UV Lamp Configuration Effects on the Curing Properties of Coatings

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Ultraviolet light (UV)-curing technology has become well established for many segments of the printing industry. This includes narrow-web flexo, sheet-fed offset, web offset, and screen printing. In many cases, a clear UV-curable topcoat is used over the inks to enhance the appearance and/or performance of the printed materials. The UV-curable topcoats may be used over UV-curable inks as well as non-UV curable inks. Common examples include:

Narrow-web flexo

— UV coatings applied over UV inks
— UV coatings over water-based inks

Sheet-fed offset

— UV coatings applied offline over conventional litho inks
— UV coatings applied inline over hybrid inks
— UV coatings applied inline over UV inks

Web offset

— UV coatings applied inline over heat-set offset inks
— UV coatings applied inline over UV offset inks

Today's modern UV presses will often have lamps after each ink station as well as lamp(s) in the final station for curing the coating. In spite of the wide spectrum of coating applications, there is little information available regarding the optimum lamp design for curing of the clear topcoat.

There are many terms used to describe a UV-lamp system. However, the basic performance characteristics can be captured with four fundamental terms:[1]

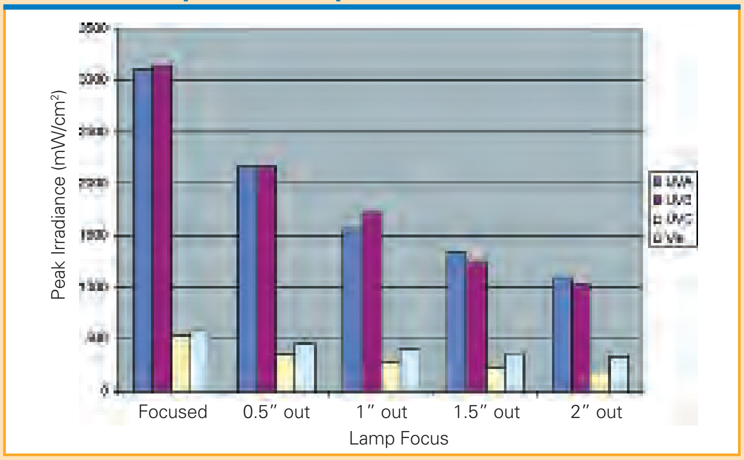
1. Irradiance—radiant power arriving at the surface from all forward angles. It is usually expressed in watts or milliwatts per square centimeter (W/cm^2 or mW/cm^2). The energy (expressed in J/cm^2 or mJ/cm^2) delivered to the substrate depends on the line speed and the irradiance.
2. Peak Irradiance—the intense peak of the focused power directly under the lamp. This is the maximum point of the irradiance profile measured in W/cm^2 or mW/cm^2.
3. Spectral Distribution—the irradiance from the lamp is not the same for all wavelengths. It can be expressed in terms of the irradiance or peak irradiance for different wavelength bands. One scheme characterizes the wavelength by UVA (315-400 nm), UVB (280-315 nm), UVC (200-280 nm) and Visible (400-700 nm).
4. Heat Output—measured by various methods including the temperature rise of the substrate.

The effect of the lamp characteristics on the curing properties of inks was examined in a previous study.[2] This study concluded that peak irradiance was very important for achieving optimum curing properties of the ink.

In this study, the curing properties of clear graphic arts topcoats were examined as a function of the lamp characteristics. A single-base coating

Figure 1

Effect of lamp focus on peak irradiance



was used with four different photoinitiator packages (PI-1 to PI-4) in order to determine the relationship between the initiator package and the lamp characteristics.

Lamp variables included in the study were:

— Lamp design: tight focus (Aetek Ultrapak, 2.3" focal length) vs. standard focus (Aetek UVXL, 4.25" focal length)

— Reflector type: polished aluminum vs. dichroic

— Reflector shape: elliptical versus parabolic

— Filter: hot mirror quartz (HMQ) vs. no filter

— Lamp focus: in focus and up to 2" out of focus

— Lamp power input: (250, 400 and 600 w/in)

The lamp output (energy and peak irradiance) for each system was characterized using an EIT PowerPuck radiometer with measurements taken at 25 fpm.

