



Abstract

It is the aim of this study to investigate the potential of 308 nm excimer UV curing in web and sheet fed offset printing and to discuss its present status. Using real-time FTIR-ATR and stationary or pulsed monochromatic (313 nm) irradiation chemical and physical factors affecting the curing speed of printing inks such as nature and concentration of photoinitiators, reactivity of the ink binding system, ink thickness and pigmentation, irradiance in the curing plane, oxygen concentration and nitrogen inerting, multiple pulse exposure, the photochemical dark reaction and temperature dependence were studied.

The results were used to select optimum conditions for excimer UV curing in respect to ink reactivity, nitrogen inerting and UV exposure and to build an excimer UV curing unit consisting of two 50 W/cm 308 nm excimer lamps, power supply, cooling and inerting unit. The excimer UV curing devices were tested under realistic conditions on a web offset press **zirkon supra forte** and a sheet fed press **Heidelberg GTO 52**.

Maximum curing speeds of 300 m/min in web offset and 8000 sheets per hour in sheet fed offset were obtained.

1. Introduction: Monochromatic vs. polychromatic UV radiation for curing of printing inks

Until the mid-90ies, no monochromatic UV source was available which could compete in cure speed and curing performance with the polychromatic medium pressure mercury lamps, which were able to achieve a high UV radiant power with an excellent technical standard of the lamp and the related curing equipment. Moreover, photoinitiator absorption was matched to the mercury emission lines in a nearly perfect manner. As a result, radical generation rates were obtained high enough to rapidly overcome oxygen inhibition in the layer to be cured and to enable fast cure speeds.

The maximum production speed at which the *cured product still meets the needs of its function properties to be commercial* is called *cure speed*.

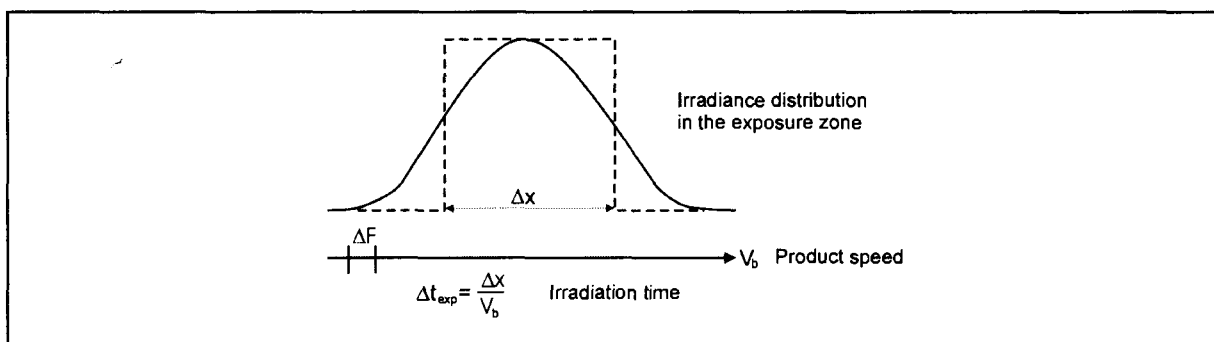
The cure speed defined in such a way depends on following conditions:

- spectral distribution of the lamp,
- reactivity of the printing ink,
- irradiance and irradiance distribution in the curing plane,
- thickness of the ink,
- oxygen concentration (air or inert),
- coating temperature.

For a given formulation the cure speed can be studied as a function of all the parameters mentioned above. In that sense, consistent experimental data can be obtained.

The cure speed concept, which is not based on a clean kinetic approach as applied for the polymerisation rate, is illustrated in the following scheme. As shown in the upper part, a certain irradiance distribution is seen by a ink increment dF passing the exposure zone Δx with a uniform speed v_s . Within a total irradiation time $\Delta t_{exp} = \Delta x/v_s$, the induction period Δt_i has to be overcome, and after the conversion time Δt_{con} the monomer conversion must reach a distinct level. The cure speed is then given as

$$v_s = \Delta x / (\Delta t_i + \Delta t_{con}) \quad (1)$$



Since more than 20 years medium pressure mercury lamps are used in web and sheet fed offset. Figure 1 shows typical positions of UV curing processors in a web and sheet fed press.

For web and sheet fed offset, two concepts of UV curing are used: final curing or a combination of interdeck and final curing. Printing wet-in-wet of up to four colours and subsequent drying is possible without significant loss in quality. However, interdeck UV curing prevents trapping of one colour on another and stops dot gain.

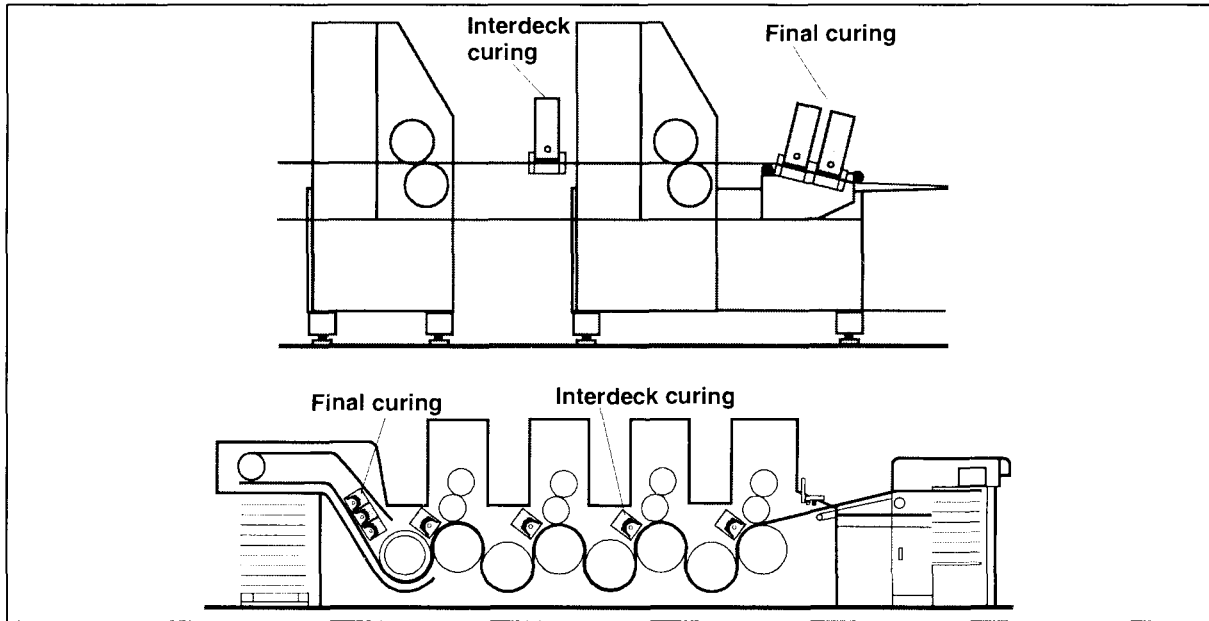


Figure 1 UV Curing Processors in Web and Sheet Fed Offset Presses

In curing of printing inks, interesting new possibilities were opened up with the development of a completely new class of UV sources - the excimer lamp⁽¹⁾. The term excimer radiation is normally used in connection with excimer lasers. Excimers (**exc**ited **di**mers, **tri**mers) are weakly bound excited states of molecules that do not possess a stable molecular ground state⁽²⁾.

The most important excimers are formed by electronic excitation of rare gases (He_2^* , Ne_2^* , Ar_2^* , Kr_2^* , Xe_2^*), rare gas-halides (ArF^* , KrF^* , XeCl^* , XeF^* etc.), halogens (F_2 , Cl_2 , Br_2 , I_2) and mercury halogen mixtures (HgCl , HgBr , HgI). Excimers are unstable and decay by spontaneous optical emission.

Stimulated (laser) excimer emission can be generated in pulsed high pressure glow discharges. On the other hand, dielectric barrier (silent) discharges⁽¹⁾ or microwave discharges⁽³⁾ can be used to produce quasistationary or continuous incoherent excimer radiation. Such emitters are called excimer lamps.

For curing of printing inks we used XeCl excimer lamps exhibiting cylindrical geometry of the discharge gap and showing monochromatic emission at 308 nm.

A typical cylindrical discharge lamp suitable for excimer UV generation⁽⁴⁾ is shown in Figure 2.

