Heat Management Methodology for Successful UV Printing on Film Substrates

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Abstract:

Now in 2005, UV systems possess heat management controls that fine tune the exothermic and delivered heat in the UV curing process. This paper will explore the various methodologies and controls that allow film processors to cure UV adhesives, UV inks, and UV coatings when applied to thin film substrates.

UV Fundamentals:

The UV curing process generates two types of heat, exothermic heat and delivered heat. Exothermic heat is created by a chemical reaction such as the polymerization of the UV chemistry (Figure 1). Delivered heat is generated from the UV lamp. This delivered heat must be monitored and controlled to avoid damaging any of the components that comprise the UV processing unit, as well as to maintain substrate integrity.

UV lamps are made of quartz glass and can come with electrodes internal to the lamp's ends or without electrodes. Electrodeless UV lamps are generally limited in length up to ten inches and have narrow lamp diameters. The diameter of an electrode UV lamp can vary tremendously. Typically, the higher the lamp wattage - the larger the lamp diameter needed to dissipate heat created from the bulb. Also, the longer the length of the UV lamp - the larger the diameter needed to maintain structural integrity. A narrower UV lamp provides less surface area from which to dissipate the heat. Consequently, narrower lamps typically emit a higher level of IR energy.

All UV lamps require heat to generate UV energy. The heat produced by the lamp is necessary to emit peak UV intensities along the length of the lamp. Heat must be kept constant along the length of a UV lamp. Doing so provides consistent UV output across the entire lamp length and greatly reduces the likelihood of either hot spots or cold spots developing at the surface of the lamp. Either hot or cold spots can rapidly destroy the structural strength of the UV lamp and generate a defective product.

The most common UV lamp used in the printing and converting industries today is the standard mercury lamp. The standard mercury lamp generates peak intensity at 365nm (Figure 2a). Total UV output ranges from 200nm – 440nm (Figure 3). Some UV chemistries require a metal halide lamp for curing. Metal halide or doped bulbs shift spectral emissions. Two common doped bulbs are Iron, concentrated from 330nm – 390nm, and Gallium, concentrated from 400nm – 440nm (Figures 2b & 2c). Metal Halide lamps require higher striking voltages and also have higher operating temperatures than standard mercury lamps.

While energy distribution of UV lamps vary among UV manufacturers. Typical UV lamp energy distribution is approximately: 1/3 UV +1/3 light + 1/3 heat.

For many UV curing applications heat generated from the UV lamps is of minor concern. However, for film converters, monitoring and minimizing delivered heat to the substrate is of fundamental significance. The converter must limit the peak temperatures reaching their substrates. There are a wide variety of methods utilized to control and limit heat to the substrate.

Heat Management Methods for UV Systems:

All UV curing systems need to employ a cooling process to effectively remove heat generated from the UV lamp. The two most common means of removing this heat is either air-cooling or water-cooling.

Air-cooled UV processors utilize a high volume of air directed either perpendicularly or parallel to the UV lamp to remove a large portion of the heat generated from the UV lamp. The remainder of the heat transfers to the UV processing unit and to the substrate.

Water-cooled UV processors circulate chilled water through extruded aluminum reflectors and housing components to remove the majority of the heat generated from the UV lamp. Water-cooled UV processors still need some air-cooling to scrub heat from the surface of the UV lamp. The remaining heat typically gets removed via the substrate.

As stated above, both air-cooled and water-cooled UV systems, in addition to UV energy, transfer IR energy and visible energy to the substrate. To further reduce and control IR and visible energy transferred to the substrate, UV system manufacturers utilize a variety of heat management methods.

Please note that the effectiveness and costs associated with any of the materials discussed below may vary greatly between UV system manufacturers.

UV processors will have one of the following reflector / shutter designs; parabolic, elliptical or a combination of the two. (Figure 4) Parabolic systems are designed to flood the substrate and maximize the UV exposure time, in conjunction, the exposure period of IR to the substrate. An elliptical design maximizes the UV peak irradiance and typically minimizes the time period of exposure thus reducing the time permitted for IR absorption by the substrate.

UV systems can be designed to automatically vary power output as a function of process speed. By monitoring the UV energy needed for process speed and automatically matching the UV output to this need, the converter can avoid issues associated with over cure and reduce the heat transfer to the substrate.

Dichroic coatings can also be used to reduce delivered heat. Cold mirrors, which are dichroic-coated liners / shutters, reflect UV towards the substrate and transmit IR away from the substrate. Cold mirrors typically provide maximum UV reflectance between 220nm to 380nm and reduce heat via the absorption or transmission of visible and IR energy. These coatings can be applied to aluminum, stainless steel, fused silica or other glass substrates and exhibit formability on metal reflectors. Cold mirrors can also be customized with angles of incidence such as 0, 21, 45 degrees, or a range of other degrees (Figure5). These coatings are fairly hard and must be cleaned regularly to remain effective.

Although effective, dichroic coated materials, whether glass or metal, must be cleaned consistently to demonstrate the very properties for which they were purchased. Dichroic-coated mirrors and plates are expensive and are costly to maintain.

Quartz windows or fused silica barrier plates can be positioned between the UV lamp and the substrate. These barrier plates transmit UV. These barrier plates can also have dichroic coatings applied to them. Unlike cold mirrors, these coatings reflect IR energy and transmit UV energy. These barrier plates are called hot mirrors.