Coatings were applied to C1S card stock with a #3 Mayer rod and exposed to the various lamp conditions on a variable speed conveyor. The maximum speed (± 25 ft/min) that produced a mar-free coating was recorded. The highest speed achievable with this conveyor system was 550 ft/min.

Results and Discussion

The characteristics of the light output with the various lamp configurations are shown in Table 1. As expected the focus of the lamp had a significant effect on the peak irradiance but a relatively small effect on the energy (compare condition 1 to 5 and 6 to 10). This is also shown graphically in Figures 1 and 2.

The effect of lamp design can be seen by comparing condition 1 to 15 and 16. In this case, the light energy output of the 400 W/in tight focused Ultrapak is actually more similar to the higher 600 W/in input power UVXL design. A comparison of the peak irradiance also shows considerably higher peak irradiance with the tight focus design.

Dichroic reflectors are designed to reduce heat output from lamps. The special coating reflects UV energy while allowing IR (heat) to pass and be removed by air, which is drawn over the lamp for cooling.[3] In this study, the dichroic reflectors appeared to be nearly equally effective as the polished aluminum reflectors (compare condition 1 with 11 and 6 with 12) in delivering light output. There was some variation with spectral output where the dichroic reflectors appeared most effective in the UVB and UVC regions.

Hot mirror quartz (HMQ) filters are also designed to reduce the heat output from the lamps. The HMQ filter is positioned between the bulb and the

Figure 2

Effect of lamp focus on lamp energy output

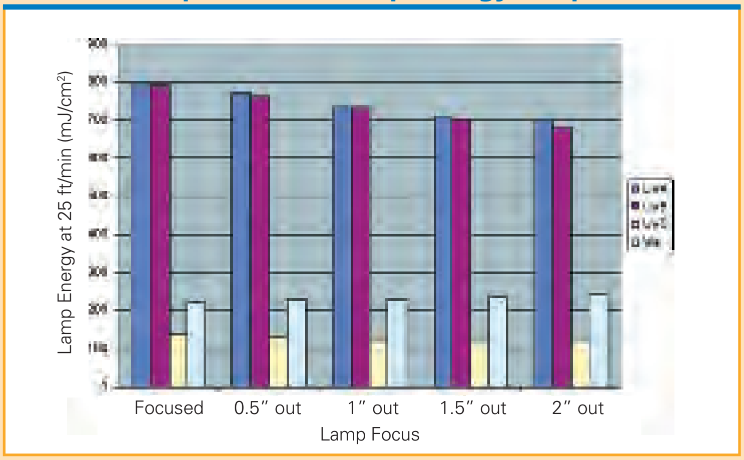


TABLE 1

Lamp configuration and light output

				Energy (mJ/cm²)				Peak Irradiance (mW/cm²)			
Ref.	Lamp Configuration	Power (W/in)	Focus	UVA	UVB	UVC	Vis	UVA	UVB	UVC	Vis
1	Ultrapak	400	Focused	795	793	138	223	3109	3152	542	579
2	Ultrapak	400	0.5" out	773	765	132	232	2179	2188	362	465
3	Ultrapak	400	1" out	734	734	126	232	1575	1721	280	418
4	Ultrapak	400	1.5" out	713	702	122	235	1346	1260	231	373
5	Ultrapak	400	2" out	700	683	120	244	1098	1046	189	333
6	Ultrapak	250	Focused	489	486	80	159	2140	2188	357	489
7	Ultrapak	250	0.5" out	481	463	77	159	1562	1297	251	402
8	Ultrapak	250	1" out	468	451	74	165	1065	1076	179	324
9	Ultrapak	250	1.5" out	446	427	71	162	870	818	140	291
10	Ultrapak	250	2" out	438	415	69	165	698	677	415	239
11	Ultrapak with Dichroic Reflector	400	Focused	790	840	147	181	2543	2973	587	418
12	Ultrapak with Dichroic Reflector	250	Focused	485	498	83	126	1602	1598	331	330
13	Ultrapak with Dichroic Reflector and HMQ Filter	400	Focused	708	718	112	174	2395	2261	465	432
14	Ultrapak with Dichroic Reflector and HMQ Filter	250	Focused	446	439	68	120	1589	1408	287	345
15	UVXL	400	Focused	575	537	82	244	1018	978	143	362
16	UVXL	600	Focused	850	812	129	325	1333	1414	196	425
17	Parabolic Reflector with UVXL Bulb	400	Unfocused	558	533	78	304	631	640	97	343
18	Parabolic Reflector with UVXL Bulb	600	Unfocused	893	867	130	452	1038	1058	156	463