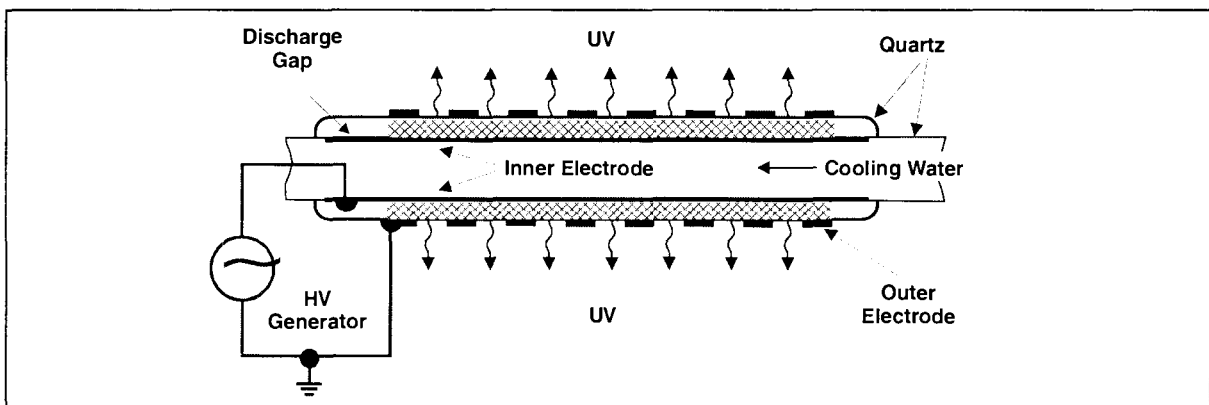


Figure 2 Cylindrical Excimer Lamp Configuration with Annular Discharge Gap and External Electrodes

When the high voltage applied to the discharge gap exceeds the breakthrough voltage, a current starts to flow, which after a short time is switched off by the decrease of the electrical field strength in the gap caused by charging the dielectric surface. The total duration of the current pulse is a few nanoseconds and excimer emission may occur in this time. A schematic representation of the voltage current characteristics and the pulsed excimer emission from a barrier discharge is given in Figure 3. A characteristic emission spectrum is shown on the right hand side.

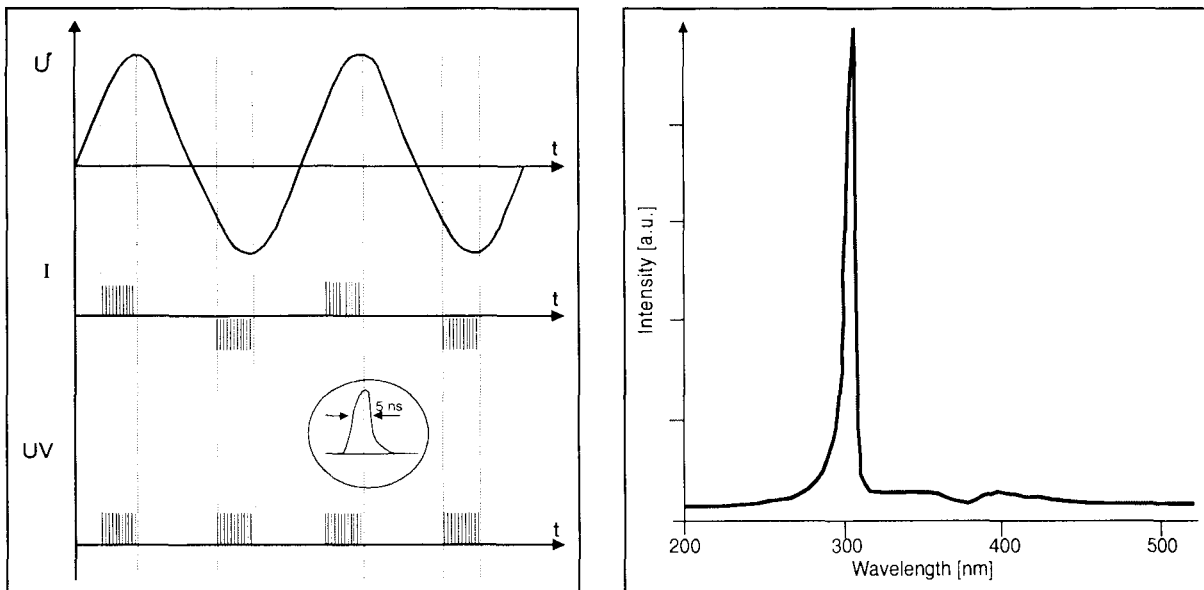


Figure 3 Dielectric Barrier Discharge - Time Profile of the High Voltage (U), the Current Pulse (I) and the Excimer Emission (UV) (left) and Spectrum of the XeCl Excimer Emission (right)

A very important feature of the barrier discharge is that the current flow through the gap is generated by a large number of randomly distributed microdischarges.

As result of the discharge conditions, the excimer radiation of a discharge lamp consists of a large number of pulsed "microlasers". This makes them very suitable as potential high power UV emission source.

In UV curing of printing inks newly developed excimer lamps have to compete with well established medium pressure mercury lamps. A comparison of important lamp characteristics shows strength and weakness of the two competing lamp concepts.

UV curing using medium pressure mercury lamps is characterised by the following features:

- very high cure speeds are possible,
- ozone is generated if curing is performed under air,
- heat transfer to the substrate or machine cannot be avoided,
- substrate decomposition cannot be completely excluded,
- mechanical shutters are needed,
- lamp start and restart consumes time.

The barrier discharge driven 308 nm excimer lamp is not as powerful as a medium pressure mercury lamp, but the following interesting characteristics have been found:

- medium cure speed possible,
- no ozone formation,
- no heat transfer to the substrate or machine,
- no substrate decomposition,
- fast pulsing possible,
- no shutter needed,
- simple control.

The obvious benefits of the use of 308nm excimer lamps in UV curing units for printing inks are accompanied by the drawback of a relative low UV output power. At present, the UV radiant power of a barrier discharge driven excimer lamp reaches about 5 W/cm, which should be compared with 40 W/cm from a medium pressure mercury arc lamp.

It is the aim of this study to investigate the potential of excimer UV curing in web and sheet fed offset printing and to discuss its present status.

2. Chemical and physical factors affecting the cure speed of printing inks

2.1 UV transmission of standard offset inks

Typical transmission spectra obtained for acrylate based standard offset UV printing inks are shown in Figure 4. Color densities (CD) of the prints measured and transmissions taken at 308 nm are given as inserts.

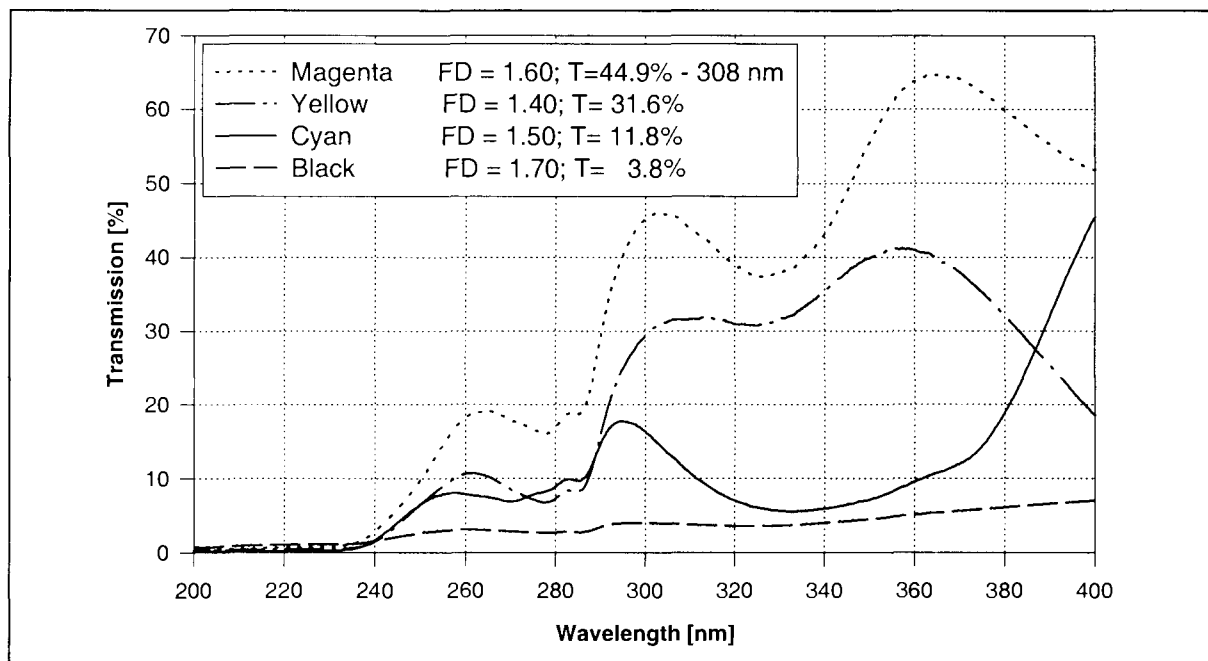


Figure 4 Optical Transmission Observed for Standard Offset UV Printing Inks. FD = Colour Density, T = Optical Transmission at 308 nm

Especially for black and cyan transmission at 308 nm is rather low. Mainly scattered light is available for curing. This leads to low double bond conversion rates. Nevertheless, curing at reasonable speed is possible if

- inks with an reactive binding system and an optimal photoinitiator composition and concentration,
- radiation sources with high radiative power and
- nitrogen inerting are used.

