Design Considerations for implementing adhesive bonding solutions utilizing the latest in UV/LED technologies

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Markets for cured adhesives continue to expand as adhesive formulations, materials, & manufacturing processes evolve. This paper will review emerging applications and the contributions to productivity and efficiency made by in-line surface treatment, precision liquid dispensing and UV/LED curing technologies.

Applications for UV Cured Adhesives

UV Cured adhesive applications are growing at a rapid rate in the medical device, electronics, photonics, and automotive markets. For example, the proliferation of an extremely fast growing smart phone and tablet industry is creating a demand for more efficient production processes. There are numerous UV curing applications for conformal coatings, touch panels, micro-speaker, and miniature cameras. An increasing trend on the dispensing side for miniaturization in all of these markets is requiring for a higher degree of repeatability.

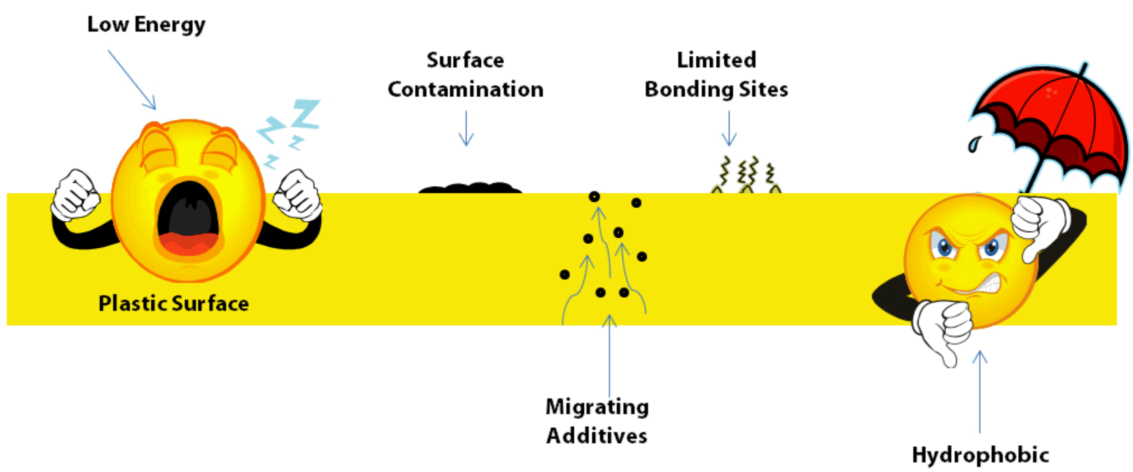
Both spot and area UV curing is attractive to these industries because of its efficiencies at reducing work in process. As more production processes move from batch to in-line, atmospheric plasma and flame surface treating technologies are emerging as valuable production tools to enable and improve adhesive bonding results. Additionally newer LED technology is finding applications where it can outperform traditional UV Lamp Technology.

The key to harnessing the benefits of these technologies is to clearly define your application when working with your adhesive, dispensing, surface treatment, curing and automation suppliers. This paper will provide insights to your options within each area.

Surface Treating

In-line surface treatment is a well proven technology for activating nonporous, low energy surfaces to become more receptive to adhesive processes. Treatment can be effective on all types of plastics, films, glass and even metals.

Prior to treating, these surfaces tend to suffer from adhesion inhibiting factors such as low surface energy, contamination, migrating additives, and limited bonding sites. (Figure 1) By cleaning, etching and functionalizing surfaces may become hydrophilic and enable the wetting out of adhesives



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Traditional methods of surface preparation include liquid primers, mechanical preparation, and are still effective but also require considerations. Liquid primers can be expensive, messy, environmentally hazardous, and may not be conducive to an in-line process. Mechanical preparations are often not delicate enough for sensitive surfaces and can generate surface debris. Vacuum plasma treatment can be very effective, but also expensive and limited to batch, offline processing.

In-line spot or area plasma and flame surface treaters offer manufacturers a new alternative to make surfaces adhesive ready. They can be mounted over conveyors and indexing systems or integrated with robotics for precision applications. As with any technology it's important to understand the features and benefits of the available technologies.

Plasma and Flame Surface Treating Technologies

Plasma is the 4th State of Matter and is an ionized gas featuring a mixture of charged ions and energetic electrons in equilibrium. The charged ions and energized electrons generated by plasma surface treaters bombard a materials surface to remove organic and inorganic materials, essentially cleaning the surface.