Radiometer data collected at 25 ft/min.

substrate. The materials used in the HMQ filter are designed to transmit UV energy while reflecting IR for subsequent removal of the heat with the air exhaust.[3] In this study, there was some loss of energy and peak irradiance across all spectral ranges when the HMQ filter was used (compare condition 11 with 13 and 12 with 14).

Parabolic reflectors are designed to produce columnated light from the lamp while elliptical reflectors are designed to focus the light in a narrow area under the bulb. As expected the parabolic reflector gave reduced peak irradiance, but had little effect on the energy relative to the elliptical reflector (compare condition 15 with 17 and 16 with 18).

The maximum conveyor speed to cure each coating is shown in Table 2. In many cases coatings with photoinitiator packages PI-2 and PI-3 had cure speeds that exceeded the maximum speed of the conveyor. In these cases, the lamp power input was reduced to 250 W/in in an attempt to differentiate the performance.

The effect of focus of the lamp was examined under conditions 1 to 5 and 6 to 10. When photoinitiator packages PI-1, PI-2, and PI-3 were used, there was very little effect of lamp focus on curing. This suggests that lamp energy is more important than peak irradiance for the curing of these coatings. The coating with PI-4 cured at slower speeds than the other initiator packages. In contrast to PI-1, PI-2 and PI-3, PI-4 cured faster with focused vs. unfocused lamps.

The effect of lamp design can be seen by comparing the cure of the coatings under condition 1 to 15 and 16. The results show that the tight focused Ultrapak operating at 400 W/in gave cure speeds comparable or faster than the standard focus UVXL even when operated at an input power of 600 W/in.

The use of dichroic reflectors (compare condition 1 with 11 and 6 with 12) did not appear to have much of an effect on the curing of the coatings. This is consistent with Table 1, which shows similar lamp outputs when these reflectors were used.

The effect of using of the hot mirror quartz (HMQ) filter was examined in condition 13 and 14. There was a noticeable reduction in cure speed when this filter was used (compare conditions 11 with 13, and 12 with 14). These results are consistent with the reduced lamp output shown in Table 1.

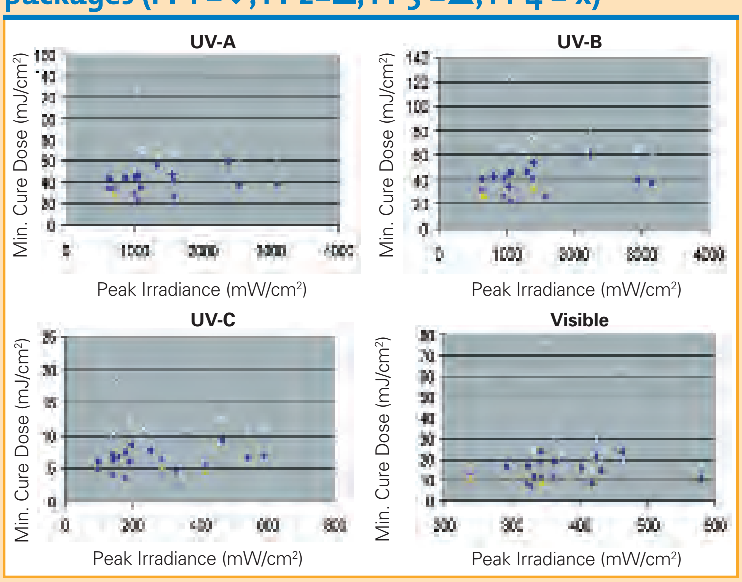
The effect of using the focused elliptical reflector vs. the unfocused parabolic reflector shows that there was little difference in the cure speed when PI-1, PI-2, and PI-3 were used. However, PI-4 did appear to cure better when the focused elliptical reflector was used.