2.2 Reactivity of offset inks towards 308 nm exposure

Real-Time Fourier Transform Infrared Spectroscopy (FTIR) with Attenuated Total Reflection (ATR) is used to study curing of printing inks at monochromatic (313 nm – a mercury emission line close to 308 nm –) exposure. Real-time FTIR-ATR spectroscopy is one of the most powerful analytical methods for monitoring UV-initiated curing processes which proceed within a fraction of a second.

It allows a time-resolved, rapid and quantitative measurement of the conversion of reactive groups (e.g. acrylate double bonds) in printing inks at defined light intensity, ink thickness, photoinitiator concentration, at pulsed or continuous light exposure and at nitrogen or air environment.

Figure 5 shows the scheme of the real-time FTIR-ATR apparatus. A detailed description of the experimental technique is given elsewhere⁽⁵⁾.

The infrared spectra were recorded in real time with a Biorad FTS 6000 FTIR spectrometer equipped with a MCT detector. The spectrometer is able to record up to 95 spectra per second at a spectral resolution of 16 cm⁻¹. A heatable single reflection diamond ATR device ("Golden Gate"; Graseby Specac) was used for sampling. Test prints with well defined ink thickness were prepared on transparent polyethylene films. The ink side of the test prints were pressed against the ATR diamond. The substrate prevents the contact of the sample with the surrounding air. Thus, oxygen diffusion into sample can be neglected during and shortly after irradiation. In this case, radicals formed after irradiation react with acrylate molecules or residual oxygen dissolved in the liquid formulation.

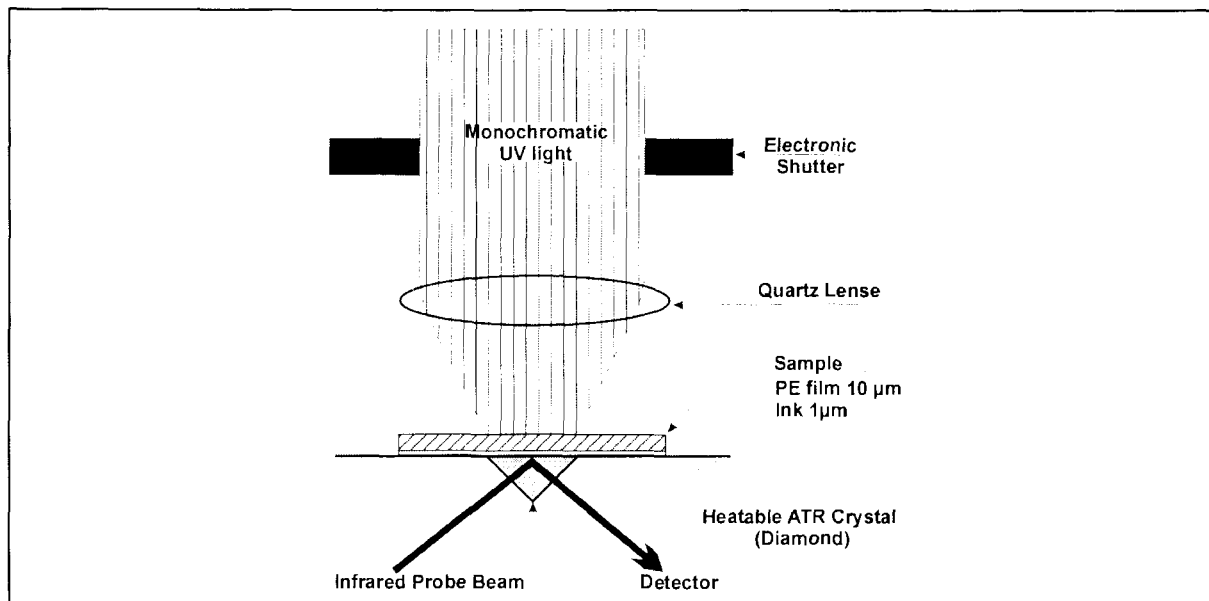


Figure 5 Scheme of an Real-Time Fourier Transform Infrared ATR (FT IR ATR) Spectrometer

UV-irradiation was performed using an Osram HBO 100 W medium pressure mercury arc lamp. The light source is equipped with a water filter for blocking infrared radiation, neutral density filters to vary the light intensity, and a 313 nm metal interference filter to provide monochromatic light. The intensity of the incident UV light was measured by a UV radiometer using a SiC detector which is calibrated to radiation with a wavelength of 313 nm by chemical actinometry. The maximum irradiance measured at diamond crystal position was 100 mWcm^{-2} . An electronic shutter directly driven by the spectrometer allows exact synchronisation between irradiation and spectra recording.

Suitable vibrational bands of the acrylate functionality ($810, 1410$ or 1639 cm^{-1}), which disappear under irradiation, can be selected to obtain the double bond conversion vs. time profile. Such profiles contain direct information about the rate of polymerisation, the dark reaction and the final degree of conversion.

2.3 Functionality of the acrylate binding system

It is well known that the functionality of acrylates has a strong influence on both the polymerisation rate and the residual monomer content. With increasing acrylate functionality, the conversion time decreases but the content of residual unsaturations rises. As the functionality increases, the higher initial concentration of acrylate groups leads to initially faster conversion but the higher viscosity of the resin, with the resulting gel-effect and the higher cross-link density, set a limit to the extent of conversion.

Figure 6 shows typical double bond conversion vs. time profiles of different acrylate binders for printing inks.

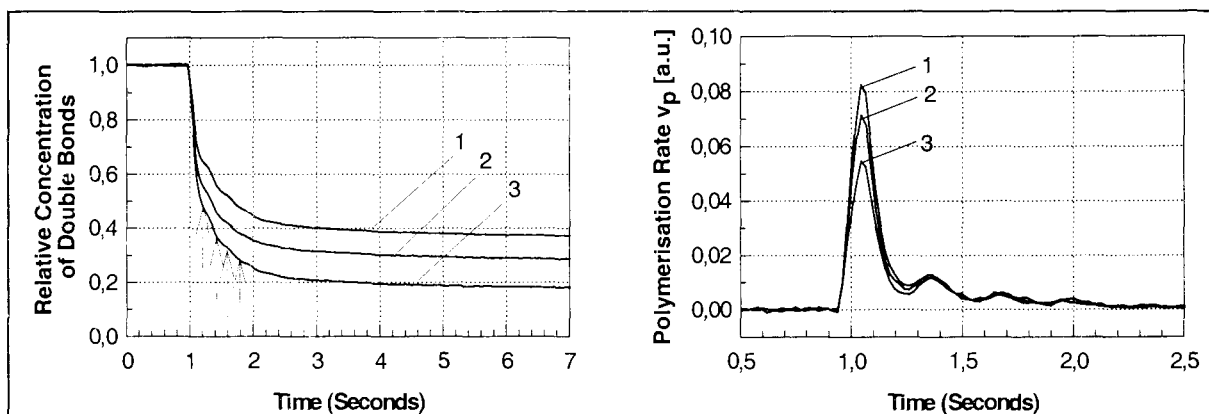


Figure 6 Double Bond Conversion and Polymerisation Rate Measured for Different Ink Binders. Pulse Irradiation at 313 nm

2.4 Photoinitiator system

Nature and concentration of the photoinitiator system used in the formulation also affect the cure speed. Under constant physical exposure conditions both induction period and polymerisation rate are influenced (see Figure 7).

