Overview of UV Curing in the Medical Industry

Manufacturers of a wide variety of medical products such as syringes, catheters, hearing aids, dialysis machines, medication patches, hydrogels, filters, test strips, etc. find UV curing of coatings, inks and adhesives speeds production and reduces costs, while insuring high product quality. This paper provides an introduction to UV curing and its application in the medical market.

Background

UV curing is a photochemical polymerization process. A UV-curable coating, ink, or adhesive has a photoinitiator, which when exposed to UV energy initiates the polymerization (drying) process. So instead of using a solvent or waterborne formulation in which the solvent or water must evaporate, typically via thermal oven processing, UV formulations cure very fast in a UV cure chamber. For more than forty years UV curing has been used in a wide variety of industrial processes. It is now the standard processing method for many products including graphic arts printing, wood coating, and smart phone displays to name a few. The medical industry has also been using UV curing for many years, but continues to find new and innovative applications, especially as new medical treatments and devices are developed.

UV curing is a line-of-sight process. This means that every surface with the wet ink, coating or adhesive must see adequate UV energy to cure. UV energy cannot penetrate opaque materials to cure in shadow areas. Obviously this can be a challenge for some three-dimensional parts. Although UV curing is a “cool” curing process, all UV systems generate heat, which can sometimes damage heat sensitive substrates. UV equipment suppliers use various techniques to adequately cure three-dimensional parts and to reduce unwanted heat on substrates. Before ruling out your application for UV curing, speak first with an equipment supplier. You may be pleasantly surprised what is possible with today’s technology.

Marking/Decorating

Whether it’s a dialysis machine or a disposable test tube, UV inks and coatings are used for product branding, measurement marking, print-on-demand serial numbers, etc. UV formulations can be printed via pad, screen, inkjet or other commonly used printing methods onto a wide variety of substrates including paper, glass, plastics, and metal. A good example of decorating is printing a logo or other decorative element onto a medical patch, bandage, or tape.

Bonding/Assembly

Primary applications for UV include curing of adhesives for assembly, sealing and also pressure sensitive adhesives. UV curable adhesives are used for bonding syringes, catheters and other medical devices. Because UV light of varied spectral output penetrates glass, polypropylene and many other plastics, both flat and complex 3D shaped parts are easily bonded instantaneously. By ensuring superior bonding at higher speeds, UV curing produces quality assemblies faster and less expensively. UV-curable pressure sensitive adhesives find application on a variety of medical tapes and bandages. Most UV curing assembly processes are done via an indexing or continuous conveyor line, while most pressure sensitive adhesives are applied on web type presses.

Coatings

UV coatings include biocompatible and sterilizable seals, clear hard coats to improve durability, and functional coatings that improve lubricity or healing, among others. Common applications include test strips, hydrogels, catheters, medical filters, and medical instrument lenses. UV curing of coatings offers higher production rates and standards of quality. Whether it's a converting operation on a wide web or three-dimensional parts, UV curing integrates easily into coating production processes.

UV Equipment

Typically UV curing is either replacing an existing manual process or a thermal oven drying process. Automated UV curing processes can dramatically improve most medical manufacturing processes where precision, consistency and quality are very important. The following is a brief overview of UV curing equipment available in the market and the advantages and disadvantages for most medical applications.

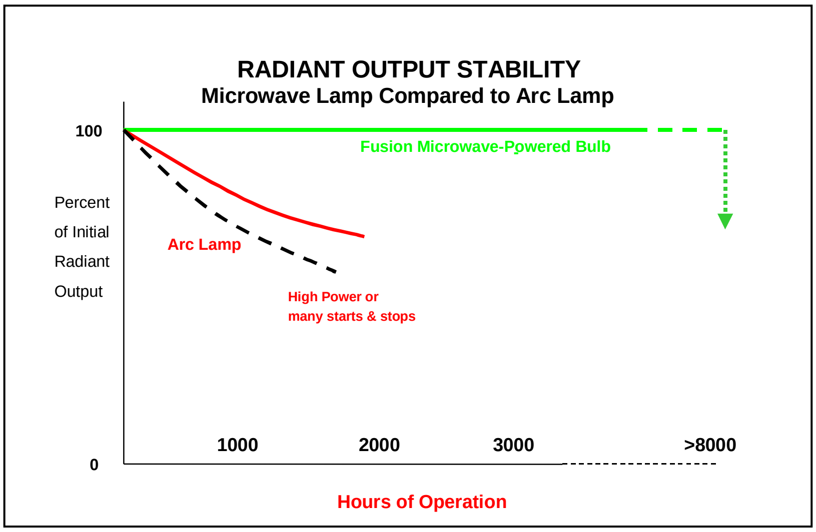
Traditional UV curing systems consist of a lamp head, or irradiator, which contains the bulb and reflector. The lamp head is controlled by a power supply or ballast, which is connected to the lamp head via electrical cables. For proper operation, the lamp head must be cooled, so there is also some type of cooling mechanism such as a blower or cooling water to maintain bulb temperatures.

