Heraeus

SOME ECONOMIC FACTORS OF UV CURING

by R. W. Stowe, Heraeus Noblelight America, LLC, Gaithersburg, MD USA

ABSTRACT

The use of UV curing as a decorating, finishing or bonding technology presents a number of economic benefits over alternative methods. An economic benefits analysis for any one application may be substantially different from another. Cost savings may accrue from factors such as better utilization of space, reduction of work-in-process, increased productivity, energy savings, production yield, reducing or eliminating VOC processing, and product quality and performance. With the surprisingly wide range of applications that are presently successful with UV curing adhesives, inks, and coatings, a single economic model will not apply uniformly. A variety of applications in printing, coating, and assembly are discussed, with some of the specific economic considerations of each. To varying degrees these cost-benefit factors can be adapted and used to assess new, but similar, applications.

INTRODUCTION

UV curing is generally recognized to offer a number of benefits and advantages over the use of conventional, or solvent-based materials. Some of these benefits can be directly related to cost while others are less tangible, and relate to product performance, quality, durability, or safety, for examples. Both tangible and intangible factors are quite specific to different applications or uses of UV curable materials. The set of advantages in one application may be substantially different from another. This tends to allow only generalizations about the benefits of UV curing. It also tends to make them vague. Underlying these generalities are some very real specific advantages.

The following discussion is an effort to distinguish some of the economic benefits of using UV curing in a variety of applications and recognize some of the functional benefits. In this discussion, it becomes apparent that the hierarchy of concerns and objectives differ with various products, processes and businesses. For example, the trade-off of capital investment versus operating cost savings will vary from case to case. Environmental and health and safety factors must be considered, and in many instances have become of primary importance.

The material that follows is a collection of economic-related benefit factors which are present in a diversity of UV applications. It is not intended to be a universal justification for the use of UV, but rather to be a helpful guide. It is hoped that these examples will provide a broad view of benefits for analyses in which economic impact is a factor in the decision to utilize or convert to the use of UV. Because they are drawn from a number of industries, they will not uniformly apply to all; however, they should be instructive.

GENERAL

In establishing an overall economic analysis, there are a number of comparisons and cost-benefits which can be considered:

- Process uptime
- Energy consumption
- Throughput, or production rate
- Reduction of work-in-process
- Material costs
    - Inks, coatings, or adhesives
    - Tooling, re-usable and non-reusable
- Capital equipment cost
- Operating cost
- VOC treatment
    - Incineration or recovery
- Maintenance costs
- Yield
- Scrap
- Disposal of waste
- Solvent collection and disposal
- Space utilization
- Insurance

The intangible benefits, as mentioned, can be even *more compelling* as a driving force, but more difficult to analyze and quantify:

- Health and safety
- Quality
- Cycle time reduction
- Increased capacity
- Process not achievable by another method

It is also clear that decisions to use UV in a process, or to adapt or convert an existing process to UV typically depend on the establishment of a <u>functional</u> benefit before a cost-benefit analysis is undertaken. In other words, "prove that it works before we invest in it." In the vast majority of new applications for UV, a functional benefit was the REASON for selecting UV, but was only later followed by the cost-benefit JUSTIFICATION.

"INTANGIBLE" BENEFITS

Some of the intangible benefits will be discussed first, primarily because they are often the dominant consideration in the decision to use UV coatings, inks, or adhesives.

<u>Quality</u>

The reasons for considering UV usually include a number of performance characteristics such as improved gloss, better scratch and abrasion resistance, better chemical resistance,

resistance to "crazing," hardness, elasticity, adhesion, or bond strength. While these technical features can be *measured precise*ly, their actual economic value is *intangible.*

Superior product performance may be returned in increased market share or increased sales. When this can be evaluated in revenues or profits, it is *tangible.*

Health and Safety

In consideration of employee health and welfare, many manufacturers are including *ELIMINATING EMPLOYEE EXPOSURE TO SOLVENTS* among their highest priority objectives. This drives their search for alternative methods.

At least one user of clear hardcoats for optical discs changed his coatings and process from solvent-based to UV primarily for employee health and safety reasons. Cost and performance factors were attractive, but secondary to the decision.

The level of safety in using UV materials (indicated by Draize values, for example) is generally considered to be superior to the solvents in the materials they replace.

Reducing Cycle Time

"Cycle time" has become a key phrase in modern manufacturing practice. It relates to the elapsed time required for an item to proceed through a process step or for a task to be completed. Reduction of cycle times is one of the fundamental elements of achieving successful JIT (Just-In-Time) manufacturing.