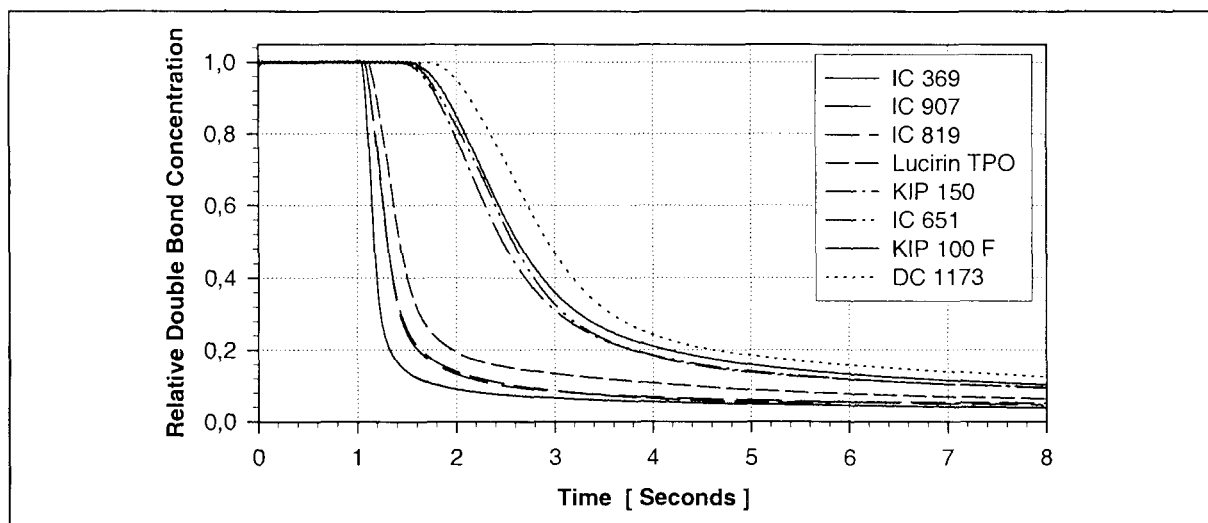


Figure 7 Double Bond Conversion in TPGDA Measured for Different Photoinitiators, Photoinitiator Concentration 1 wt.-%, Irradiance 40 mWcm^{-2} at 313 nm

To obtain a high polymerisation rate and a short induction period, the photoinitiator absorption spectrum and the emission spectrum of the curing light source should overlap as much as possible. The photoinitiator absorption spectra were tuned to strongly absorb at intense mercury emission lines. Fine-tuning of the photoinitiator absorption to monochromatic excimer radiation remains still to be done. In the case of 308 nm emission, however, photoinitiators can be favourably used which were originally tuned to mercury emission lines between 300 and 313 nm. Figure 8a shows an example using the photoinitiators IC 369, 907 and 819. Their high extinction coefficients at 308 nm are a prerequisite for fast conversion in monochromatic UV-curing.

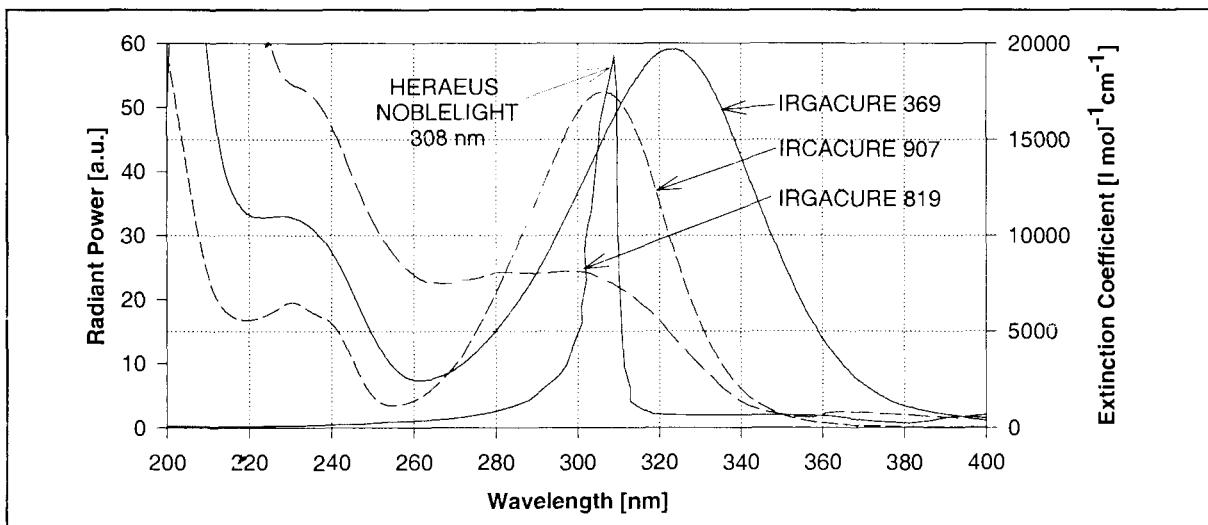


Figure 8a Spectral Overlap of Photoinitiator Absorption (IC 369, 907 and 819) and Emission from a 308 nm Excimer Lamp

The photoinitiator concentration plays also a major role. As shown in Figure 8b, initially polymerisation rate and final conversion increase with growing photoinitiator concentration but finally level off between 6 and 10 wt.% of photoinitiator content.

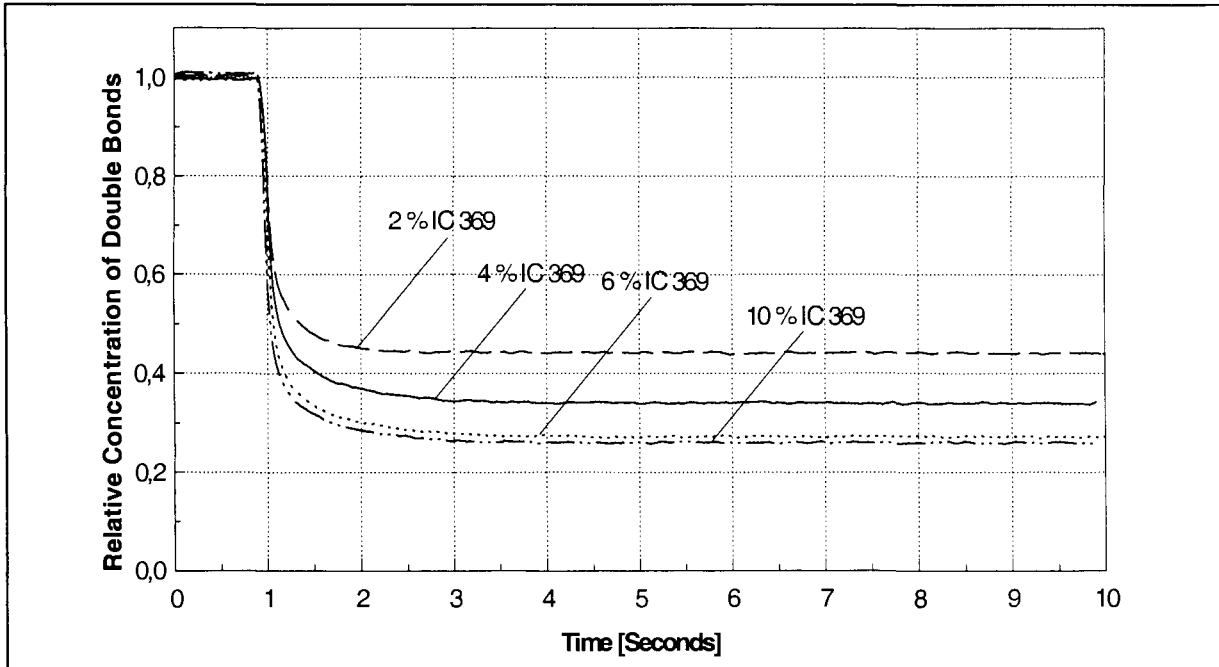


Figure 8b Double Bond Conversion of an Offset Printing Ink as Function of the Photoinitiator (IC 369) Concentration. Irradiance 60 mWcm^{-2} at 313nm

2.5 Ink thickness and pigmentation

In pigmented systems pigment and photoinitiator absorptions often superimpose. The pigment can absorb a considerable part of the incoming photons flux (see Figure 4). As a result, at constant exposure conditions for pigmented systems the induction period increases and the polymerisation rate drops. Figure 9 shows the effect of the pigment content on double bond conversion time for an ink formulation.

In a similar way the ink thickness is of crucial importance for the curing speed obtained. It is obvious from Figure 10 that a given cure speed is strictly related to distinct ink thickness or color density.