The plasma discharge also creates more bonding sites by micro-etching the surface. For some applications inert gases are introduced into the process. These specific plasma chemistries can be effective on difficult to treat surfaces such as fluropolymers by functionalizing the surface on a molecular level.

There are a variety of plasma discharge designs which can be employed to meet the geometric and treatment requirements of a specific application. The simplest form of plasma treatment is referred to as a Blown Arc Plasma. It is generated by passing a high-voltage electrical discharge between two electrodes. A single blown arc head treats anywhere from two to three and a half inches and multiple heads can be combined for wider treatment patterns.

An important thing to remember about blow arc plasma is that, they can only be used to treat non-conductive materials. This is important, not only for the material that you're treating, but also for any carriers that might be involved in handling the surface being treated.

Blown-ion plasma treatment provides a more versatile treatment range as it can treat conductive or non-conductive surfaces. Plasma is generated inside the head, and high velocity ions are blown out through compressed air. Treatment width is ~~a bit~~ narrower than blow arc systems, at about half an inch wide, and is ideal for adhesive applications in recessed areas.

Flame treating is probably the technology that most people are familiar with, as it's been around for many years. Systems today are remarkably efficient, safe and repeatable. Flame is able to treat both conductive and nonconductive materials at extremely high speeds. Treatment width can vary from as small as two inches to over 16” and beyond. The effective treatment area of the flame is very deep, which allows treatment of objects with significant contours.

Determining which Surface Treating Technologies is Best for your Application

Certain application variables may elevate or eliminate each technology. Conductivity of the surface, process speed requirements, size and geometry of the part to be treated, and part handling are all important factors in addition to the purpose of the treatment.

The best way to determine if a surface treatment solution will provide you with the results you desire is to implement it on a trial basis in your line. While this is not always practical Enercon offers free laboratory testing and can partner with other supplier on these projects.

For example figure 2 shows the test results of improved bond strength on a polyethylene substrate with a UV cured adhesive. You can see the positive effect using the pretreatment in this case improved treatment by a factor of more than three times.

Now that you’ve learned about surface treatment options, let’s take a look at your range of options when it comes to dispensing fluid adhesives.

Liquid Adhesive Dispensing Systems

To optimize your liquid adhesive dispensing system many variables need to be properly defined including viscosity of the adhesive, defining the bead or spray application, volume of adhesive used, and the desired range for consistency and repeatability. To determine the best dispensing solution for your application you need to determine, "What level of consistency and quality requirements are being demanded of the application?" Systems range from tabletop syringe dispensing systems to highly customized pieces of automated equipment.

Selecting the right supply lines for UV Chemistries

Before we look at automation options we’ll briefly cover the importance of using the right materials for your supply lines. For UV chemistries black opaque Teflon lines are commonly used as standard, even for moisture sensitive materials. Many new UV materials contain aggressive secondary moisture cure mechanisms, that have greater performance in shadowed areas.

The secondary cure mechanism, whether it be chemical, moisture, or even heat introduction, has improved over time and are being used more readily. This also has to be taken into account when designing the dispensing system to make sure that it is moisture free, as well as UV light free.

Pumping systems use high-pressure hoses for higher viscosity materials. These tend to be opaque and avoid UV penetration into the fluid lines as well. Typically stainless steel or plastic fittings are used in the dispensing system. Acrylic-based UV materials at times can react with steel or brass units, those are considerations that should be taken when designing a UV dispensing process.

During that curing phase, any type of crystallization, due to inappropriate fittings, or fluid delivery components, will restrict the flow of the material, and subsequently clog a valve or a dispensing system.

Another consideration is the shear sensitivity of the material. High shear pumping systems are often used for higher degrees of accuracy in your dispensing system. Piston or gear pumps can cure the coating and seize pump, so typically peristaltic or diaphragm pumps are preferred.

Temperature and Viscosity

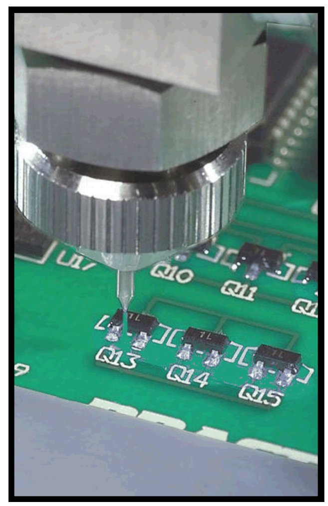
Its important for the dispensing system manufacturer to know the variation in viscosity versus the temperature of the material. If a particular chemistry is very reactive to changes in temperature it can be stabilized. Unknowingly manufacturers can run into problems because of an adhesive tank sitting next to a heating duct, or an open window that may affect the temperature of the material throughout the day.