Hot mirrors typically provide maximum UV transmittance from 220nm to 400nm and partially reduce heat to the substrate via the reflectance of both visible and IR energy. If greater IR rejection is necessary, it is possible to air space more than one of these hot mirror elements in a parallel array (Figure 6).

Only one heat management method utilized actually works in a reverse process of removing both delivered heat and exothermic as they are transferred to the substrate. Rather than reducing the IR energy and visible energy delivered to the substrate, a UV manufacturer can mount the UV processing unit directly over a water-chilled roller.

With the substrate running over the chill roll, the heat created by the chemical reaction (exothermic) and delivered heat from the UV processor is removed from the substrate as they are being transferred to the substrate. Both the temperature of the water and the volume of water delivered to the chill roll can be easily changed thus effectively and efficiently producing consistent and controlled substrate temperatures throughout the process application.

In addition, the chill roll method eliminates the high costs associated with maintaining many of the aforementioned heat management methods.

Objective:

Illustrate the effects of the above stated heat management methods on the UV dosage (J/cm^2), peak UV intensity (mW/cm^2), average and maximum temperature rise (ATR & MTR). Review the capital equipment, operational and maintenance costs related to each heat management method.

Tests:

Tests were performed on the following: Prime UV Optimum Series Air-Cooled UV processor, Prime UV Diamond Series Water-cooled UV processor, Prime UV Transport Conveyor and an 18 inch-long, 22mm diameter, 600 watt mercury vapor UV lamp. UV dosage (J/cm^2), peak UV intensity (mW/cm^2) and temperature readings were measured and collected with the UV PowerMAP from EIT. UV spectral graphs were created using the Sola-Scope and Sola-Check system from Solatell Ltd.

The following heat management methods were tested:

- Reflector / shutter design – elliptical & parabolic
- Power output varies as a function of process speed – 50 fpm & 100 fpm
- Dichroic coated reflectors / liners – i.e. – cold mirrors
- Quartz barrier plates
- Combination of quartz plates with dichroic reflectors
- Dichroic-coated barrier plates – i.e. – hot mirrors
- Combination dichroic-coated barrier plates (hot mirrors) with dichroic reflectors.
- Chill roll (Tests conducted on-site at customer utilizing high efficiency chill roll system belt driven by press drive shaft)

Capital equipment costs are estimates as to industry average for a 42-inch UV processing system operating at a maximum 600 watts per inch offering 8 power levels.

Maintenance costs assume operating time of 4000 hours per year and do not include costs associated with time needed to replace or clean components, as this would vary widely among UV manufacturers. Consumable costs do not include cost of UV replacement lamps or the costs associated with having plant personnel replace or clean these consumable components.

Results:

1. Air-cooled Versus Water-cooled UV Processing Units

Air-cooled UV Processing Unit (Table 1a):

a. Capital costs - $30,000.
b. Consumable costs - $100. (Note: Polished aluminum Reflector Liners)

Table 1a. Air-cooled UV Processor (Elliptical)
18" 22mm 600 Watt Mercury Vapor UV Bulb

Speed Ft/min	UV Dosage J/cm2	Peak Intensity. mW/cm2	Average Temp. Rise Degrees C	Max. Temp Rise Degrees C
50	1.4	2174	9	63

Water-cooled UV Processing Unit (Table 1b):

a. Capital Costs - $50,000.
b. Consumable Costs - $100.

Table 1b. Water-cooled UV Processor (Elliptical) 18" 22mm 600 Watt Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
Ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.18	2166	4	51

A comparison of Tables 1a and 1b shows the following for the water-cooled vs. air-cooled systems:

- Peak Irradiance (UV A) stays constant
- UV Dosage (J/cm^2) falls 17% - reduced exposure time
- MTR decreases as more IR energy removed via water-chilled housing
- ATR drops – reduced exposure time – more IR energy removed via water-chilled housing

2. Reflector / Shutter Design – Parabolic vs. Elliptical:

a. Capital costs - same
b. Consumable costs – same

Table 2a. Parabolic Reflectors 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
Ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.5	1383	9	64

Table 2b. Elliptical Reflectors 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.4	2174	9	63

As shown in Tables 2a and 2b above, with Elliptical vs. Parabolic reflectors:

- Peak irradiance (UV A) increases 57%
- UV Dosage (J/cm^2) stays constant
- MTR stays constant
- ATR stays constant – exposure time remains the same

3. Power Output Varies as a Function of Process Speed:

a. Capital costs – Standard with many UV systems or slight up charge.
b. Consumable costs – slightly lower.

Table 3a. UV Power Constant – 50 FPM
Air-cooled / Elliptical
18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb

Speed ft/min	**UV Dosage** J/cm2	**Peak Intensity.** mW/cm2	**Average Temp. Rise** Degrees C	**Max. Temp Rise** Degrees C
50	1.4	2174	9	63

Table 3b. UV Power Constant – 100 FPM
Air-cooled / Elliptical
18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb

Speed ft/min	**UV Dosage** J/cm2	**Peak Intensity.** mW/cm2	**Average Temp. Rise** Degrees C	**Max. Temp Rise** Degrees C
100	.71	2165	9	34

A comparison of Tables 3a and 3b above, running at 100 fpm vs. 50 fpm shows the following:

- Peak Irradiance (UV A) stays constant
- UV dosage decreases approximately 50%
- MTR drops 46% or 29 degrees
- ATR stays constant

4. Dichroic Coated Liners / Shutters – Cold Mirrors:

a. Capital costs – $2600.
b. Consumable costs –$1300.