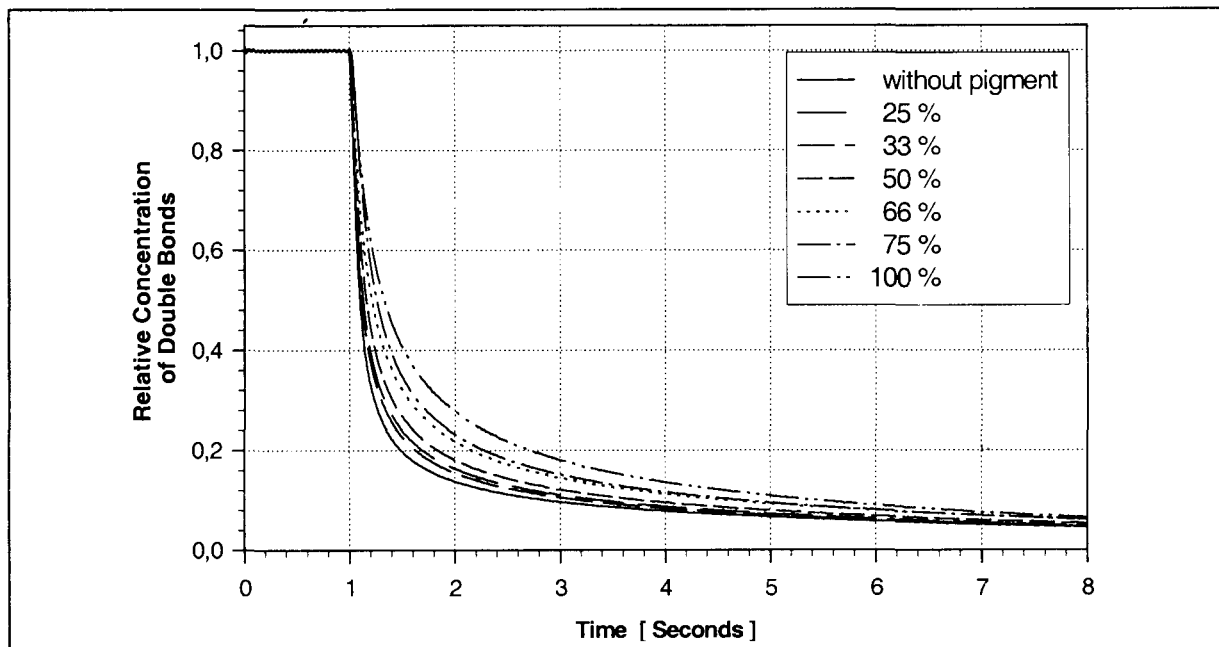


Figure 9 Double Bond Conversion in a Printing Ink as Function of Relative Pigment Concentration. Irradiance at 313 nm 48 mW cm^{-2}

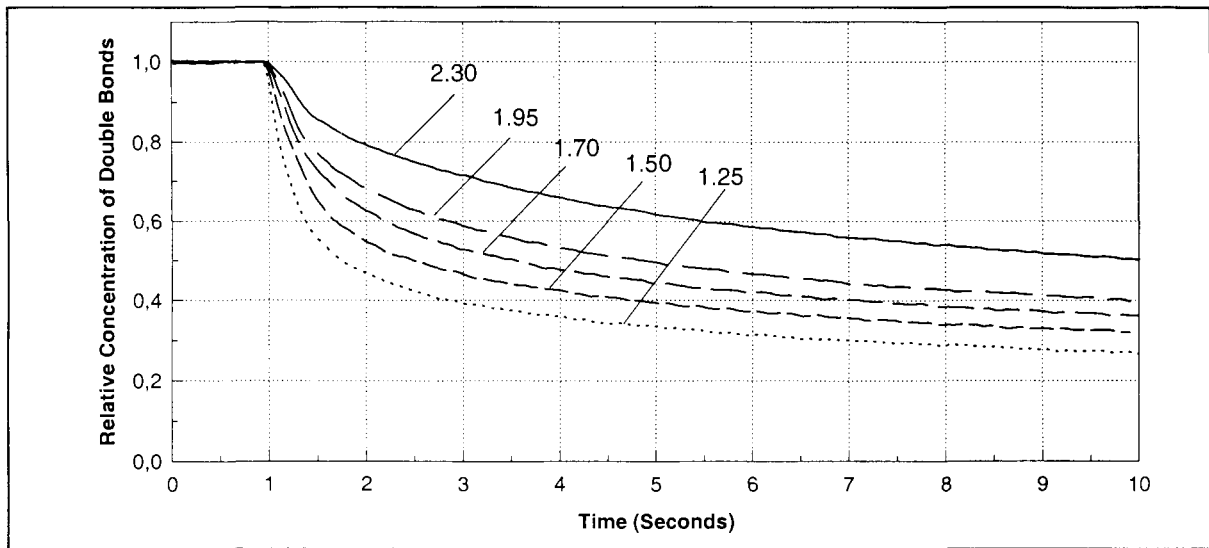


Figure 10 Double Bond Conversion of a Black Offset Printing Ink as Function of the Color Density of the Print. Irradiance 60 mWcm^{-2} at 313 nm

2.6 Irradiance in the curing plane

Dividing the polymerisation kinetics into three main steps: initiation, chain propagation and termination, the following expression for the polymerisation rate v_p has been derived ⁽⁶⁾ :

$$v_p = k_p (k_t)^{-1/2} [M] (\Phi_i I_a)^{1/2}, \quad (2)$$

where k_p and k_t are propagation and termination rate constants, $[M]$ is the monomer concentration, I_a is the number of photons absorbed per second and Φ_i is the yield of start radicals.

The induction period Δt_i of the polymerisation is roughly estimated by

$$\Delta t_i = [O_2]_0 / \Phi_T I_a, \quad (3)$$

where $[O_2]_0$ is the initial oxygen concentration, Φ_T the yield of the photoinitiator triplet and I_a the number of photons absorbed per second as given in Eqn.(2).

It is obvious from equation (2) and (3) that the polymerisation rate v_p as well as the induction period Δt_i are dependent on I_a , the number of photons (given in mol l^{-1}) absorbed per second within the sample. I_a is directly proportional to I_0 , the number of photons impinging per cm^2 sample surface and second. I_a further depends on the photoinitiator absorbance. The irradiance measured in the curing plane is proportional to I_0 , i.e., the polymerisation rate should increase according to the square root of irradiance, whereas the induction period should decrease linearly at growing irradiance.

The polymerisation rate determines a conversion time Δt_{con} at which a certain degree of cure is obtained. On the other hand, the minimum exposure time Δt_{exp} to reach the desired conversion is the sum of induction and conversion time. At increasing irradiance the induction time Δt_i decreases linearly but the conversion time decreases according to the square root:

$$\Delta t_{\text{exp}} = \Delta t_i + \Delta t_{\text{con}} = [O_2]_0 / \Phi_T I_a + \beta / (\Phi_i I_a)^{1/2}, \quad (4)$$

where β is a proportionality factor.

As a result of eqn. (4), it is expected that the cure speed $v_s = \Delta x / \Delta t_{\text{exp}}$ rises less than linearly with growing irradiance, for example, if irradiance is increased by a factor of two the resulting exposure time is longer than half the initial one.

Eqn. (4) was derived under the assumption that oxygen diffusion does not take place during exposure. Application of eqn. (2) further implies that

- monochromatic light is used, which is absorbed exclusively by the photoinitiator
- the absorption is small and homogeneous in the volume irradiated and
- the extent of conversion is low.

As mentioned above, this is an idealised case. There is experimental evidence that UV curable coatings may respond to changes in UV irradiance. By increasing the irradiance at constant dose, improved chemical resistance of the coating or higher cure speeds have been reported ^(7,8).

2.7 Multiple exposure

In many UV curing applications the desired curing speed cannot be reached by using only a single lamp. In these cases the exposure time is too short to generate sufficient conversion. Therefore, it is common to use multilamp irradiation units. Using real-time FTIR a simple simulation of the multilamp effect becomes possible.

Figure 6 shows the experimental simulation of the curing behaviour of different ink binders which pass four "lamps" (indicated by arrows). The pulse exposure time was chosen to be 100 ms and the delay between the pulses was set to 200 ms. The first derivative of the conversion vs. time profiles yields the polymerisation rate (see right hand side of Figure 6). Under our experimental conditions already the first exposure pulse leads to more than 80% of the final conversion. The picture may change when shorter exposure pulses and/or less reactive inks are used. Then the second or even a third exposure pulse may effectively contribute to conversion.

2.8 The photochemical dark reaction (postcuring)

Figure 11 shows the conversion vs. time profile obtained during and after a 313 nm pulse irradiation of an offset ink. The effect of the first and the second irradiation pulses can be seen as steps in the prompt double bond conversion, whereas the effect of the third and fourth pulse is less pronounced. Within the following 9 seconds a strong dark reaction can be observed. The dark reaction can also be seen to occur in the time interval between pulse exposure.