Controlling the temperature of the material tank, the fluid lines, and the valve itself are all options if the material is very sensitive. This is important in a time and pressure scenario, where we rely on chemistry to create a consistent application, because there is no metering in the process at that point. This can be improved by introducing a diaphragm or gear pump system that will proportion the material regardless of small variations in viscosity.

Automation Considerations for Dispensing

Manual adhesive dispensers- typically a time and pressure process via a syringe or dispense wand, an addition of a controller can allow shot size to be determined by operator or via time. The advantage to this solution is a very low initial investment. Disadvantages include poor shot repeatability, operator dependent for volume and position, and the lowest % material utilization.

Semi-automatic adhesive dispensers- combine time and pressure or metered dispensing operation with some basic motion. Automating the position of the part itself eliminates relying on the operator to consistently move the part into the proper position for dispensing. Advantages of semi-automatic dispensers include added accuracy within dispense shot, position, or both; and they require only a moderate initial investment to achieve more control. Disadvantages are that repeatability can vary and there is still manual part handling.



Automatic adhesive dispensers- utilize automated motion with robotics or other means for highly repeatable positional accuracy and dispense accuracy is based on the fluid delivery design. When combined with automated part handling such as conveyors, indexing systems, rt robotics or other means, this system enables a high volume and very repeatable process with efficient material utilization (up to 99%). Almost any fluid delivery option can be used in this system. The only disadvantage is this solution requires the highest initial investment.

As accurate as a robot can be, and these are typically plus or minus a thousandth of an inch repeatability on each axis, the shot to shot accuracy, is always determined by the fluid delivery design. With automated systems there is much greater material utilization because of the positioning system and waste of material goes down significantly.

The next step in the process is determining the best curing system.

UV and LED Curing Systems

Two technologies being used today in curing applications are UV lamp and LED curing solutions. Each of these technologies offer a distinct set of advantages and limitations.

UV curing starts with the photo initiator that's included, whether that's a UV curable adhesive, ink, or coating. The curing reaction starts when sufficient light of the correct wavelength range is absorbed by the photo initiator.

That's an important point to note, because every photo initiator has a very specific spectral range where they absorb light and start that reaction. It is critical that the spectral output of the light source matches with the absorption range of the photo initiator.

Once the polymerization reaction starts, enough energy needs to be provided to get that reaction through to a point that the material is fully cured. While there are many different variables along the way that can affect the final cured properties of the material, for our purposes we're going to look at those properties directly controlled by the light source. That would include the dose, and the radiance, or the energy density provided by the light source multiplied by the time.

In applications where the parts are being held in place, the exposure time that the parts are being subjected to is not controlled. In other applications where the parts may be moving on a conveyor, the exposure time is often controlled by the speed of that conveyor, and it controls the dose of energy that gets to the UV adhesive, or coating. Another important factor is the spectral contents, or the wavelength of light that are being shown down onto the material. Finally there is heat, which is a byproduct of the reaction the polymerization reaction is exothermic.

If an application has a sensitivity to heat this could have a significant impact on the technology used in the curing process. It does generate heat, but the light source used, can have significant effects on the amount of heat seen by the parts, and so if this is a consideration with your parts, and it often is in many different curing applications, then this could be one of the areas where it may determine what technology is best for you.

If we look at the typical maximum radiance from an LED spot curing system, most LED systems can achieve up to about 10 watts per square centimeter, which is really more than enough irradiance for almost any curing application.

(FIGURE LD1)

	LED Spot Cure	Lamp Spot Cure	LED Area Cure
			
Typical Max. irradiance	10W/cm^2	30W/cm^2	8W/cm^2
Typical Spot Size	2 – 4mm	5-10mm	25 x 50 or 75mm
Optical Power	> 500mW	6-8W	100 – 140W
Wavelengths	365nm, 385nm 400nm	250-600nm	365nm or 395nm
Cure Type	static	static	static or continuous

They are however limited to small spot sizes, and that's how were able to achieve the higher radiance level, such as 10 watts per square centimeter, by using a lens to focus that energy into a very small spot. The actual optical power coming from an LED spot source is only about 500 mW. Since it is focused, it can generate significant irradiance in a small spot size.