Table 4a. Standard Reflectors
Air-cooled / Elliptical
18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb

Speed ft/min	**UV Dosage** J/cm2	**Peak Intensity.** mW/cm2	**Average Temp. Rise** Degrees C	**Max. Temp Rise** Degrees C
50	1.4	2174	9	63

Table 4b. Dichroic Reflectors Air-cooled / Elliptical 18 inch, 22 mm 600 Watt/inch Mercury Vapor UV Bulb				
Speed ft/min	**UV Dosage** J/cm2	**Peak Intensity.** mW/cm2	**Average Temp. Rise** Degrees C	**Max. Temp Rise** Degrees C
50	1.39	2262	9	51

A comparison of Tables 4a and 4b above, running dichroic vs. standard shows the following:

- Peak irradiance (UV A) increases 4%
- UV dosage increase stays constant
- MTR drops 19% or 12 degrees.
- ATR stays relatively constant

5. Quartz Barrier Plates:
   a. Capital costs – $2000.
   b. Consumable costs –$1100.

Table 5a. Standard – No Barrier Air-cooled / Elliptical 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed ft/min	**UV Dosage** J/cm2	**Peak Intensity.** mW/cm2	**Average Temp. Rise** Degrees C	**Max. Temp Rise** Degrees C
50	1.4	2174	9	63

Table 5b. Quartz Barrier Plate Air-cooled / Elliptical 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed ft/min	**UV Dosage** J/cm2	**Peak Intensity.** mW/cm2	**Average Temp. Rise** Degrees C	**Max. Temp Rise** Degrees C
50	1.35	2060	8	56

A comparison of Tables 5a and 5b above running quartz vs. standard shows the following:

- Peak irradiance (UV A) decreases 4%
- UV dosage decreases 5%
- MTR drops 11% or 7 degrees
- ATR stays relatively constant

6. Combination of Quartz Barrier Plates with Dichroic Reflectors:

a. Capital costs – $4600
b. Consumable costs –$2400

Table 6a. Standard – No Barrier Air-cooled / Elliptical 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.4	2174	9	63

Table 6b. Quartz Barrier Plates and Dichroic Reflectors Air-cooled / Elliptical 18 inch, 22mm 600 Watt/inch Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.24	2149	9	43

A comparison of Tables 6a and 6b above, running quartz with dichroic vs. standard reflectors shows the following:

- Peak irradiance (UV A) decreases slightly
- UV dosage decreases 11%
- MTR drops 32% or 20 degrees
- ATR stays relatively constant

7. Dichroic Coated Quartz Barrier Plates – Hot Mirror

a. Capital costs – $4000.
b. Consumable costs –$2100.

Table 7a. Standard – No Barrier Air-cooled / Elliptical 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.4	2174	9	63

Table 7b. Hot Mirror Air-cooled / Elliptical 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.38	2165	7	51

A comparison of Tables 7a and 7b above, running hot mirror vs. standard shows the following:

- Peak irradiance (UV A) stays constant
- UV dosage stays constant
- MTR drops 19% or 12 degrees
- ATR falls slightly

8. Combination of Dichroic Coated Quartz Barrier Plates – Hot Mirrors and Dichroic coated reflectors

c. Capital Costs – $6600
d. Consumable Costs –$3700

Table 8a. Standard – No Barrier Air-cooled / Elliptical 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.4	2174	9	63

Table 8b. Hot Mirror with Dichroic Reflectors Air-cooled / Elliptical 18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb				
Speed	**UV Dosage**	**Peak Intensity.**	**Average Temp. Rise**	**Max. Temp Rise**
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.3	2249	7	31

A comparison of Tables 8a and 8b above running hot mirror vs. standard shows the following:

- Peak irradiance (UV A) increases slightly
- UV dosage drops 7%
- MTR drops 50% or 32 degrees
- ATR falls slightly

9. UV Mounted Over High Efficiency Chill Roll – Belt driven in-line on press:

a. Capital Costs – $11000.
b. Consumable Costs –$100.

Table 9a. Standard – No Barrier
Air-cooled / Elliptical
18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb

Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.4	2174	9	63

Table 9b. UV Mounted Over Chill Roll
Air-cooled / Elliptical
18 inch, 22mm, 600 Watt/inch Mercury Vapor UV Bulb

Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
ft/min	J/cm2	mW/cm2	Degrees C	Degrees C
50	1.35	2145	2	5

A comparison of Tables 9a and 9b shown running a chill roll versus the standard shows the following:

- Peak irradiance (UV A) stays relatively constant
- UV dosage stays relatively constant
- MTR drops 92% or 58 degrees
- ATR drops 77% or 7 degrees

<u>Conclusion:</u>

A converter must first determine the temperature limits of the products being produced or may be produced in the future. Only with this information in hand is it possible to effectively evaluate which heat management method(s) discussed would be best for his or her operation.

As previously shown, the costs and effectiveness of the various heat management methods can vary tremendously. Certain methods are better suited for specific applications and UV chemistries.