The time required for a solvent coating to dry, or the cure time necessary for a two-part adhesive, or the overall run time of a complex print job are only a few examples of cycle times which can be shortened with the incorporation of UV curing

While these reductions in cycle time can be evaluated in specific and tangible cost savings (and are discussed later), they also have an important *intangible competitiv*e benefit in improved product delivery time or response time.

In a somewhat extreme case, a screen printer was able to win and complete a large sign job overnight -- a feat not possible with his thermal wicket dryers -- and the premium he received for fast delivery of the job nearly paid for the UV equipment that he used!

Increasing Production Capacity

Any process requiring less space, allowing higher production speeds, involving less direct labor, makes those facilities and resources available for higher production capacity. Less down time and higher throughput increase machine utilization, and have a direct effect on plant capacity. In general, UV curing offers increased productivity and better plant and equipment utilization.

Process Not Achievable by Another Method

Some of the *technical* benefits of UV curing have permitted processing which would be difficult by other means. These include extremely high speed processing, owing to the nearly instantaneous reaction and to the recent development of high "intensity" UV lamps.

Processes in which the product ("substrate") cannot tolerate heat, such as thin film plastics, or could be injured by high energy radiation, such as electronic assemblies, represent unique opportunities for UV processing. For heat-sensitive materials, a number of technical improvements can be used to further reduce the heat effects of this intrinsically low-heat process.

"TANGIBLE" BENEFITS

Process Uptime

Tag and label printers consistently report that with UV curable ink and varnish, clean-up time and set-up time is reduced by the fact that UV curables do not dry in the press. Savings are in the range of 1 hour of clean-up and 111 hours or more of set-up. Machine costs for a letterpress may be about $100 per hour; a 6-color press about $200 per hour; and a specialty press could bill out at as much as $1000 per hour.

One-shift operations will gain a greater *percent* uptime than three-shift, and total job run times will affect the gain achieved with UV. Even with 24-hour operations, a screen print decorator reports 80% efficiency (uptime) using UV inks compared to 70% with conventional inks prior to his *total* conversion to UV.

The number and types of presses, type and complexity of jobs, run lengths all affect uptime. The reduction of set-up and clean-up required with UV is the most often recognized operating cost benefit associated with UV.

PRESS SET-UP/CLEAN-UP TIME COST

UV Cured Material:

1 hr/day @ $500/hr = $ 500/day

Solvent or water based material:

2 ½ hr/day @ $500/hr = $1,500/day

Energy Consumption

A large gas dryer ("oven") consumes 1.10 MBTU/Hr (and requires large blowers) for the same production capacity achieved with a UV dryer requiring only 82 kW total:

ENERGY CONSUMPTION

THERMAL - GAS:		
1.10 MBTU/hr x $4.05/MBTU	=	$ 4.46/hr
Blowers: 56 kW x $0.07/kW-hr	=	$ 3.92/hr
340 day/yr x 24/da x $8.38	=	$68,381/yr
UV - ELECTRIC:		
82 kW x $0.07/kW-hr	=	$ 5.74/hr
340 day/yr x 24/da x $5.74	=	$46,838/yr

Reduction of Work-in-process

This factor has become one of the most powerful cost factors in reduction of manufacturing cycle time as well as having a direct impact on the cost of quality.

A manufacturer of complex electro-optical devices manufactures a product which, when assembled, carries a value of approximately $50,000, and produces 50 assemblies per month. Ten to fifteen adhesive bonds are required in each of the subassemblies which go into a complete product, and a total of approximately 100. When using both RTV and epoxies for these bonds, each bond or seal required two to three days to set up before it is tested, and sequential assembly is necessary. The total cycle time of the product was *four months.*

The use of UV curable adhesives reduced the cycle time of a subassembly t*o 2 hours,* and the total product cycle time to 4 *days*. The work-in process product value (assuming a straight-line value added rate) of 4 months was:

WORK-IN-PROCESS

USING 2-PART ADHESIVES:

$$\frac{\$50{,}000/\text{unit} \times 50/\text{mo} \times 4\text{ mo}}{2\ (\text{G.P. of } 50\%) \times 2\ (\text{to average})} = \$2{,}500{,}000$$

USING UV ADHESIVES:

$$\frac{\$50{,}000/\text{unit} \times 50/\text{mo} \times 0.03\text{ mo}}{2\ (\text{G.P. of } 50\%) \times 2\ (\text{to average})} = \$18{,}750$$

This example was simplified in that one-half of the finished product value (price) was used as an assumed cost, and that the product cost rises steadily from zero to full cost over the product cycle. The significance of the example is the huge amount of capital which can be tied up in work-in-process.