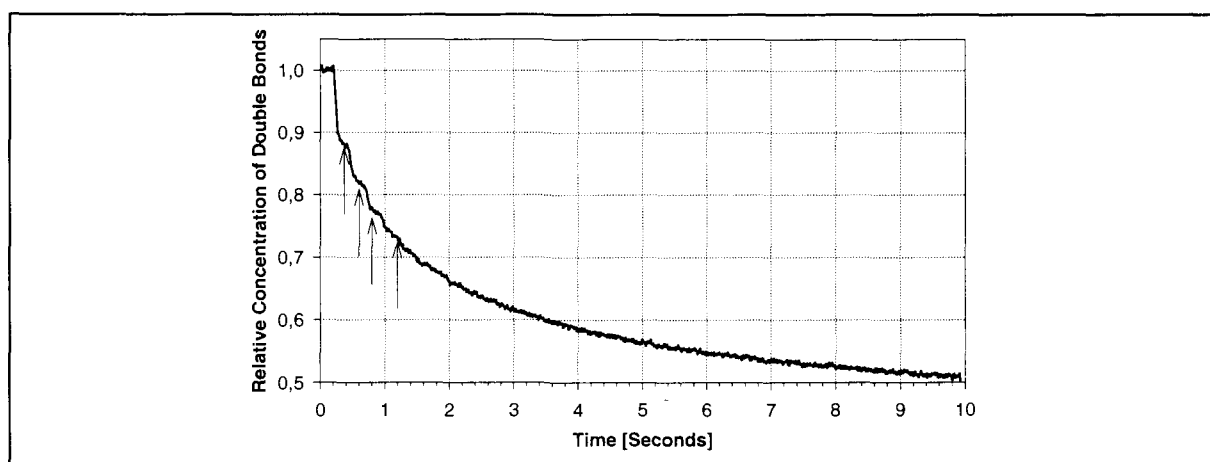


Figure 11 Web Offset UV Ink Magenta: Double Bond Conversion After Exposure with a Series of 313 nm Light Pulses, Delay Between Pulses 200 ms, Irradiance 50 mWcm⁻²

Figure 11 illustrates the typical "postcuring" behaviour of a printing ink which cures by a radical mechanism. Even in that case double bond conversion can proceed to a level which exceeds that of prompt conversion. Depending on the exposure conditions the photochemical dark reaction can contribute between 50 and 80% to the final conversion. It has been proven by electron paramagnetic resonance (EPR) that in cured inks radicals survive over hours⁽⁹⁾.

Thus, the photochemical dark reaction is of crucial importance for curing of printing inks. A pulse exposure is needed which "triggers" the curing reaction. The following dark reaction leads to final conversion.

2.9 Effect of oxygen and nitrogen inerting

In UV curing, reactions of photoinitiator triplet, initiating and propagating radicals with oxygen lead to an induction period before monomer conversion can take place. To induce curing the exposure time has to be longer than the induction period. Thus, the oxygen content of the sample can strongly affect the cure speed. At low irradiance and contact of the sample to the surrounding air, curing can even be prevented by oxygen. The "cured" ink remains tacky, an effect which is frequently called "oxygen inhibition". This effect is often restricted to thin surface layers and it is less pronounced or even disappears at increasing depth.

In UV curing under air, oxygen inhibition is a result of the parallel action of oxygen depletion by irradiation and oxygen diffusion into the sample.

To estimate the effect of oxygen diffusion under real curing conditions, a simple model can be applied. The mean distance Δr that diffusing oxygen can travel during a time t can be expressed as

$$\Delta r = (2Dt)^{1/2} \quad (5)$$

where D is the diffusion coefficient of oxygen within the ink.

Table 1 contains the Δr values calculated for different diffusion coefficients after $t = 100$ ms. This time is selected because it is in the range of typical exposure times and induction periods.

Table 1 Diffusion Coefficients for Oxygen and Mean Diffusion Distances Δr after 100 ms

	Liquid		Highly viscous liquid or solid	
Diffusion coefficient of oxygen [cm^2s^{-1}]	10^{-5}	10^{-6}	10^{-7}	10^{-8}
Mean diffusion distance [μm]	14.1	4.5	1.4	0.45

It is obvious from Table 1 that in a low-viscosity liquid, diffusion is fast and can easily compete with oxygen depletion up to a depth of about $10 \mu\text{m}$. In practice, this effect is noticed as tacky surface. The diffusion depth is strongly reduced at a higher viscosity but is still of importance. This is for example the case for offset printing inks, where the ink thickness is in the range of $1 \mu\text{m}$.

If UV curing of coatings or inks occurs in contact with air, a considerable amount of photons is wasted in order to reduce the oxygen concentration. Additionally, volatiles are generated via peroxy radicals, which can contribute to an undesired odour of the cured products.

To avoid oxygen inhibition, nitrogen inerting (sometimes also called "nitrogen blanketing") is the preferred technique. Nitrogen inerting means that oxygen surrounding the ink and adhering on the ink surface is removed by a rapid nitrogen flow. Using this technique, oxygen residual concentrations of ppm can be obtained in the inerting gas. Inerting is usually done in a closed chamber with small web inlet and outlet slits, a few hundred milliseconds before UV curing takes place. Effective oxygen diffusion from coating to the gas nitrogen phase results in a considerable decrease of the concentration of dissolved oxygen. The induction period decreases and the ink undergoes faster curing.

Even if UV irradiance is high enough to enable UV curing under air, nitrogen inerting leads to important technological benefits:

- reduced energy consumption,
- reduced heat transfer to the substrate,
- no ozone production,
- reduced smell of the cured product,
- reduction of photoinitiator concentration possible,
- reduced amount of extractables from the cured product.

For most UV curing applications mature technical solutions for nitrogen inerting are now available. In particular, for curing of coatings and inks on paper and film the nitrogen consumption can be kept on a level at which the costs of nitrogen inerting are compensated by savings in power costs.

2.10 Effect of temperature

The temperature dependence of the cure speed can be described by the combined action of three effects:

- the decrease of the induction period at a rising temperature,
- the effect of temperature on the polymerisation rate and
- the decrease of the residual unsaturation at increasing temperature ⁽¹⁰⁾.

The most pronounced temperature effect is that on the duration of the induction period. If the induction period is comparable to the monomer conversion time, the temperature of the coating markedly affects the cure speed. In inerted systems the induction time is, in general, small in comparison with conversion time. Here the third point comes into play: the higher degree of cure, which can be observed at increasing temperature, means that the conversion desired for the *product to be commercial* can be reached at a shorter conversion time.

3. Estimation of the cure speed from real-time FTIR results

The following example illustrates, how the cure speed can be estimated from real-time FTIR results:

- Profile and amplitude of the irradiance created by the 308 nm excimer lamp in the product plane (200 mm below the lamp) is measured using a CUV 270 silicon carbide diode which was calibrated by chemical actinometry. If the area of the irradiance profile is kept constant, an irradiation interval Δx and an averaged irradiance I_m can be assumed as 5 cm and 200 mWcm^{-2} , respectively. Power and geometry of the excimer irradiator entirely correspond to an industrial excimer lamp unit for web offset printing (see Figure 12).

Assuming that 30 ms two-lamp exposure provides the desired degree of cure and that an increase in irradiance by a factor of 4 (from 50 to 200 mWcm⁻²) leads to half of the exposure time, the maximum product speed is estimated as

$$V_{\max} = \Delta x / \Delta t_{\text{exp}} = 0.05 / 0.015 = 3.3 \text{ ms}^{-1} = 200 \text{ mmin}^{-1}. \quad (6)$$

In practice, using the same ink and UV curing unit as shown in Figure 12 a product speed of 300 m/min is obtained. There are mainly two effects which prevent a better simulation of practical cure speeds: the uncertainties imposed by small ink thickness differences and the photochemical dark reaction.

Especially for fast running curing processes, it is that dark reaction which mainly provides conversion.

Hence, to obtaining a high cure efficiency also means to create conditions for an effective dark reaction.

4. Excimer UV curing in web offset

4.1 General experimental conditions

We report printing trials which were performed using

- a commercial web offset printing press *zirkon supra forte*
- 308nm excimer lamps manufactured by Heraeus Noblelight, Hanau, Germany
- a test printing plate made according German FOGRA recommendations
- a scale series of commercially available printing inks UX 9175 X, manufacturer Gebr.Schmidt Druckfarbenfabriken Frankfurt, Germany,
- nitrogen inerting.

4.2 Characteristics of the excimer UV source

Main characteristics of the excimer lamps used in the UV curing unit (Figure 12) are summarised in Table 2. Water-cooling of the cylindrical discharge lamp is easily accomplished by a cooling circuit feeding the UV cassettes and the power supply. Figure 13 shows the scheme of the cooling system used. The deionised water flows from the inner to the outer walls of the discharge vessel. Thus the surface temperature of the lamp becomes only slightly higher than that of the environment. Emission of convected heat is prevented.