Linking UV output to process speed is one of the least costly yet most effective ways to limit heat transfer to the substrate. Although the initial investment may be the highest, installing the UV processor over a high efficiency chill roll is the most effective way, if desired, to maintain a specific substrate temperature. An additional benefit of this heat control method is that it necessitates the least amount of maintenance time and dollars. However, this method isn't practical for some converting processes nor for certain UV retrofit applications and linking UV output to process speed may not be enough. In these cases employing one method, or any combination of the other, needs to be considered.

When researching the other methods, a converter should collect the costs associated with replacing all consumable components (i.e. – reflector liners, shutters, hot mirrors, cold mirrors, UV lamps, etc.) and maintaining these materials (i.e. – cleaning and checking the effectiveness.) A converter must be aware that these dichroic-coated materials may lose much of their effectiveness if not kept clean. Consequently, one must consider the cleanliness of the process as well as the time restraints inherent in one's process before investing in any one of these heat management methods. A harsh operating environment can significantly reduce the life expectancy of many of these materials.

The heat management methods do reduce temperatures, but in some cases, also affect the UV dosage and UV intensities being delivered to the substrate. Whether these effects are detrimental or beneficial to the process needs to be evaluated as well.

Figure 1. UV Curing Process Comparison

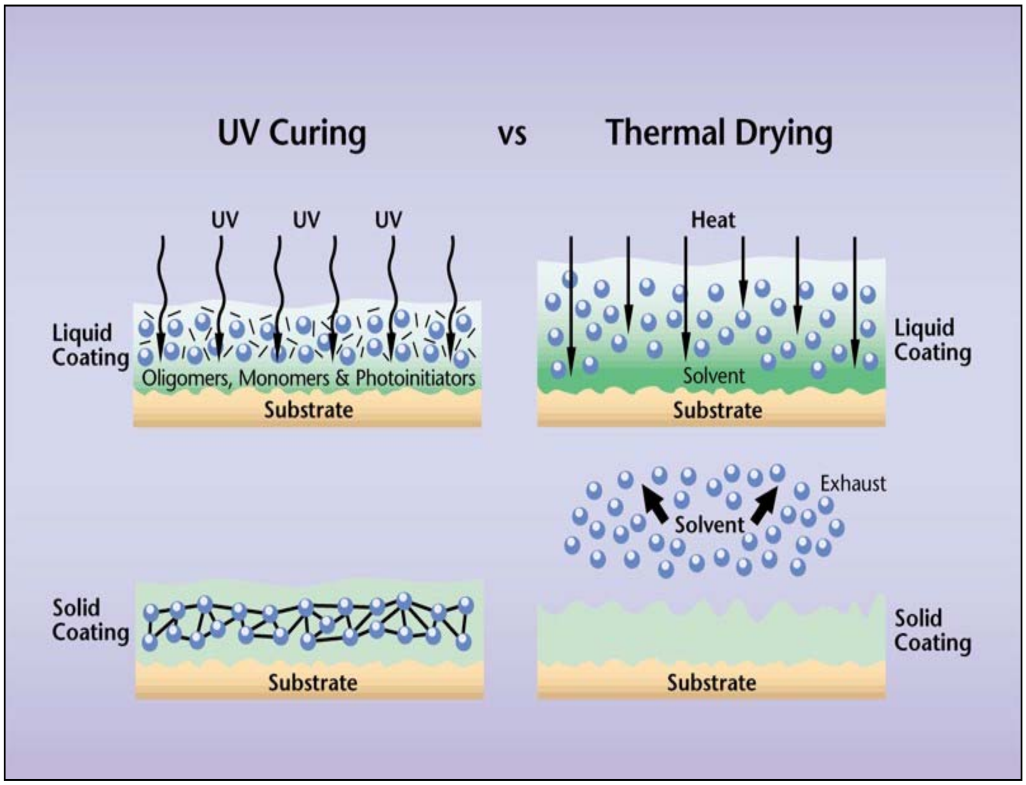


Figure 2a. Standard Mercury Lamp

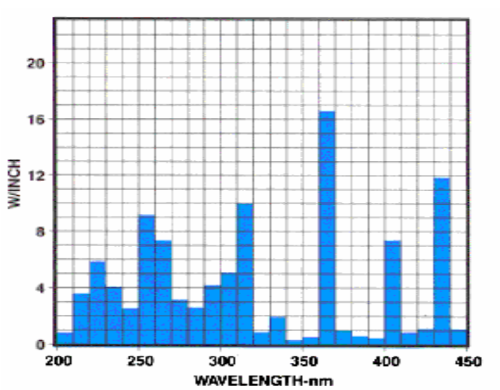


Figure 2b. Metal Halide, Doped Bulb - Iron

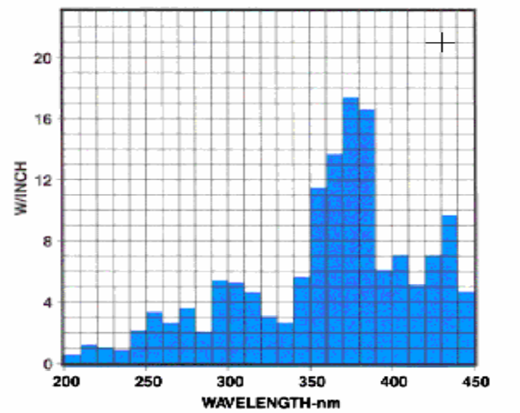


Figure 2c. Metal Halide, Doped Bulb - Gallium

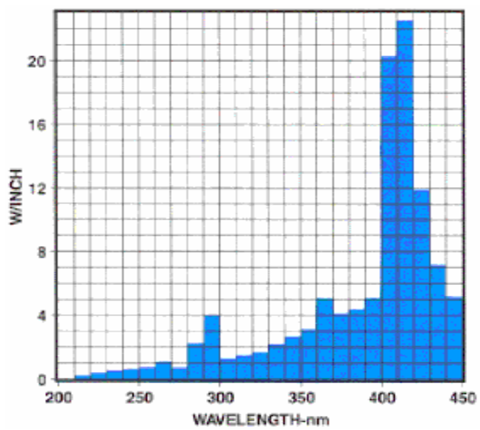


Figure 3. UV Output Range Spectrum

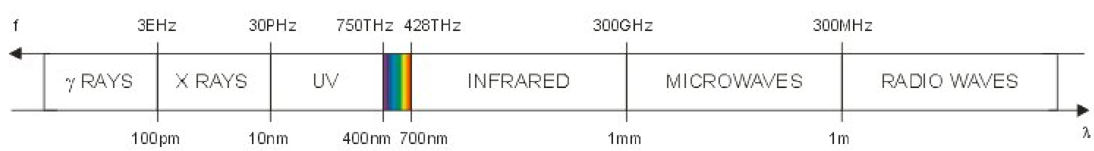


Figure 4. Parabolic vs. Elliptical Reflectors

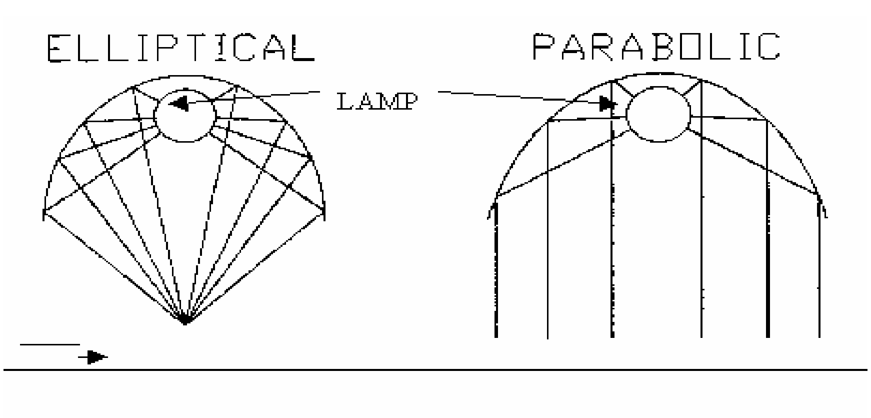


Figure 5. Hot Mirror

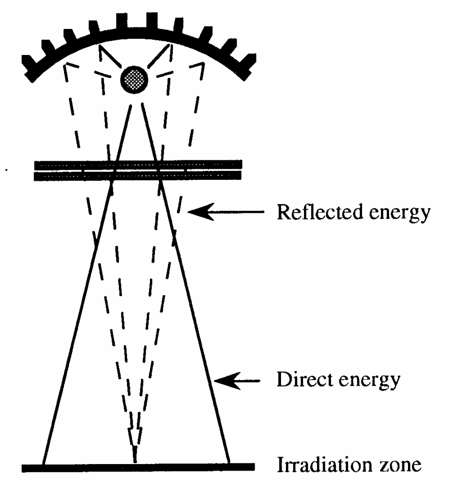
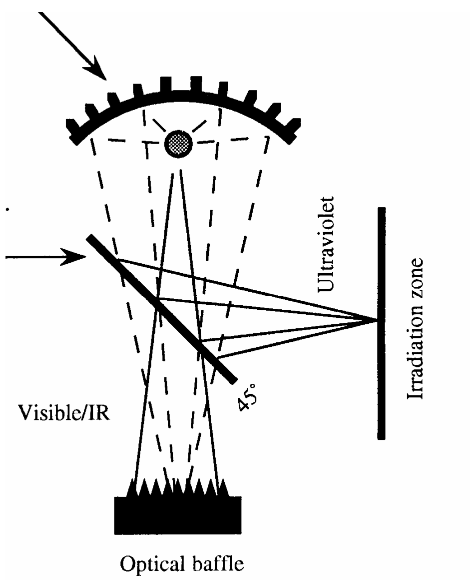


Figure 6. Cold Mirror



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Heat Management Methodology

Successful UV Printing on Film Substrates

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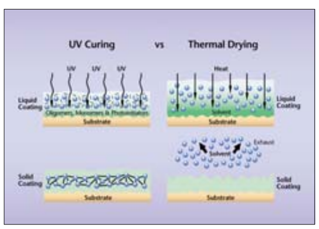
Heat Generation

UV Curing Systems Generate Exothermic & Delivered Heat

- **Exothermic heat – created by a chemical reaction**
- **Delivered heat – generated from the UV lamp**

Exothermic heat created by the polymerization of the UV chemistry



Heat Generation

All UV Lamps Require Heat to Generate UV Energy

- **Required to emit peak UV intensities along lamp length**
- **Need consistent heat along lamp length**
- **Prevent hot or cold spots on lamp surface**

Hot or cold spots can destroy the structural integrity of the UV lamp as well as generate a defective product.

