UV-curing inks and coatings for offset printing
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Introduction

The compelling advantages of UV printing qualify this process for a multitude of different applications. This is why it’s one of the market segments of the printing industry that is experiencing growth. The reservations of just a few years ago in respect of potential environmental and health hazards posed by printing inks, lacquers and presses have been refuted thanks to improved technologies and changes to constituent components.

What is UV radiation?

Ultraviolet radiation, or UV radiation for short, is part of natural sunlight. As a form of electromagnetic radiation, it’s in the spectral range between 100 and 380 nanometres, which is invisible to the human eye (the visible band of the spectrum is between 380 and 700 nm).

Very high-energy UV radiation has already been deployed in a great many technical applications covering an extremely wide range of sectors and industries for many years. In the printing industry, UV radiation is used to cure, that is dry, inks and lacquers. The electromagnetic radiation is generated by technical means with the aid of electrical energy, and there are numerous variants of spectral composition and methods used to generate it.

The ultraviolet component of the light spectrum is divided into three wavelength ranges that are used for different purpose in UV printing:

- **UVC radiation (200 to 280 nm)** ensures that UV inks cure almost immediately in the drying process and is employed for surface curing.
- **UVB radiation (280 to 315 nm)** has an effect that reaches deeper into the ink film. The longer-wavelength light in this range facilitates improved curing.
- **UVA radiation (315 to 380 nm)** is closest to the visible range of the electromagnetic spectrum and is capable of curing the deeper layers of highly pigmented inks and thick lacquer films.

![The natural light spectrum; in the printing industry, UV radiation is generated by technical means.](image)
Strengths of UV offset

The advantages of UV offset are manifold. The main one is the ability of the ink film to cure in a matter of seconds – facilitating on the one hand extremely fast production speeds and on the other immediate postprint finishing.

Furthermore, the actual finished print features high levels of physical and chemical stability and resistance. Complaints made about conventional sheet-fed offset prints in relation to problems such as rubbing, carboning, scratching, changes in colour due to setting or absorption into the substrate, ghosting or inadequate dot definition on uncoated papers do not arise with UV. As no or just very little anti-setoff powder is required, the print result is smooth and free of any haptic disruptions.

UV printing enables higher levels of gloss to be achieved than possible with the conventional offset process. This explains why UV inks, and particularly UV lacquers, are used as attractive design media for creating special effects in specific, small areas or even across large areas – such as matt or gloss effects and combinations of the two.

The printing ink remains absolutely fresh in the press and does not pile; nor does it form a skin in the can. That said, the ink must not be exposed to UV radiation on its path from the can to and through the press before it reaches the actual UV lamps.

In comparison with conventional offset printing, this system is extremely flexible as regards substrates and formats. The range of substrates that can be used with UV inks and lacquers includes matt- and gloss-coated papers and boards, film-laminated and metallised materials, plastic films and laminates. The formats, that is, sizes, possible range from large sheets to narrow webs.

Last but not least, sustainability aspects constitute yet another argument in favour of UV printing: depending on the configuration, it’s possible to make considerable energy and cost savings. Thanks to the use of solvent-free ink systems, the printing process remains VOC-emissions-free. When printing with iron-doped or LED UV lamps, the radiation-induced curing process does not result in any ozone emission. This has a twofold benefit: there is no need to install an extraction unit and there are no health and safety risks to workers.
**Applicability**

UV printing is used in numerous applications. UV sheet-fed is the preferred production process for packagings such as premium folding boxes for cosmetics, spirits and perfumes and for high-quality brochures, direct mail, postcards and calendars in the commercial sector. Further applications include labelling, in-mould labels, bank notes and plastic cards.

Print jobs performed using the UV web offset process include forms, direct mail, labels, flight tickets, supplements, brochures and packaging.

**Reflector systems**

**Standard UV**

**Lamps**

Until now, inks are mostly cured with the aid of mercury vapour lamps, which have a wide UV spectrum with three main wavelengths: 254, 315 and 366 nm. The lamp comprises a quartz arc tube with a fill of inert gas and mercury. The inside and the surface of the glass tube can reach very high temperatures (up to 1100°C and 900°C respectively).