Table 2 Characteristics of the excimer UV source used

Lamp type	Excimer lamp (Heraeus Noblelight)
Emission spectrum	Monochromatic, 308 nm
Discharge excited by	RF, about 300 kHz
Specific electrical power	50 W/cm
Maximum irradiance	200 mWcm ⁻²
Number of lamps used in the printing trials	2
Nitrogen inerting	yes
Heat transfer to substrate	no

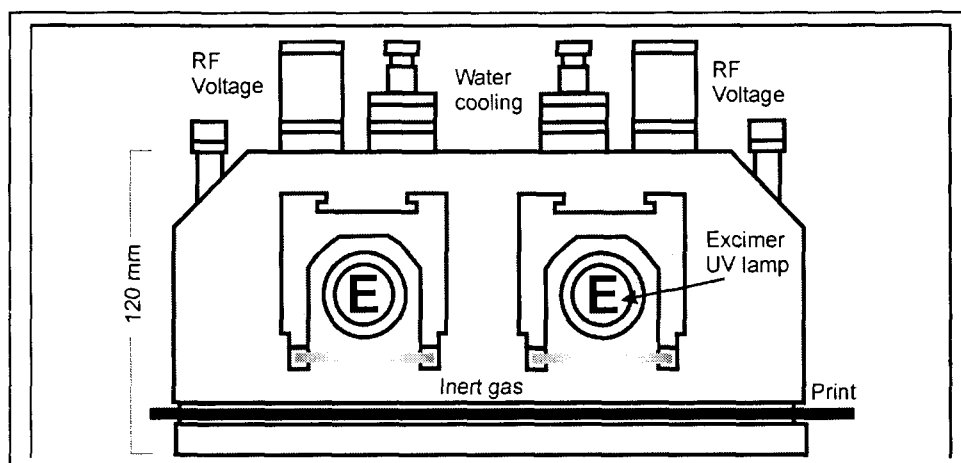


Figure 12 Inerted UV Curing Unit Consisting of Two 308 nm Excimer Lamps

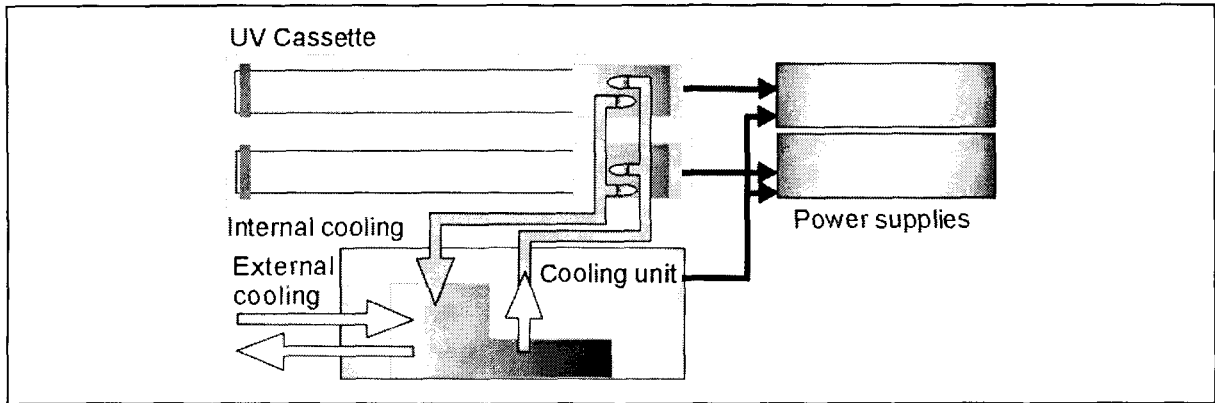


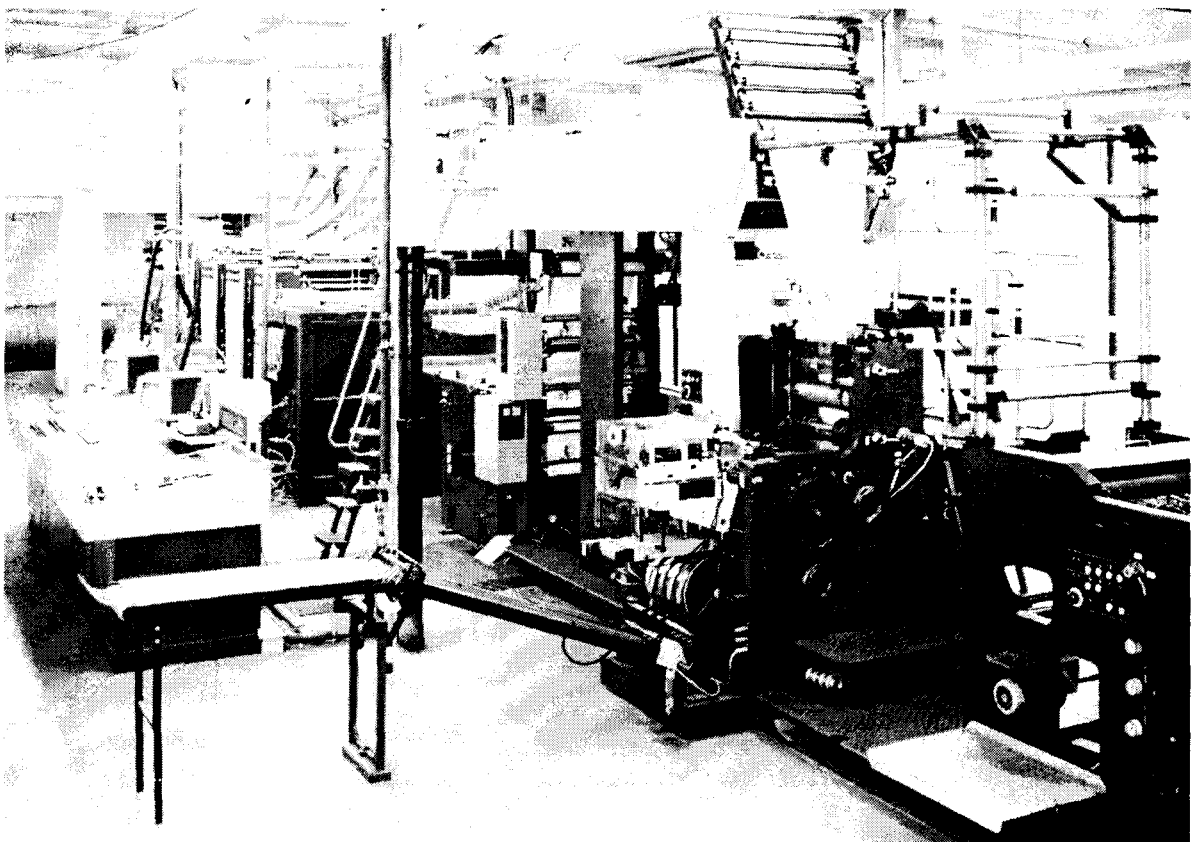
Figure 13 Heat Management in an UV Excimer Curing System

4.3 Web offset printing press

Parameter and performance characteristics of the printing press used are given in Table 3. It should be mentioned that the maximum web speed is 50.000 sheets per hour corresponding to 376 m/min. For a short time a maximum speed of 400 m/min can be obtained.

Table 3 Operation Characteristics of the Web offset printing press zirkon supra forte

Running speed, mechanical	50.000 (52.000) sheets/h
Web width, max - min	660 - 450 mm
Printing width, max	640 mm
Printing length, max	441 mm
Plate size	492 x 675 mm
Blanket size	498 x 700 mm
Number of printing units	5



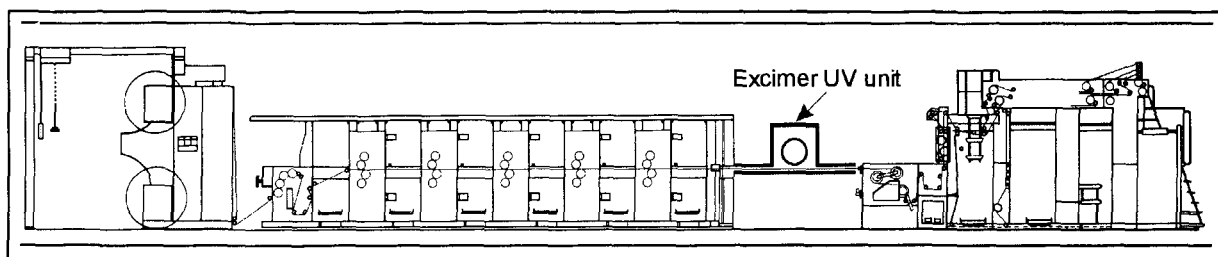


Figure 14 Web Offset Press Zirkon Supra Forte and Position of the Excimer UV Unit Within the Web Offset Press

The UV curing unit was placed behind the last printing unit, i.e., in final curing position. Especially interesting for curing test was a printed black area and a 300% ink coverage area consisting of a superposition of yellow, magenta and cyan.

4.4 Test results

Immediately after leaving the press the prints were tested by thumb twists. Curing was regarded as perfect when the colors at any area of the print could not be wiped out.

Further testing was done by determining the amount of extractables from the test prints:

An defined area from the multicolor part of the prints was extracted for 10 min with 10 ml acetonitril in an ultrasonic bath. After that time the extracted solution was analysed using reversed phase high performance liquid chromatography (HPLC - Shimadzu LC 10 with diode array detection). Calibration of HPLC peaks was done using wet inks under the same HPLC conditions. The photodiode array detector of the HPLC allowed a very sensitive detection of the residual photoinitiator content, of stable photoinitiator decomposition products and of residual monomers.

Figure 15 shows the results of the extraction tests.