The results reported above suggest that cure energy is more important than peak irradiance for curing coatings with photoinitiator packages PI-1, PI-2 and PI-3. In order to examine this effect in more detail, the minimum dose to cure each coating was calculated from the lamp energy given in Table 1 in combination with the cure speed given in Table 2. Figure 3 shows plots of the minimum cure dose vs. the peak irradiance. A separate plot was generated for each of the spectral regions (UVA, UVB, UVC and Visible). The plots show that for PI-1, PI-2 and PI-3 the minimum cure dose needed to cure the coating shows very little if any dependence on the peak irradiance. This appears to be true for all regions of the lamp spectrum. The photoinitiator package PI-4 in contrast shows more effective curing at higher peak irradiance levels.

The importance of energy vs. peak irradiance for curing coatings with photoinitiator packages PI-1, PI-2 and PI-3 is in contrast to an earlier report showing the importance of peak irradiance for curing inks.[2] These results are not unexpected.[4] Inks contain pigments which tend to block UV light. High peak irradiance from a focused light source is needed to penetrate the ink and reach the photoinitiator and curable ink vehicle components at the ink/substrate interface. Topcoats by contrast do not contain pigment. Efficient curing of topcoats is typically more limited by surface cure which is inhibited by atmospheric oxygen. Surface cure is more of a function of the total energy that reaches the coating rather than the peak irradiance.

FIGURE 3

Effect of peak irradiance on the minimum cure dose of topcoats with different photoinitiator packages (PI-1 =◆, PI-2=■, PI-3 =▲, PI-4 = x)



Conclusions

From a practical perspective the important conclusions resulting from this study are as follows:

— Current lamp systems employing focused designs are well suited for curing inks as well as properly formulated non-pigmented coatings.

— Dichroic reflectors do not provide any advantage for curing coatings and are not needed unless the application is sensitive to lamp heat that cannot be managed with polished aluminum reflectors.

Table 2

Coating cure speed with different lamp conditions

				Coating Cure Speed (ft/min)			
Ref.	Lamp Configuration	Power (W/in)	Focus	PI-1	PI-2	PI-3	PI-4
1	Ultrapak	400	Focused	525	>550	>550	325
2	Ultrapak	400	0.5" out	>550	>550	>550	300
3	Ultrapak	400	1" out	>550	>550	>550	275
4	Ultrapak	400	1.5" out	>550	>550	>550	275
5	Ultrapak	400	2" out	500	>550	>550	250
6	Ultrapak	250	Focused	ND	>550	>550	ND
7	Ultrapak	250	0.5" out	250	>550	>550	ND
8	Ultrapak	250	1" out	250	525	>550	ND
9	Ultrapak	250	1.5" out	250	>550	>550	ND
10	Ultrapak	250	2" out	ND	325	375	ND
11	Ultrapak with Dichroic Reflector	400	Focused	525	>550	>550	325
12	Ultrapak with Dichroic Reflector	250	Focused	ND	475	>550	ND
13	Ultrapak with Dichroic Reflector and HMQ Filter	400	Focused	300	>550	>550	225
14	Ultrapak with Dichroic Reflector and HMQ Filter	250	Focused	ND	275	325	ND
15	UVXL	400	Focused	325	525	>550	200
16	UVXL	600	Focused	375	>550	>550	275
17	Parabolic Reflector with UVXL Bulb	400	Unfocused	325	425	>550	100
18	Parabolic Reflector with UVXL Bulb	600	Unfocused	475	>550	>550	175

— HMQ filters do reduce light exposure and coating cure. They should be avoided unless absolutely needed to manage heat.

— State-of-the-art topcoats are capable of very high-cure speeds to meet the needs of high-speed graphic art applications.

— Working together with both your coating and lamp supplier will help assure the best performance for your UV-coating applications.

Acknowledgement

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References

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