For special applications such as spot inks, high-density ink films or opaque white, we are seeing increasing use of iron- (also gallium-, indium-, lead- or cobalt-) doped mercury lamps because their maximum radiation values are at different wavelengths; they have higher radiation levels in the UVA and UVB ranges. Compared with a pure mercury-filled lamp, this type of lamp emits 2.4 times more UVA radiation and therefore offers much better sub-surface curing of the ink. Moreover, as highly reactive or highly sensitive UV inks are used with this curing-unit technology, fewer UV lamps need to be installed on the press for the curing process. This reduction in power consumption is yet another benefit of this system, in addition to the significantly lower level of heat generated and the total absence of ozone emissions. These two positive ‘byproducts’ do away with any need for cooling and ozone extraction.

![Composition of a standard mercury UV lamp](image-url)
Reflectors

The design of a UV lamp has a significant influence on how an ink cures. There are three different geometric forms of reflector:

- parabolic
- elliptical
- variable

As only around 35 to 45% of a lamp’s radiation reaches the substrate directly (primary radiation), the secondary energy is redirected onto the substrate by a reflective coating. The aim is to obtain the maximum radiation output from the lamp while consuming as little energy and generating as little heat as possible. The magnitude of the radiation reflected depends on the material the reflective coating of the lamp is made of; for example, glass tends to reflect more at a wavelength of between 200 and 400 nm, while chrome reflects better from 400 nm and higher.

In the case of the reflectors, what are called "cold mirror reflectors" are now available on the market, which reflect only the UV rays and no longer the thermal radiation (IR) also generated by the lamps. This reduces the temperature to which sensitive substrates are exposed. The same effect can be achieved using 'UV cold-light lamps' that no longer generate any thermal radiation at all.

One important detail that must be taken into account in order to ensure the efficient curing of UV inks is the effective lifetime of a UV lamp. Generally speaking, a UV lamp functions without any problem for up to 4000–5000 hours, with its UV output decreasing gradually towards the end. Due to this reduction in UV radiation, inks are no longer adequately cured as the lamp reaches the end of its life. The service life of a lamp depends massively on the actual build quality of the lamp, on efficient cooling, how often the lamp is cleaned and the frequency with which it is switched on and off. We therefore recommend that users install a meter to record the number of operating hours and that they replace the lamps regularly.

LED lamps

Over the past few years, the market has also seen the dawn of LED UV curing systems for the intermediate and final drying of print applications. In contrast to the technology of conventional UV lamps based on gas discharge, LED lamps employ semiconductor electronics.

LED lamps are "monochromatic lamps", i.e. they radiate in just one specific wavelength range, starting at 365 nm and rising to 405 nm in steps of 10 nm. The matching UV ink and its photoinitiators are tuned precisely to one of these wavelength ranges.

As the diodes are very small, the LED curing units are very compact and take up little space. The diodes are arranged in arrays with different lengths and widths. Mixed mounting or separate control of two different wavelengths in the same system are possible.

LED UV has a great many advantages. The lamps are energy-efficient, consuming just a fraction of the energy a standard mercury vapour lamp does. Furthermore – like with
doped lamps – since a single lamp positioned in the delivery is enough to do the job, power consumption with this process is also much lower. Since no thermal radiation is generated and released with this technology, the need for cooling is much lower. What's more, less consideration needs to be taken of temperature-sensitive substrates; thus no registry problems can occur and pile temperatures remain low. Like with doped lamps, production results in no ozone emissions that have to be removed by an extraction system. LED lamps can be used immediately and unlike mercury vapour lamps do not require a warm-up time lasting several minutes; they can be switched on and off during production (cycled) without having to be shielded with shutters during the breaks.