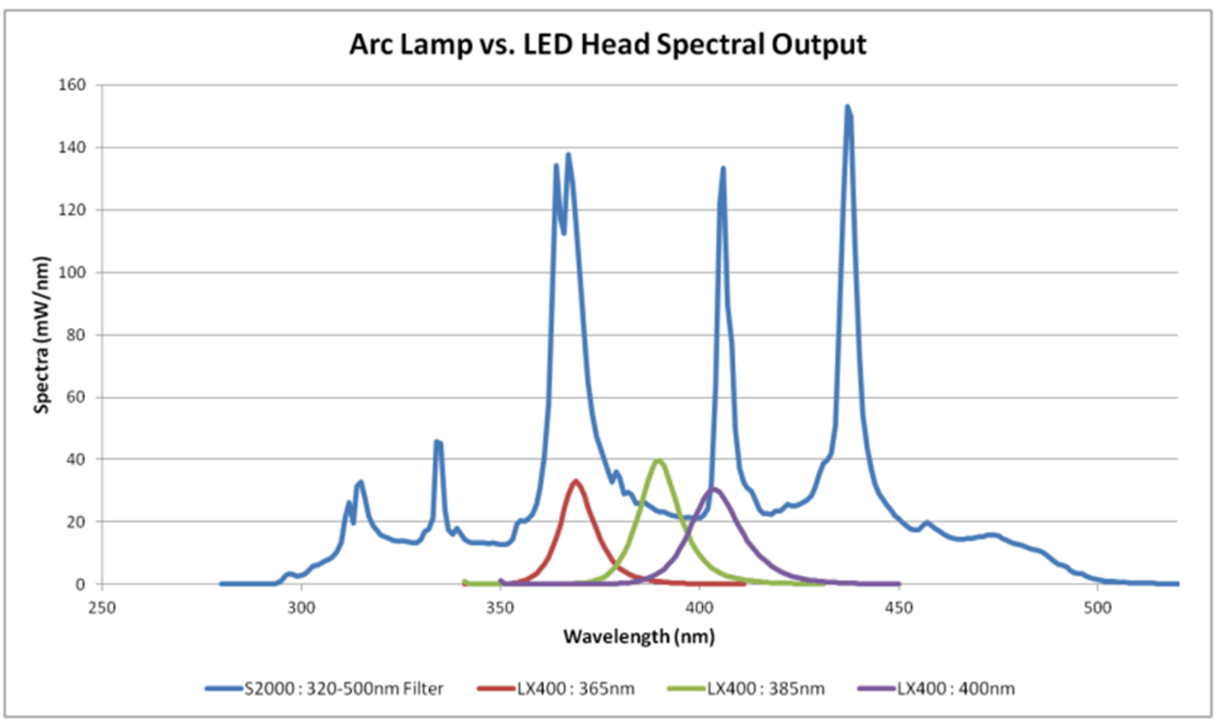
An UV lamp spot curing system has a significantly higher irradiance, up to 30 watts per square centimeter, much higher than you would use for most curing applications. Most spot curing systems will give the option of adjusting the amount of output down from 30 watts per square centimeter.

The spot size is much larger than available with LED because when looking at the optical power, a typical lamp spot curing system has about 10 times the optical power than an LED system. There is the flexibility of larger spot sizes and the potential of curing faster, because a higher amount of power available for the curing process.

One of the ways to overcome this with LEDs, is by using a LED area cure systems. LEDs are able to get an irradiance level of eight watts per square centimeter, which would be sufficient for most curing. The area curing is now covering a much larger area, about 25 x 50 millimeters, one inch by two inch, or one inch by three inch area. There are hundreds of LEDs within that area, and now the optical power is much, higher which gives more flexibility in curing, by not being limited to small spot sizes.

For most spot curing applications, the parts are generally held in place while the parts are given an exposure for one, five, or 10 seconds, with an LED area curing system, there is the flexibility of continuous curing. By using conveyor type curing, the ability to continuously curing parts starts to increase throughput because there's a much higher optical power available.

The chart below shows the differences in the spectral content between a lab-based system and an LED, and this is really one of the key differences between the lamp and LED technology. On this chart the blue line is typical mercury arc lamp.



In this case, a 320 - 500 nm filter has been applied to the spectral output of the. The full-spectrum of a mercury lamp will extend from 200 nm and below where it generates ozone, which could be an issue for some applications. It extends into the infrared above 700-800 nm where you can start generating heat from that spectrum.