In this same case of cycle time reduction, additional direct savings also were achieved. Many of the bonds made previously using two-part adhesives could not be reworked if they were faulty, resulting in scrapped subassemblies. On the other hand, a fault in a UV bond could be reworked, reducing s*crap* and increasing *yield.*

Additionally, the time to detect a fault had been 2-3 days, during which time other process related faults might continue. Detection with UV cured bonds was immediate, further reducing quality related costs.

Cost of Ink, Coating, or Adhesive

Ink

One of the first and most common observations about UV materials is that "they are more expensive."

Generally, screen inks, metal decorating litho inks, and letterpress inks are comparable in cost on an applied basis for UV-curable and solvent based. The principle differences in cost per unit volume relate to the *percent solids* in the as purchased form. Variations in cost can also be attributed to color and pigment loading. 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 example, a conventional pad printing ink can be purchased in a 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 cost 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.

Screen ink for decorating on plastic may cost $80 to $100 per gallon for *either* UV *or* conventional and give comparable coverage.

The significance of the dollar cost of ink on a finished product basis varies tremendously with the application. Ink-jet printing and pad printing, for example, tend to be low-volume usage and differences in direct ink cost to be less critical. High volume use is more sensitive to small differences in per-unit cost.

The direct cost of ink is easily calculated for any application and production volume when *cost* and y*ield* are evaluated. If this cost is higher, then it must be offset by savings elsewhere in the process in order to provide a net gain.

Coating

Press varnishes, optical clearcoats, coating of plastic components, and even conformal coatings for electronic assemblies can be evaluated for cost in a similar way.

An example of a coating for a metal decorating application is a very useful model:

- cost of UV varnish, 100% solids, 9.4 lbs/gallon:
  $37.50/gallon
- cost of high solids water-base coating, 48% solids, 8.75 lbs/gallon:
  $8.25/gallon

COST PER UNIT PRODUCED:

$$\frac{\$/gal}{lbs/gal} \times \frac{wet\ coat\ weight\ per\ unit, lbs}{\%\ solids} = coating\ cost\ per\ unit$$

<u>UV Cured Varnish:</u>

$$\frac{\$37.5}{9.4} \times \frac{0.10\ g/unit}{1.00} \times \left(2.2\ \times 103\frac{lb}{g}\right) = \frac{\$0.88}{thousand} units$$

<u>High Solids Water-based Varnish:</u>

$$\frac{\$8.25}{8.75} \times \frac{0.16\ g/unit}{.48} \times \left(2.2\ \times 103\frac{lb}{g}\right) = \frac{\$0.69}{thousand} units$$

The cost differential can be multiplied by production rate and extended to a per-month or per year cost. One significance of the above example is that the <u>huge difference</u> in cost per gallon is reduced to a <u>small difference</u> after taking solids and coverage into account. The *apparent* difference of 355% is an *actual* difference of 26%. In this example, it would still be necessary to overcome this deficit with other savings in the process.

An electronics manufacturer had switched to water-based urethane varnish for conformal coatings in order to comply with southern California's tough emission standards. After two years, he then switched to UV, citing only two reasons: (1) lower coating cost and (2) reduced maintenance cost, primarily from reduced cleaning requirements of spray equipment. The following analysis is a relatively simple model:

Tangible Cost	
Cost of water-based coating	$13,600
Cost of UV coating	- 5,700
Annual savings, material	$ 7,900
Annual maintenance savings	+ 4,800
Annual savings	12,700
UV equipment cost	$21,700

Payback: $\frac{\$21,700}{\$12,700/\text{yr}}$ = 1.7 yrs = 21 mo.

The same manufacturer reported further savings:

Indirect cost savings in improved process flow and handling, per year: $5,000

Adhesives

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 materials difference.

Tooling

Reusable and non-reusable tooling would include such items as printing plates, pad print pads, and screen print screens. Differences here seem to be small. For longer run jobs it may be desirable to use plates or pads which resist the UV curable materials.

Reusable elements, such as screens, may gain some use-life benefit from the fact that fewer scrub-downs are required with UV materials, as UV inks do not dry or set up in them.