<table>
<thead>
<tr>
<th></th>
<th>Standard UV</th>
<th>Iron-doped UV</th>
<th>LED UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamp lifetime</td>
<td>Approx. 1,000–5,000 h</td>
<td>Approx. 15,000–20,000 h</td>
<td></td>
</tr>
<tr>
<td>Energy consumption</td>
<td>high</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Temperature increase</td>
<td>Room temp. + &gt;20°C</td>
<td>Room temp. + 5°C</td>
<td>Room temp. + 5°C</td>
</tr>
<tr>
<td>Ozone emissions</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>high</td>
<td>low</td>
<td>low</td>
</tr>
<tr>
<td>Scope</td>
<td>Emit in UVA, UVB and UVC ranges</td>
<td>The share of radiation in the high-energy UVC range is much lower than with a standard lamp</td>
<td>Emit only in a very narrow UVA range</td>
</tr>
<tr>
<td>Application</td>
<td>Warm-up phase of several minutes; stand-by by means of shutter solution</td>
<td>Immediately ready for operation on being switched on; cyclable; zoneable</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>Lamp and reflector easy to replace</td>
<td>Not possible to replace individual diodes, just the entire unit</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>

**Fig. 7:** Radiation spectra of different types of UV lamp: top – that of a standard mercury vapour lamp; centre – that of an iron-doped mercury lamp; bottom – that of an LED lamp

**Tab. 1:** Comparison of the different types of lamps
Composition of UV ink

Vehicle

Like in conventional ink systems, the vehicle accounts for the largest share of the formulation of a UV ink. The chemical composition of the vehicle is fundamentally different from that of the vehicles used in conventional inks. In the case of the UV vehicle, we are dealing primarily with synthetic products that contain terminal acrylate groups. These react with the radicals created by the effect of the UV radiation to very quickly produce close-mesh crosslinkages. This crosslinkage forms the matrix that holds the ink film together mechanically. At the same time, it's possible to control characteristics such as flexibility and resistance in a targeted way through the choice of basic raw materials used.

UV-reactive oligomers are usually based on acrylated epoxy resins, polyesters, polyethers and polyurethanes. Oligomers have a relatively high molecular weight and a wide molecular weight distribution (between 450 and 5,000 g/mol = Dalton). The viscosity and tack of the ink, which are of crucial importance for its application, are fundamentally influenced by the oligomers. They also determine the final characteristics of the cured ink film, such as its hardness/flexibility, adhesion and scratch resistance.

These oligomers are used depending on the characteristics desired from the ink:

- **Epoxy acrylates**
  - High chemical resistance
  - Hardness
  - High viscosity
  - High reactivity

- **Polyester acrylates**
  - Low viscosity
  - Flexibility
  - Adhesion
  - Pigment wetting

- **Polyurethane acrylates**
  - High chemical resistance
  - Adhesion
  - High reactivity
  - Flexibility

- **Polyether acrylates**
  - Low viscosity
  - High reactivity

The oligomers cited above are produced in stainless-steel reaction vessels. Depending on the product, synthesis is conducted either under pressure or pressureless and at temperatures of between 160 and 230 °C. All important process parameters, such as the dosing level, temperature and pressure, are nowadays monitored, regulated and documented by a state-of-the-art process control system. These parameters are evaluated very precisely as part of development work and the scale-up process, and are standardised for the production process that follows. Quality control testing is con-
ducted using chemical/physical variables such as the acid number and hydroxyl (OH) number, the molecular weight distribution and the viscosity, to name just a few. The viscosities of some oligomers can be very high. The final viscosity is therefore often regulated using what are known as ‘monomers’. Their low viscosity is founded mainly on their lower molecular weight (<500 u) and their very narrow molecular weight distribution. The type and functionality of the monomers is very varied, which is why they are also of great importance with respect to application of and the final properties of the ink.

**Pigments**

Pigments are the solid components of the ink that give it its colour. Their characteristic colouring results from their ‘reflection and absorption spectrum’ in the visible wavelength range. However, these characteristics are also characteristic of the non-visible UV range and can therefore have a negative impact on the effectiveness of the photoinitiator.

