp energy, cosθ of reflected light, R_e = Reflector efficiency.

In the case of the light source mentioned earlier with a distance from surface of over 100mm a slight improvement can be seen in light output reaching the surface and a much tighter grouping using the reflectors.

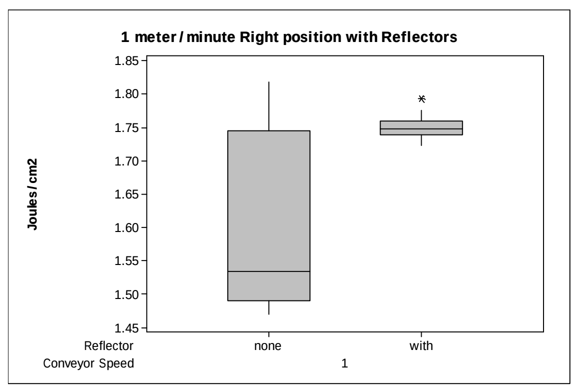


Figure 14 Comparison of light output at 1.0 meters/minute

This improvement does not carryover as the conveyor speeds increase.

In setting up similar processes keep in mind the distance from the UV lamps to the surface of the assembly is critical.

CONCLUSIONS

Several factors have been shown to affect coating thickness and a regression equation with good correlation index has been established to fit this model. UV cure parameters require a complete systems view; it is not just conveyor speed but position within the oven as well as fixturing.

Finally you must understand your incoming board cleanliness and the amount of "process dirt" that the assembly process reduces the surface energy.

FUTURE WORK

Develop a model for spray dynamics to determine the minimum distance to components (X, Y, Z axis) and keep out features that the process is capable of. Determine minimum component spacing and topography requirements needed to provide optimum coverage of assemblies with challenging packaging requirement and a high mix of tall and short components.

Develop a test for surface energy to provide more quantitative results that dyne pens.

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