UV Lamp

UV Curing Lamps

- **Typically made of quartz glass**
- **With & without electrodes**
- **Electrodeless limited to 10”**
- **Lamp diameters vary**
- **Narrower bulb – less surface to dissipate heat**
- **Wall thickness differs**
- **Length & wattage limitations**

Electrodeless UV Lamps

Electrode UV Lamps

UV Energy

Energy Distribution of UV lamps

- **Varies among UV manufacturers**
- **Typical UV lamp energy distribution is approximately:**

UV Lamp Energy = 1/3 UV + 1/3 Light + 1/3 Heat

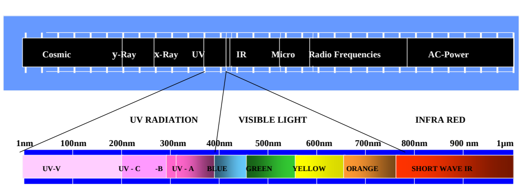
UV Lamp Types

UV Spectrum - Standard Mercury – Metal Halide

UV Spectrum

UV output ranges from 200 – 440nm

Electromagnetic Spectrum



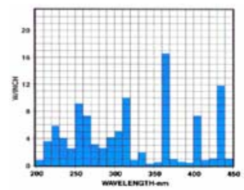
UV Lamp Types

UV Spectrum - **Standard Mercury** – Metal Halide

Standard Mercury

- **Most common UV lamp for Printing & Converting Industries**
- **Peak UV intensities at 365nm**

UV Spectral Analysis
of a Mercury Vapor
UV Lamp.



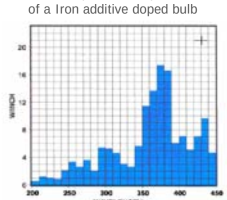
UV Lamp Types

UV Spectrum - Standard Mercury – **Metal Halide**

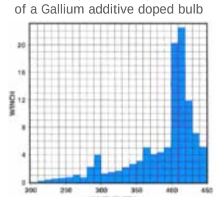
Metal Halide (Doped bulb)

- **Shift spectral emissions to match specific UV chemistry**
- **Higher operating temperatures – radiate more IR**
- **Two common types are; Iron (330 – 390nm) and Gallium (400 – 440nm)**

UV Spectral Analysis
of a Iron additive doped bulb



UV Spectral Analysis
of a Gallium additive doped bulb



Heat Management

Should Heat Management be a Concern for your Application?

- **Many UV curing applications: heat - minor concern**
- **For film converters: heat - major concern**

Film Converters

- **Must monitor & minimize delivered heat**
- **Must limit peak temperatures**
- **Many H.M.M. (heat management method) to consider**
- **Must select right H.M.M for application and budget**

UV Processors

UV Processor Cooling Methods

All UV curing systems need

- **Cooling process to remove heat generated from UV lamp**

Two common cooling methods to manage and remove heat

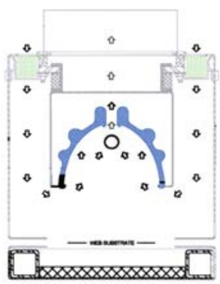
- **Air-cooled**
- **Water-cooled**

UV Processors

Air-Cooled – Water-Cooled

Air-cooled UV processors

- **Utilize high air volume to remove large portion of heat generated from lamp**
- **Remaining heat transfers to:**
  - **UV processing unit**
  - **Substrate**



Air-cooled UV Processor Design

UV Processors

Air-Cooled – **Water-Cooled**

Water-cooled UV processors

- **Circulate chilled water through extruded aluminum reflector and housing components**
- **Still require some air-cooling to scrub heat from lamp surface**
- **Remaining heat removed via substrate**
- **Costs:**
  - **Substantially more expensive then air-cooled**
    - **Purchase**
    - **Operate**
    - **Maintain**
    - **More complex**

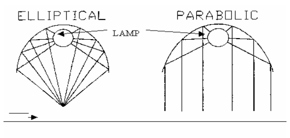
Water-cooled UV Processor Design

UV Processors

Reflector / Shutter Design

UV Processors utilize one of the following:

- **Elliptical – maximizes UV peak irradiance / minimizes exposure time**
- **Parabolic – floods substrate / maximizing UV exposure time**
- **Combination of Parabolic & Elliptical**



Heat Management Methods

Speed/Power – Cold Mirror – Barrier Plates – Hot Mirror – Chill Roll

Power output as function of process speed

- **Monitor UV energy needed for process**
- **Automatically match UV output to process speed**
  - **Avoid over cure issues**
  - **Reduces heat transfer to substrate**

Heat Management Methods

Speed/Power – **Cold Mirror** – Barrier Plates – Hot Mirror – Chill Roll

Dichroic coated liners / shutters

- **Reflect UV towards substrate**
- **Transmit IR away from substrate**
- **Maximize UV reflectance between 220 – 380nm**
- **Reduce heat via absorption or transmission of visible & IR energy**

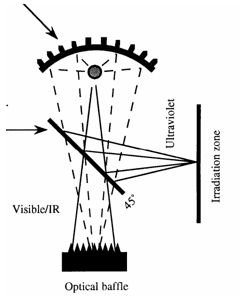
Cold Mirrors – dichroic coated reflective material

Heat Management Methods

Speed/Power – **Cold Mirror** – Barrier Plates – Hot Mirror – Chill Roll

Dichroic coated quartz plates

- **Reflect UV towards substrate**
- **Transmit IR away from substrate**
- **Can customize angles of incidence**
  - **0, 21, 45 degrees**