In this context, the chromaticity point and composition of the photoinitiator must be very well coordinated. The pigment transmission curves depicted below illustrate why colour tones with a high white or black content are especially critical in respect of full curing.

**Photoinitiators**

An important functional constituent of UV-curing printing inks are the photoinitiators. These are chemical compounds that on absorbing UV light create what are called ‘radicals’, which in turn initiate polymersation (curing) in the unsaturated acrylic acid groups. Radical polymerisation takes place very rapidly, and the molecular weight rises very rapidly. The higher functional oligomers and monomers also result in close-mesh crosslinking of the ink film. This high level of reactivity is what characterises UV inks, because the print products are immediately cured right through and can be very quickly finished.

There is a very large selection of photoinitiators available. The main criterion when it comes to choosing which one to use is their absorption spectrum; this is the specific wavelength range in which a photoinitiator is capable of producing free radicals by means of a photochemical reaction.

As already described in the section above, the absorption spectra of the pigments and photoinitiators can overlap. This can significantly compromise their effectiveness.

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**Acid numbers**: Chemical variable used to determine acidic components in fats or oils.

**Hydroxyl (OH) number**: A hydroxyl group (–OH) is a functional group of the alcohols or phenols that give a molecule its polar properties. The hydroxyl number (or OH number) is the measure of the content of hydroxyl groups in organic materials such as resins, coatings or solvents.

**Molecular weight distribution (MWD)**: This describes the proportional distribution of the molecular weight of the molecules.
As mentioned, photoinitiators that absorb radiation in the higher wavelength range are always used for sub-surface curing. Surface curing on the other hand is essentially controlled by photoinitiators that absorb in the higher-energy, lower wavelength range.

The photoinitiators employed for radical polymerisation can be divided into two categories:

Type 1: The photoinitiator dissociates, i.e. breaks down, into two radicals – α-cleavage

Type 2: These photoinitiators abstract a hydrogen atom from an adjacent molecule.

One frequently talks of a ‘synergist’ that these photoinitiators require. In most cases, tertiary amines are employed as synergists.

The various UV radiation systems (standard mercury vapour lamps, iron-doped mercury lamps and LED lamps) demand different types of photoinitiator and quantities tailored to the respective spectrum.

**Additives**

Additives used include stabilisers, extenders and lubricants. Stabilisers guarantee the shelf life of the inks as long as they are stored properly (dark, dry and at room temperature). Extenders are as a rule inorganic mineral substances that are used to adjust the flow characteristics of the ink. Lubricants fulfil the same function as waxes do in a conventional offset ink.
Curing of UV inks

UV curing relies on the ‘intimate’ interaction between the UV radiation source, the constituents of the ink (photoinitiators, vehicle, pigments, additives) and the production parameters (such as the radiation intensity and press speed). In the case of UV-curing systems, we distinguish between cationic-curing and radical-curing systems. In the next section, we will focus on just the latter because they account for a much larger share of the market.

Radical polymerisation

Curing of the ink film takes place immediately downstream of the final printing unit, in the coating unit or even in-between the separate printing units. Since the ink doesn't contain any volatile components and also has extremely little time to absorb into the substrate, the thickness of the cured ink film is the same as that of the ink when applied wet. It is, therefore, a 100% system.

The actual curing process is based on a chemical reaction – known as radical polymerisation – that forms very long, three-dimensional molecular structures from the initially short linear molecule chains. The photoinitiators in the ink are activated by the UV light and break down into free radicals. These free radicals are particles that possess unpaired electrons and are consequently highly reactive. Together with the vehicle of the ink – made up of oligomers and monomers –, they form long molecular chains. The ink film solidifies in a matter of seconds.

Curing

With radical UV curing, 95% of the ink cures completely in just a fraction of a second; the rest cures within the following 24 hours. Generally speaking, a UV print product is considered to be fully cured when it is “fit for its intended purpose”; that is, when it can be further processed as scheduled (cut, folded, bound, packed, used).