More recently, UV LED curing systems are also available offering the added benefits of long life and small form factor for easy integration into existing marking, decorating, and coating machines.

The type of UV curing equipment (mercury arc, spot cure, microwave-powered, or UV LED), specific bulb type, and orientation to the part will depend on the chemistry, overall process design, and maintenance considerations. Many medical adhesives cure best with a long wavelength, iron or metal halide additive (350-430nm, often referred to as "D" or "V") type bulbs for efficient through cure. Some decorative inks cure best with a short wavelength mercury bulb (250-300nm, often referred to as “H”). Typically the chemistry formulator will specify which wavelengths to use.

- Arc lamps (also referred to as electrode type) have electrodes at either end of a quartz tube and emit broad spectrum UV energy.
- Spot cure systems are available with either mercury arc or UV LED technology typically with a light guide or wand to direct the energy to a small cure area of an inch diameter or less. Some UV LED systems do not use a light guide, rather the LED chip is located at the point of cure. Spot cure systems may be hand-held in manual processes or incorporated into high-speed automated systems for micro assembly bonding applications. The advantage is the energy can be directed precisely where it is needed, without damaging other sensitive components.
- Microwave-powered lamps (also referred to as electrodeless type) are simply a totally enclosed quartz tube. Instead of striking an arc between two electrodes to excite the gasses in the bulb, microwave energy penetrates the quartz to excite the gasses. They also emit broad spectrum UV energy.
- UV LED curing systems, commercial since the mid 2000’s, use light emitting diode technology to emit essentially monochromatic UV energy at 365, 385, 395 or 405 nm wavelengths. Individual LEDs are packed into arrays behind an emission window of a UV LED curing system. For efficient operation and long life the LEDs must be cooled, but it’s significantly less compared to traditional technologies and often self-contained inside the small form factor and light weight lamp heads.

The choice between mercury arc, spot cure, microwave-powered, or UV LED curing technology depends on several factors. Spot cure systems are ideal for precise curing of small areas. Arc lamp systems are generally less costly, but do not last as long or have stable output over their short life as illustrated in the chart below. This is especially true for the longer wavelength, additive bulbs where the electrodeless bulbs are guaranteed for typically six to ten times the life of an arc type bulb and a UV LED system operates 20,000 plus hours.



Arc lamps generally use shutters when a process requires lamps to shut off for short periods, such as some type of indexing conveyor line or when an automated line stops intermittently or unexpectedly. Microwave-powered lamps restart in seconds and UV LED lamps are instant on/off, so shutters are not required. Shutters can require additional maintenance.

Microwave-powered and UV LED systems are available in modular units that fit easily into marking, decorating, bonding and coating machines. UV LED systems offer the smallest form factor without the need for bulky cooling systems and are the most energy efficient, but they can be more expensive and are not very effective at working distances greater than about 50mm or more. UV LEDs offer long wavelength output which is ideal for many bonding applications.

UV Curing Technology Comparisons				
Characteristic	**Mercury Arc**	**Spot Cure**	**Microwave-powered**	**UV LED**
Life	500-2,000 hours	See arc or UV LED	3,000-8,000 hours	20k+
Stable Wavelength Output	No	See arc or UV LED	Yes	Yes
Stable Energy Output	No	Yes	Yes	Yes
Shutters	Yes	See arc or UV LED	No	No
Cure Area	6 inch area or more	1 inch diameter or less	6 inch area or more	Can be customized to process
Cooling	Air or water	Typically air	Typically air	Air, self-contained
Form Factor	Largest	Smallest	Small, Modular	Smaller, Modular

Formulations

UV curable formulations are available from a wide variety of suppliers. Some suppliers specialize in custom formulators designed to meet your specific requirements. Other larger formulators may offer a wide variety of standard products and may or may not be able to customize them to meet your specific needs. Formulators typically specialize in adhesives, inks, or coatings and sometimes for specific applications or substrates, although there are always exceptions.