Heat Management Methods

Speed/Power – Cold Mirror – **Barrier Plates** – Hot Mirror – Chill Roll

Barrier plates

- **Quartz or fused silica**
- **Positioned between lamp and substrate**
- **Transmit UV energy**
- **If dichroic coated used as hot mirrors**

Quartz Barrier Plates – are positioned between the lamp and the substrate

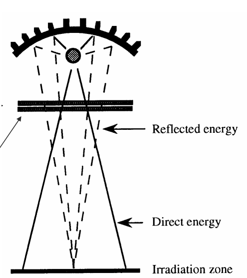
Heat Management Methods

Speed/Power – Cold Mirror – Barrier Plates – **Hot Mirror** – Chill Roll

Dichroic coated quartz barrier

- **Opposite of cold mirrors**
  - **Reflect IR and transmit UV**
- **Provide maximum UV transmittance from 220 – 400nm**
- **Partially reduce heat to substrate via reflectance of visible & IR energy**

Greater IR rejection can be achieved by placing these plates in a parallel array.



Heat Management Methods

Speed/Power – Cold Mirror – Barrier Plates – Hot Mirror – **Chill Roll**

Water-cooled chill roll

- **UV processor mounts over chill roll**
- **Removes delivered & exothermic heat**
- **Regulate both water temperature / volume**
  - **Consistent & controlled substrate temperature**
  - **Virtually eliminates costly maintenance**

Substrate runs over the chill roll.

Heat Management Methods

Dichroic Coatings

- **Although effective, must clean regularly to remain successful**
- **Mirrors and plates - expensive and costly to maintain**
- **Lab environment vs. production floor**
- **Certain applications may dictate use of dichroic coatings**

H.M.M Testing

UV System & Equipment Used

UV System

- **Prime UV Optimum Series Air-cooled UV processor**
- **Prime UV Diamond Series Water-cooled UV processor**
- **Prime UV Transport Conveyor**
- **18 inch - 22mm 600 watt mercury vapor UV lamp**

EIT's UV PowerMap for:

- **UV dosage (J/CM2)**
- **Peak intensity (UV-A)**
- **Temperature readings**

Solatell's Sola-Scope & Sola-Check system for:

- **UV spectral graphs**

H.M.M. Testing

Heat Management Methods Tested

Methods tested:

- Reflector / shutter design – elliptical & parabolic
- Power output varies as a function of process speed – 50 fpm & 100 fpm
- Dichroic coated reflectors / liners (Cold Mirrors)
- Quartz barrier plates
- Combination of quartz plates with Cold Mirrors
- Dichroic coated barrier plates (Hot Mirrors)
- Combination of Hot Mirrors with Cold Mirrors
- Chill roll (tests conducted on-site at customer utilizing high efficiency chill roll system belt driven by press drive shaft)

H.M.M. Testing

Capital Equipment & Maintenance Costs

Capital equipment cost estimates:

- Based on industry average for 42 inch UV processor
- Maximum 600 watts per inch
- Up to 8 power levels

Consumable costs:

Assume operating time of 4000 hours per year

Does not include:

- Costs associated with time needed to replace / clean components
- Cost of UV replacement lamps

Results

1. Air-cooled vs. Water-cooled UV Processing Units

Air-cooled UV Processing Unit

- Capital costs - $30,000
- Consumable costs - $100

Water-cooled UV Processing Unit

- Capital costs - $50,000
- Consumable costs - $100

Air-cooled vs. Water-cooled Elliptical 18" 22mm 600 Watt Mercury Vapor UV Bulb					
	Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
	ft/min	J/cm2	mW/cm2	degrees C	degrees C
Air	50	1.4	2174	9	63
Water	50	1.18	2166	4	51

Water-cooled vs. air-cooled systems shows the following

- Peak Irradiance (UV A) stays constant
- UV Dosage (J/cm2) falls 17% - reduced exposure time
- MTR decreases as more IR energy removed via water-chilled housing
- ATR drops – reduced exposure time – more IR energy removed via water-chilled housing

Results

2. Reflector / Shutter Design – Parabolic vs. Elliptical

- Capital costs – same
- Consumable costs - same

Shutter Design Elliptical vs. Parabolic 18" 22mm 600 Watt Mercury Vapor UV Bulb					
	Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
	ft/min	J/cm2	mW/cm2	degrees C	degrees C
Parabolic	50	1.5	1383	9	64
Elliptical	50	1.4	2174	9	63

Elliptical vs. Parabolic Reflectors shows the following

- Peak Irradiance (UV A) increases 57%
- UV Dosage (J/cm2) stays constant
- MTR stays constant
- ATR stays constant – exposure time remains the same

Results

3. Power Output Varies as a Function of Process Speed

- Capital costs – Standard with many UV systems or slight up charge
- Consumable costs – slightly lower

Power Constant - 50 fpm vs. 100 fpm Air-cooled / Elliptical 18" 22mm 600 Watt Mercury Vapor UV Bulb				
Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
ft/min	J/cm2	mW/cm2	degrees C	degrees C
50	1.4	2174	9	63
100	0.71	2165	9	34

Comparison of 100 fpm vs. 50 fpm shows the following

- Peak Irradiance (UV A) stays constant
- UV Dosage (J/cm2) decreases approximately 50%
- MTR drops 46% or 29 degrees
- ATR stays constant