The printing process and the materials used must be well coordinated in order to achieve perfect curing of the UV ink. Curing requires UV radiation of a defined wavelength range with a certain intensity per time unit.

Too little radiation energy would either leave the ink film tacky resulting in the surface being less durable or the ink could exhibit partial surface curing and poor adhesion to the substrate (→Ink adhesion). Poor resistance to solvents and mechanical stress, low surface slip, unpleasant odour (→Odour) and poor gloss are further undesirable characteristics of the print result if the degree of curing is inadequate.

However, if the crosslinking density of the ink is too high, the ink film contracts too much. An ink that is too dense is very inflexible, can become brittle or break and is almost impossible to overprint with further films of ink or lacquer. What’s more, the ink is unsuitable for special postprint finishing steps such as hot foil blocking or ther-
motransfer printing. In addition, exposure to too much radiation energy damages the substrate. It can yellow, and very thin films with a thickness of <70 – 100 µm can warp or curl.

The following parameters are important for the curing process:

- **Lamp**
  - Number of lamps
  - Quality of the lamps: they must not cast a shadow and they must be clean
  - Age of the lamps: lamp output diminishes over time
  - Temperature of the lamps: a lamp that is overcooled does not provide the necessary radiation intensity
  - Clearance between the lamps and the ink film
  - Energy output of the UV lamps: it must be coordinated with the sensitivity spectrum of the photoinitiators
- **Printing process**
  - Speed at which the material being printed passes the lamps: if the printing speed is too fast, the lamps do not have enough time to do their job
  - Cleanliness: residues of conventional vehicles and washup solutions on the rollers disrupt the curing process
- **Printing ink**
  - Opacity of the ink
  - Formulation of the ink: quantity and coordination of the photoinitiator
  - Ink/water balance: if too much ink or water is used, the ink film cannot cure
  - Ink application rate
- **Substrate**
  - Colour of the substrate: Transparent or black does not reflect
  - Material: UV radiation must not alter the material

**Measuring the radiation output/density**

To ensure that the output of a UV system remains fit for purpose and is not diminished by the lamp ageing or the system becoming covered in dust or dirt, we recommend that the pressman regularly measures the UV output of the lamps – preferably one a week. There are a number of suitable measuring systems on the market, which function using different methods.

For instance, a radiometer or a probe can be used to take measurements immediately at the UV unit, or adhesive strips can be attached to the substrate – to a sample sheet or the web – that are then analysed after printing.

In the case of measurements taken using a radiometer or adhesive strips, the distance between the UV lamp and the substrate, the geometry of the reflector and the press speed are also taken into account. When measuring using a probe, the lamp output is measured without these factors. A radiometer can only be used with machines equipped with a transport belt (e.g. finishing machines), while adhesive strips can be used with all common presses and finishing machines. Probes on the other hand can only be used on specially prepared UV units. The adhesive strips change colour depending on the intensity of the UV light they are exposed to. The degree of discoloration is measured and evaluated either using a special measuring instrument or a spectrophotometer. With each measuring method, we recommend that you carry out
a measurement with a new lamp and new reflectors that you can then use as a control against which you can compare the actual condition of the UV system at regular intervals. A threshold can be set for when it is advisable to replace the UV lamp or the reflectors or when the UV system should be serviced.

**Ink adhesion**

**Between the substrate and printing ink**

The chemical bonding forces within a fully cured UV ink are higher than the bonding forces between the ink and the substrate. Satisfactory wetting of the substrate and adhesion of the ink on the substrate is achieved by influencing the surface tension of both the ink and the substrate.

With cast-coated papers and boards, the surface tension of the substrate is low. For this reason, the ink must be specially formulated with an increased number of polar groups when working with these materials. Adequate adhesion can also be achieved by pretreating the substrate inline in the press configuration using a method known as *corona treatment*.