The lamp is a very broad spectrum versus the three smaller peaks in the center, which is a LED spot curing spectrum. Those have three different wavelengths available at 365 nm, 385 nm, and 400 nm. This creates at very narrow bandwidths, typically about 15 nm bandwidths. It creates lower power, but this narrow bandwidth means that the LEDs need to be very specific on which wavelength when matching up to a photo initiator.

A lamp-based system is a very broad spectral output and is much easier to match up the output of a life system to the requirements of the photo initiator. The LED system uses very narrow bandwidths. It is very critical to understand the absorption range of your photo initiator. It needs to match up the bandwidth of LEDs that are being using with the requirements of the photo initiator.

This may limit the choice of adhesive depending on the photo initiators being used. They may not be able to match up to the LEDs available. Typically, LEDs are available in 365, 385, and 400 nm. There are LEDs available in higher wavelengths, but today from a commercial availability, 365 nm is the lowest wavelength that is available.

If adhesive compatibility is one of the key factors that you're looking at, and this could be for example if you use multiple adhesive with different photo initiator absorption range, you're certainly going to have an easier time matching up those requirements using a lamp-based curing system.

The benefit of a LED is that the heat generated during the curing process is able to be minimized. The wavelength of light is being specified to the requirements of the photo initiator, therefore a very narrow spectrum of light is being used.

In a curing reaction, the light is being absorbed by the adhesive, but you also have light that can be absorbed by the parts. The dark, or colored materials, will often absorb visible light, and many plastics will absorb light below 300 nm depending on the plastic being used.

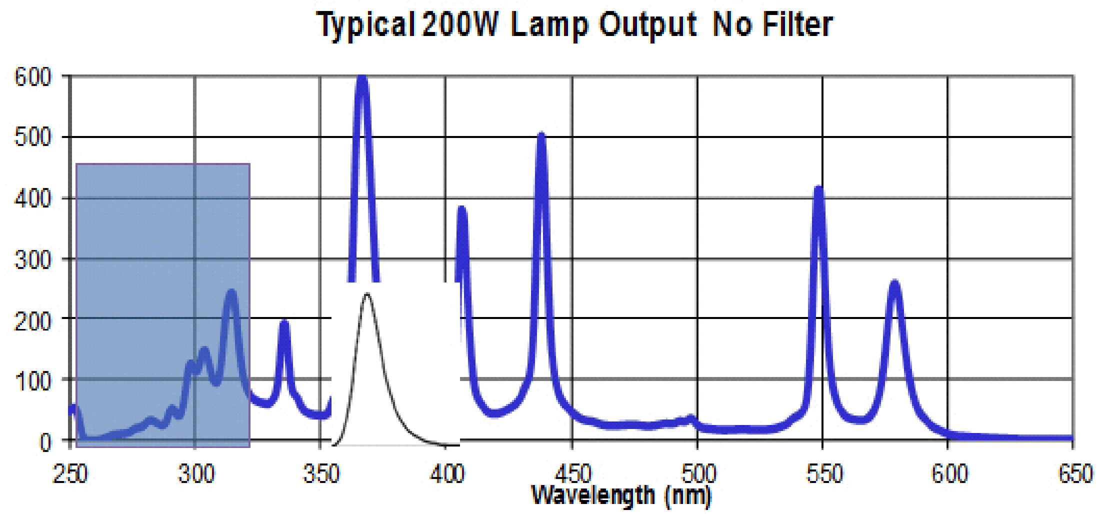
When introducing a broad spectrum of light, such as a lamp based system, a large portion of that spectrum may be absorbed by the parts, generating heat. With the lamp systems, band pass filters are used help filter out some of the unwanted wavelengths and reduce the heat. However narrow spectrum of the LEDs ensures the lowest amount of heat, for applications where the heat is critical.

For example, with applications such as OLED displays or touch panels, it's very critical to minimize the amount of heat. Some of these applications are transitioning to LED, because they benefit from the ability to tune channel into the narrow spectrum and eliminate the excess heat produced during the curing process.

Another consideration when selecting the right curing process is the surface finish. This is common concern when using LED technology. A number of different adhesives, coatings, particularly with the free radical adhesives and coatings are susceptible to what's called oxygen inhibition and results in a tacky surface.

There are ways that you can improve upon the situation. There are specific adhesive and coating formulations that are available to minimize the problem with a secondary cure mechanism, such as a moisture cure.