UV chemistries are typically very high solids, low or no VOC formulations. Some UV chemistries, especially for adhesive or sealing applications, may be formulated for dual cure in which the UV exposure sets or holds parts in place, while an oven or ambient cure completes the cure.

The important thing is to work with a formulator who is familiar with your application and has available approved medical grade adhesives and coatings. Especially for new processes, it’s also important that the UV equipment supplier be involved as early as possible because a successful project requires design input from both a formulating and curing perspective from the start. A complete list of UV formulators with approved medical grade materials is available from Heraeus Noblelight.

Cost/Benefit Analysis

Any time you are considering a new process it's important to ensure it will have an acceptable return on investment. When analyzing costs and benefits for a UV curing project you'll typically find that the UV formulations cost more per volume than traditional formulations. However, you'll also find that reduced labor costs, scrap, VOC emissions, along with increased production rates and other benefits more than offset the increase in costs of UV formulations.

Below are two examples highlighting different cost benefits associated with a UV curing process. The first focuses on a reduction in work-in-process (WIP) and the second focuses on UV-curable ink and adhesive costs. These two examples are taken from a paper titled, *Some Economic Factors of UV Curing*, by Dick Stowe.

Example 1: Reduction of WIP

A manufacturer of complex electro-optical devices assembles a finished product with a value of approximately $50,000 and produces 50 assemblies per month. Each subassembly requires ten to fifteen adhesive bonds to make the complete product, for a total of about 100 bonds. When using both RTV and epoxies for these bonds, each bond or seal required two to three days to set up before being tested and then assembled. The total cycle time of the product was four months.

The use of UV curable adhesives reduced the cycle time of a subassembly to 2 hours and the total product cycle time to 4 days. The WIP product value (assuming a straight-line value rate) of 4 months was:

Using 2-part adhesive - $2.5 million
Using UV adhesive - $18,750

This example shows how a significant amount of capital can be tied up in WIP and the dramatic reduction possible with UV curing. This customer also significantly reduced scrap because they were able to rework faulty UV bonds on subassemblies, which was not possible with the 2-part adhesives.

Example 2: Costs of Inks and Adhesives

Generally UV curable inks are comparable in cost on an *applied basis* to traditional solvent-based inks. The principle differences in cost per unit volume relate to the percent solids in the as-purchased form. Consequently, comparison of cost per unit area or per product unit of dry film by weight or by coverage is a more meaningful comparison.

For a meaningful comparison of solvent-based versus UV-curable ink costs, compare the cost per unit area or cost per product unit of dry film by weight or by coverage.

For example, a conventional pad printing ink can be purchased in concentrated form for $45 to $60 per liter, to which thinner, retarder, etc. is added. Mixing labor and loss will add to its net cost. The attention to the ink and re-adjustment during printing increases the effective cost of its use. When these costs are considered, it may compare to a UV-curable ink at $120 per liter, which needs no adjustment or stabilizing, requires little attention and gives higher solids coverage.

A typical assembly adhesive may cost $32.00 per liter (not including catalyst), compared to $53.00 for a one-part UV curable. One bond may use $0.15 in UV-curable material compared to $0.10. Multiplied by number of total bonds, a cost differential is easily calculated. Interestingly, it is in adhesive applications that some of the most dramatic savings are achieved in process-related costs that completely overshadow the direct material cost difference.

Future Trends

Drug delivery systems including transdermal patches and medicated stents are being cured with UV and UV light emitting diodes (LEDS) are now available for adhesive curing applications. UV has been used for many years to purify water, but more recently found application for sterilization of medical parts. 3D printing/additive manufacturing of medical products is yet another area where UV curing is finding new application.

The medical market continues to see strong growth and should remain strong as the baby boomers age. There will be an increased need for more home medical devices as a means to reduce health care costs. As medical research leads to new therapies, UV curing will certainly be a part of the many new medical devices and products to come. Whether it's curing an ink, coating or adhesive, UV curing can increase productivity and product quality, which is so vital to the medical market.

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