Capital Equipment Cost

The comparison of capital cost of a thermal system to a UV system is quite direct, as either would be quoted completely by its manufacturer. Installation cost is easily obtained. However, owing to the vast range of equipment size depending on capacity and application, a generalization here is necessary. A small thermal cure unit, such as for a small press, would cost approximately the same as a UV unit - about $10,000. The larger the system, the greater the capital cost difference; UV will represent a smaller cost, in the range of 50% of large capacity thermal system.

Capital Equipment Cost	
60" Wide Web	
UV Cure	$ 72,000
Thermal Cure	$ 212,500

Emissions (VOC) Treatment

A very real alternative with the use of solvent-based material is to remove any VOC's (volatile organic compounds) from the exhaust. Systems to achieve this can be quite efficient and effective. There is a range of approaches available, from incineration with simple afterburner, through energy-recovery heat exchangers, to high efficiency secondary heat recovery systems. Heat exchanger and heat recovery systems utilize the thermal energy from solvent vapor incineration to supplement or, in very high efficiency systems, to supply heat for the drying process. The amount of solvent loading in the exhaust stream will affect the net amount of energy required.

The capital cost and the operating costs of these various systems will, in principle, "trade-off," as illustrated in the following simplified example for a small shop of two or three presses, running one shift:

Equipment	**Capital Cost**	**Annual Operating Cost**
Simple afterburner	$ 50,000	$200,000
Burner, with primary heat exchanger	$200,000	$ 75,000
High heat recovery system	$350,000	$25,000

The capital cost and operating cost of conversion to UV must be compared to the capital cost and operating cost of incineration and heat recovery.

Maintenance Cost

Every type of system and process has its unique maintenance profile. All endeavor to reduce or eliminate equipment-caused down time. Scheduled and preventive maintenance cycles are the most accepted techniques of reducing failure related loss. In large systems, the *controlled cost* of maintenance is a preferred alternative to surprise shutdowns. In either case, the time-to-replace and the down time for maintenance are important.

Conveying systems passing through thermal dryers are themselves subject to damage and wear. Lubricants, for example, deteriorate rapidly resulting in excessive bearing and guide wear.

A quick comparison of the conveyor chain in a thermal metal deco system versus a UV system follows. It should be noted that the length of the conveyor also has a major effect on

Thermal
Conveyor Chain Replacement Cost:
300 ft, $15/ft, 6 changes/yr = $27,000/yr
UV
Conveyor Chain Replacement Cost:
100 ft, $15/ft, 4 changes/yr = $6,000/yr

replacement cost:

Other components of maintenance cost comparison are (1) direct labor for replacements, and (2) cycle time, including cool-down and start-up time to complete maintenance.

There are partially offsetting costs in this same system:

Thermal	
Replacement of controls, operators, gas train, etc.	$5,400/yr
UV	
Replacement of bulbs, reflectors, etc.	$19,200/yr

These two maintenance comparisons can be combined:

NET SAVINGS (UV): **$ 7,200/yr**

Yield

Yield is the number of units produced without having to be reworked or scrapped. Yield can be evaluated at any point in a process, or can be a measure of the overall process quality.

A manufacturer of instruments for use in extreme and hazardous environments, which require waterproof gas pressure seals, experienced a twofold increase in seal acceptance after changing over to UV curable material for the seal. The savings accounted for in reduced rework alone represented 15 to 20% of that process step.

Scrap

Although related to yield, this is slightly different, as it must include "necessary" loss, such as material run off during set-ups or change-overs. It is material which cannot be turned into useful product.

Printers report that often "a thousand" feet are run off before completing setup and good product runs on the press. The average cost of a label stock, for example, may be $0.35 per MSI (thousand square inches). At this rate, the stock cost of set-up of a 7-inch wide label web can be:

SET-UP SCRAP

(1,000 ft) x (7 in) x (12 in/ft) x ($0.35) = $84.00

While this will vary from job-to-job and from shop to-shop, it will be a cost. Generally, owing to shorter set-up and reduced need to "work out" ink color and viscosity, UV can reduce this scrap by about 50%. In addition to scrap, unrecovered machine operating time contributes to cost during set-up.

Another cause of loss or scrap in printing is color shift. With no need to adjust inks during a run, this factor seems to be substantially reduced or eliminated with UV ink.