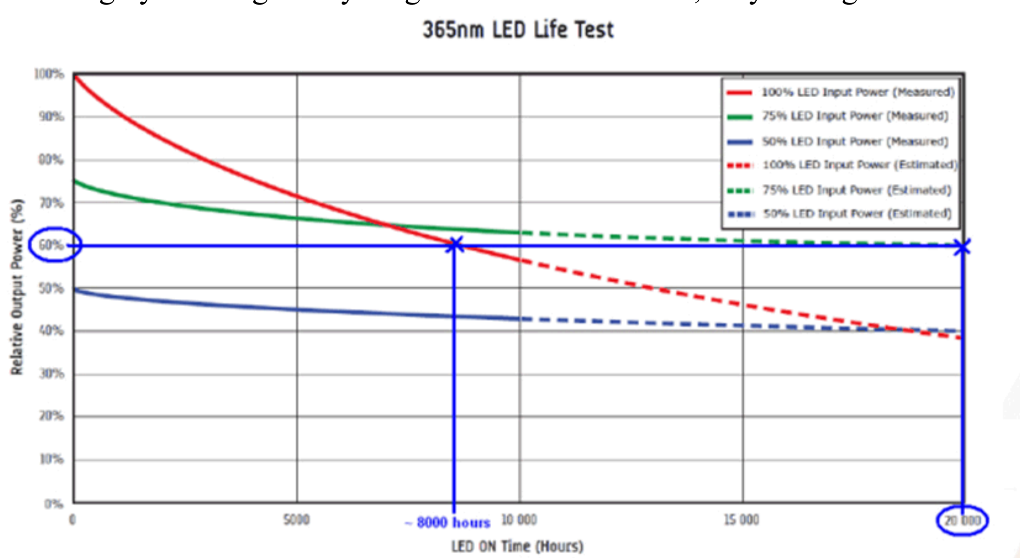
Another option that is used on adhesives and coatings is through the use of UVC, short wavelength UV. You can see in the chart below, there's a blue highlight for the area of UVB and UVC wavelengths. It is typically used to improve surface finish on the different UV curable formulations. Unfortunately, as mentioned LED's peek at 365 nanometers. The short-wavelength is not available with LED technology to improve the surface finish. If surface finishes are important in an application, and the formulation being used is incompatible with the LED to produce a nice, hard glossy finish a lamp-based systems then LED may not be correct technology for your process.



LIFE OF LED

One of the areas where the LEDs provide significant advantage, and the reason customers are transitioning to LED is because of the lifetime. Typically LEDs have a life of over 20,000 hours. There are a couple factors that contribute to the lifespan: how hard you drive the LEDs and the temperature of the LED itself. It’s important to maintain a junction temperature that's within the specification of the LED to get the lifetime.

One of the common misconceptions is that LEDs do not degrade over time. Figure 5 shows that even though you will get very long lifetimes of the LED, they do degrade over time.



Again, this is another consideration within your process, LEDs should be set at a level to minimize the degradation over time, but also to manage that and to be able to measure the output to make sure it is repeatable.

Lamp-based systems typically last three to four thousand hours. The 20,000 hours of an LED is definitely a significant advantage and can help in reducing the running costs for your process. This is another benefit of LED curing process.

Environmental Benefits of LED

In addition to being longer lasting than traditional UV lamps, LEDs have environmental advantages as a green technology because of the materials being used. The materials are very low in solvent content, so the VOC content is much lower than other solvent-based inks or coatings, for example. The other thing with LEDs is that they require significantly less electrical power to run versus the comparable lamp system.

For example, in applications such as the fiber coating when you take a comparative look at the saving in electrical power on switching from a lamp to an LED, it is enough for them to look at making that transition.

The savings on running costs are enough for them to actually pay for the capital cost of the equipment. That's definitely a consideration for people, when they're looking at whether LED or lamp is the best form of light technology for their application.

LED Curing Summary

To summarize on what we advise our customers when they're looking at whether or not to use lamp or LED-based technology in their curing. Consider that the lamp has higher power and a broader spectrum of adhesive compatibility whereas LED's have a narrow spectrum that helps minimize the heat.

For heat-sensitive applications, LED has definite advantages. Also, factors such as longer lifetime and the lower energy consumption can provide some ongoing cost savings for an application by using LED. One should take into account that with the different technologies, you could get different properties from adhesives, and coating. When developing a new process, test the new parameters to ensure that the materials in your curing process meet the requirements for your parts.

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