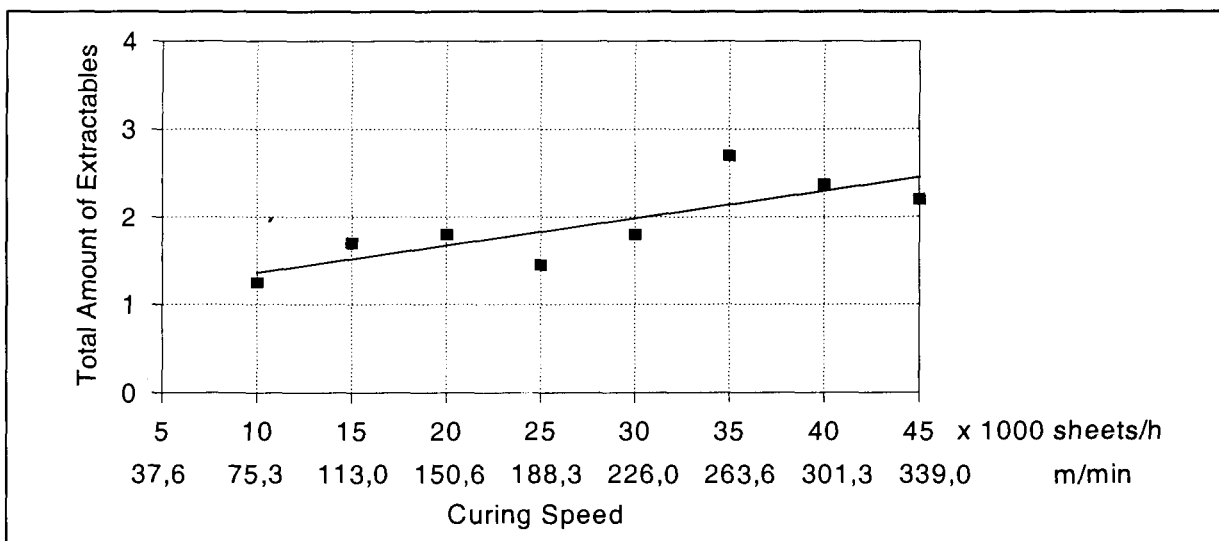


Figure 15 Total Amount of Extractables from Prints Cured under Nitrogen Two Lamp Excimer UV Curing Unit

Even at a web speed of 45.000 sheets per hour (corresponding to 339 m/min) the total amount of extractables measured was well below the limit of 5 mg per dm².

A nitrogen flow of typically 30 m³/h was applied to keep the residual oxygen concentration below 500 ppm. Under these conditions the following maximum curing speed was obtained:

300 m/min for black and 300% ink coverage

400 m/min for yellow, magenta and cyan.

In the meantime, excimer UV curing units of the type described in this paper were successfully commercialised by Heraeus Noblelight, Hanau, Germany.

Interdeck curing units are also available. Due to an improved design of the inert gas chamber, the nitrogen consumption was reduced to typically 5 m³/h per unit.

5. Excimer UV curing in sheet fed offset

5.1 General experimental conditions

We report printing trials which were performed using

- a commercial sheet fed offset press **Heidelberg GTO 52**
- 308nm excimer lamps manufactured by Heraeus Noblelight, Hanau, Germany
- a test printing plate made according German FOGRA recommendations
- a scale series of commercially available printing inks, manufacturer SICPA, Germany,
- nitrogen inerting.

Figure 16 shows the general design of the sheet fed press. The excimer UV curing unit is placed in front of the impression cylinder.

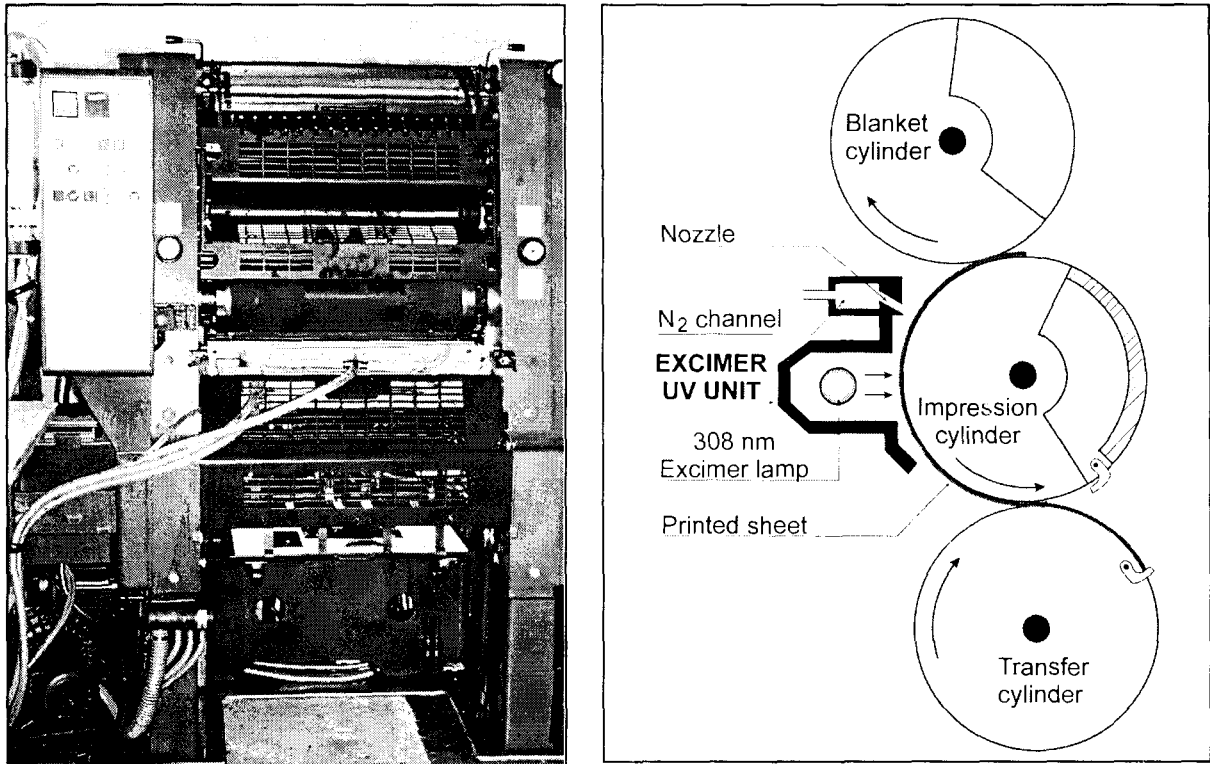


Figure 16 Sheet Fed Offset Press Heidelberg GTO 52 and Position of the Excimer UV Curing Unit

5.2 Characteristics of the excimer UV source

For the sheet fed trials a one lamp 308 nm excimer UV curing unit was used. The basic characteristics of this system are the same as given in Table 2. However, considerable changes had to be made to accomplish nitrogen blanketing of the printed sheets before curing. The impression cylinder has clamps for the sheet transport. When it is rotating air is "pumped" into the curing zone. Therefore, a special nozzle inerting system was designed in order to cover the printed surface of the sheet by nitrogen before curing⁽¹¹⁾.

5.3 The sheet fed press

Table 4 Operation Characteristics of the sheet fed printing press Heidelberg GTO 52

Running speed, mechanical	3000 - 8000 sheets/h
Sheet dimension	max. 36 x 52 cm min. 10.5 x 18 cm
Print dimension	max. 34 x 50,5 cm
Diameter of plate, blanket and impression cylinder	180 mm
Number of printing units	1

5.4 Test results

The test were performed printing black with a colour density of 1.65 – 1.75.

Immediately after leaving the press the prints were tested by thumb twists. Curing was regarded as perfect when the colours at any area of the print could not be wiped out.

The amount of extractables was determined as described above. Curing was regarded as perfect if less than 5 mg/dm² was extractable.

A nitrogen flow of typically 10 m³/h was applied.

Under these conditions a maximum curing speed of 8000 sheets per hour was obtained.

The first excimer UV curing units for sheet fed offset are now being commercialised.

6. Conclusion

The development of highly reactive offset printing inks and an improved design of nitrogen inerting units were the most important prerequisites for the successful use of 50 W/cm 308 nm excimer lamps in excimer UV curing units for printing inks which allow maximum curing speeds of

**300 m/min in web offset and
8000 sheets per hour in sheet fed offset.**

Technological benefits expected from the use of dielectric discharge driven 308 nm excimer lamps in excimer UV curing units such as

- no ozone formation,
- no heat transfer to the substrate or machine,
- no substrate decomposition,
- simple control

could all be demonstrated under real printing conditions.

However, curing speeds of 300 m/min in web offset or 8000 sheets per hour in sheet fed offset are below the maximum printing speed of fast running machines. An increase of the UV output power of the excimer lamp is the only realistic way to reach curing speeds which correspond to the fastest machine speeds in printing.

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