Printers report scrap and loss can be as high as 40% with solvent-based inks and varnishes. They claim reduction to as low as 5% with UV curable equivalents. These estimates may be extreme, but even if more conservatively estimated, are an important cost element to compare.

Another scrap comparison was provided by a pad printer who had previous experience with 2 component ink. Because the ink had an 8-10 hour "life," he would have to dispose of 30-40% of the ink. Using UV curable ink reduced this to "nearly zero."

Solvent Collection and Disposal

Disposal of waste from any process may be a cost factor, and recently has received more attention. Liquid "Hazardous waste" is usually mixed with absorbers, sealed in 55-gallon drums, and hauled by a licensed contractor for subsequent incineration or disposal at approved locations. The typical direct cost for removal is $400 to $600 per drum.

Solvents and waste inks must be treated as "hazardous waste." Because of the requirement to pack with absorbers, each drum of waste is expanded to three, increasing the cost to $1200 to $1800 per drum of waste. Users of solvent-based materials will often invest in distillation equipment - a modest size recovery still will cost about $10,000. This reduces disposal and returns (usually) usable solvent to the process.

Solventless material can be disposed of as "hazardous," or can simply be *reacted,* rendering it "non-hazardous" and disposed of as ordinary solid waste in most jurisdictions.

Space Utilization

A drying oven for a conventional web coating line may extend for 50 to 100 feet, a space consumption in the neighborhood of 500 to 1000 square feet. At a floor space cost alone of only $\$0.50/ft^2/month$, that costs $3000-6000 per year. The equivalent UV "dryer" would require 50 to 100 square feet. In instances where floor space carries a premium cost, total indirect operating costs could be significantly sensitive to this element.

More important is the utilization of the same space: a thermal dryer for a one-pass bottle screen printer may be 40 feet long, while an entire 3-color printer with UV cure at each color station is only 13 feet in length.

Adhesive and potting applications using two part adhesives or RTV types of compounds must allow cure time, usually measured in days. This is most costly in terms of cycle time and tied-up work-in-process inventory, but when the number of parts is large, the consumption of floor space could be significant.

Heraeus

Insurance

No specific information or examples are available regarding the comparison of coverage for UV or solvent-based systems, but is believed that considerations of hazard should favor UV processing.

CONCLUSION

The number and variety of applications presently using UV curing technology is tremendous. In each and every application, the reasons and justifications for using UV or for converting to the use of UV vary widely from the next.

Often, a performance factor such as a requirement created by the end product, or a safety concern, or a regulatory pressure, related to atmospheric emissions, for example, will force consideration of UV as a process alternative. In such instances, many of the economic benefits are discovered only later.

This collection in this paper has attempted to consider economic information organized by feature and advantage, rather than by individual user or application type. Applications referred to are meant to function as examples. In this way it may be a helpful "checklist" from which only those benefits which are considered applicable can be extracted.

In relating the above examples to specific analyses, value may be vastly different -- that does not mean it is "wrong" -- it is the *principle* of that economic feature which is important.

A reluctance to consider UV for a specific process can arise from incomplete analysis. It is not unusual for some specific obstacle to be overcome, requiring investment. Obstacles may include the need for a material formulation with exact end properties, which is not available off-the-shelf, or in the development of rollers, plates, etc., which will be compatible.

Any of these "investments," including the time invested in process development can be evaluated in terms of their "payback." It is with that idea that the sampling of economic benefits above are presented. Each has a very different contribution to the analysis or justification for a prospective application, and even within a type, will vary according to the size of the production rate and capacity.

***

This paper was originally presented at RadTech '94 North America Orlando, FL USA, May, 1994 and was published in the Conference Proceedings RadTech International North America, pages 353-359. Minor updates reflect current energy and other pricing where is was obtainable. Since the goal of this paper is to serve as a checklist of typical tangible and intangible areas of economic savings from UV curing, readers should use their own actual costs, **not** those presented here in the examples. Heraeus Noblelight UV curing experts can assist you with the specification of a UV curing system and the associated costs to help you determine your return on investment (ROI).

www.heraeus-noblelight.com

Germany
Heraeus Noblelight GmbH
Heraeusstraße 12-14
63450 Hanau
Phone +49 6181 35 4499
Fax +49 6181 35 164499
hng-uv@heraeus.com

USA
Heraeus Noblelight America LLC
910 Clopper Road
Gaithersburg, MD 20878
Phone +1 301 527 2660
Fax +1 301 527 2661
info.hna.uvp@heraeus.com

HNG UVP143E/04.19