Results

4. Dichroic Coated Liners / Shutters – Cold Mirrors

- Capital costs – $2600
- Consumable costs – $1300

Standard Refectors vs. Dichroic Reflectors Air-cooled / Elliptical 18" 22mm 600 Watt Mercury Vapor UV Bulb					
	Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
	ft/min	J/cm2	mW/cm2	degrees C	degrees C
Standard	50	1.4	2174	9	63
Dichroic	50	1.39	2262	9	51

Dichroic vs. standard shows the following

- Peak Irradiance (UV A) increases 4%
- UV Dosage (J/cm2) stays constant
- MTR drops 19% or 12 degrees
- ATR stays relatively constant

Results

5. Quartz Barrier Plates

- Capital costs – $2000
- Consumable costs – $1100

Standard - No Barrier vs. Quartz Barrier Plate Air-cooled / Elliptical 18" 22mm 600 Watt Mercury Vapor UV Bulb					
	Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
	ft/min	J/cm2	mW/cm2	degrees C	degrees C
Standard	50	1.4	2174	9	63
Quartz	50	1.35	2060	8	56

Quartz barrier vs. standard shows the following
- Peak Irradiance (UV A) decreases 4%
- UV Dosage (J/cm2) decreases 5%
- MTR drops 11% or 5 degrees
- ATR stays relatively constant

Results

6. Combination of Quartz Barrier Plates with Dichroic Reflectors

- Capital costs – $4600
- Consumable costs – $2400

Standard - No Barrier vs. Quartz Barrier with Cold Mirrors Air-cooled / Elliptical 18" 22mm 600 Watt Mercury Vapor UV Bulb					
	Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
	ft/min	J/cm2	mW/cm2	degrees C	degrees C
Standard	50	1.4	2174	9	63
Q. w/ C.M.	50	1.24	2149	9	43

Quartz with dichroic vs. standard shows the following
- Peak Irradiance (UV A) decreases slightly
- UV Dosage (J/cm2) decreases 11%
- MTR drops 32% or 20 degrees
- ATR stays relatively constant

Results

7. Dichroic Coated Quartz Barrier Plates – Hot Mirrors

- Capital costs – $4000
- Consumable costs – $2100

Standard - No Barrier vs. Hot Mirror Air-cooled / Elliptical 18" 22mm 600 Watt Mercury Vapor UV Bulb					
	Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
	ft/min	J/cm2	mW/cm2	degrees C	degrees C
Standard	50	1.4	2174	9	63
Hot Mirror	50	1.38	2165	7	51

Hot mirror vs. standard shows the following
- Peak Irradiance (UV A) stays constant
- UV Dosage (J/cm2) stays constant
- MTR drops 19% or 12 degrees
- ATR falls slightly

Results

8. Combination of Hot Mirrors & Cold Mirrors

- Capital costs – $6600
- Consumable costs – $3700

Standard - No Barrier vs. Hot Mirror with Cold Mirror Air-cooled / Elliptical 18" 22mm 600 Watt Mercury Vapor UV Bulb					
	Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
	ft/min	J/cm2	mW/cm2	degrees C	degrees C
Standard	50	1.4	2174	9	63
Hot & Cold	50	1.3	2249	7	31

Hot mirror with cold mirror vs. standard shows the following

- Peak Irradiance (UV A) increases
- UV Dosage (J/cm2) drops 7%
- MTR drops 50% or 32 degrees
- ATR falls slightly

Results

9. UV Processor Mounted Over High Efficiency Chill Roll

Belt driven in-line on press

- Capital costs – $11,000
- Consumable costs – $100

Standard - No Barrier vs. UV Mounted over Chill Roll Air-cooled / Elliptical 18" 22mm 600 Watt Mercury Vapor UV Bulb					
	Speed	UV Dosage	Peak Intensity.	Average Temp. Rise	Max. Temp Rise
	ft/min	J/cm2	mW/cm2	degrees C	degrees C
Standard	50	1.4	2174	9	63
Chill Roll	50	1.35	2145	2	5

Chill roll vs. standard shows the following

- Peak Irradiance (UV A) stays relatively constant
- UV Dosage (J/cm2) stays relatively constant
- MTR drops 92% or 58 degrees
- ATR drops 77% or 7 degrees

Conclusions

Conclusions & Recommendations

Before selecting a Heat Management Method

- Determine temperature limits of products - materials
- Determine the effectiveness of H.M.M
  (May vary dependent upon UV Manufacturer)
- Collect all costs associated with maintaining and replacing all consumable components
- Be Aware:
  - Dichroic coated materials lose effectiveness if not cleaned on a regular basis

H.M.M:

- Do reduce temperatures
- May affect UV dosage and UV intensities reaching the substrate

Conclusions

Final Evaluation & Decision Time

Items to Review:

- **The process**
- **The application**
- **Capital equipment costs**
- **Heat management methods**
  - **Process limitations (equipment constraints?)**
  - **Maintenance time**
  - **Consumable costs**
- **UV Manufacturer**
  - **Knowledge**
  - **Experience**
  - **SUPPORT & SERVICE**

Thank You

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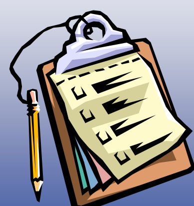

Please remember to turn in your evaluation sheet...