**Corona treatment:**

The surface to be treated is briefly exposed to a curtain of corona discharge plasma that is generated by applying a high voltage to a linear array of electrodes. Free electrons present in the air ionise and crash into the surface with great energy. At the surface, they break up the molecular bonds and generate highly reactive free radicals, which in turn react with the oxygen in the air. Various unsaturated molecules are formed on the substrate surface, which then build a chemical bond with the vehicle of the ink. Corona treatment merely modifies the surface characteristics of the material without influencing its volumetric characteristics.

Similarly, UV ink can only be applied to a film if the ink has a lower surface tension than the film. As UV ink has a surface tension of 36 to 38 mN/m, the surface tension of the film – which is sometimes lower than this – has to be increased by chemical means. This is likewise done using corona treatment.

Care must be taken when working with materials that have already previously been corona-treated, because the effects of the corona pretreatment significantly diminish over the space of a few days to weeks and inks are less able to adhere to the material. For this reason, you should always check the level of surface tension of the film using test inks or special pens before starting the print run.

**Between the printing ink and overprint lacquer**

Adhesion also plays an important role in the interaction of printing ink and overprint lacquer. A UV ink can be combined to great effect with a UV lacquer. This combination facilitates maximum gloss values. However, conventional printing inks can only
be coated with a UV lacquer if a film of primer is applied in-between. Your ink manufacturer will gladly inform and advise you regarding the interactions between printing inks, lacquers and substrates and which combination is best suited to your own particular purpose.

**Odour**

The substrate can also be the source of unwanted odours. When paper or board is exposed to UV radiation, decomposition products can give off an odour the pungency of which depends on the stock in question.

Odours can also arise from the UV lamp: oxygen is split into atomic oxygen by the interaction of short-wave ultraviolet light with a wavelength below 200 nm and air, giving rise to ozone – a gas that has a distinctively sharp, pungent smell reminiscent of chlorine.

Another source of odour can be the printing ink or overprint lacquer: the decomposition products from photoinitiators and residual monomers are volatile and organoleptically detectable.

**Migration potential of UV offset inks**

When it comes to food, confectionery and consumables packaging printed with UV-curing inks and/or lacquers, migration is a highly relevant issue (for a description of how migration occurs, see INKFORMATION brochure entitled “Printing Inks for Packaging Printing”). Several components of UV ink have low molecular weights: monomers comes in at between 250 and 430 µ and photoinitiators generally between 120 and 380 µ. These very small molecules can migrate into or through the substrate.

The migration problem can be solved by finding the right formulation for the ink. An ink that is to be used to print packaging intended for foodstuffs, confectionery or consumables must comprise migration-optimised raw materials, e.g. specially selected monomers and high-molecular photoinitiators. The molecular weight of the individual raw materials should be greater than 1,000 µ in low-migration systems.

As low-migration UV inks are manufactured under special GMP-compliant conditions, contamination during production with constituents that are susceptible to migration can be totally ruled out.
**Handling UV inks**

**Occupational health and safety**

Like other printing inks, UV inks do not contain any raw materials designated as “very toxic” (T+) or “toxic” (T) or known to be carcinogenic, mutagenic or reprotoxic. The reactive components of UV inks and lacquers, however, can cause skin irritation and allergic reactions prior to their being cured. Parts of the body that are particularly vulnerable are the mucous membranes and the nasopharyngeal cavity (nose and throat). Products that can cause skin irritation are marked Xi. These and other hazards that can be encountered when dealing with UV inks and lacquers should be counteracted by handling the products correctly and implementing appropriate occupational health and safety measures.

- Wear protective gloves made of neoprene or nitrile.
- Avoid skin contact! In case of skin contact, wash immediately with soap and water; never use a solvent.
- Use a skin care product.
- Wear protective goggles.
- Follow standard industrial hygiene rules when handling and processing chemicals, e.g. do not eat, drink or smoke.
- Install first-aid equipment, including an eye wash.
- Change soiled clothing and have it washed without delay.
- Never take work clothes home.
- Clean up any spilt ink or lacquer immediately, because it does not solidify.
- Dispose of left-over, uncured ink and lacquer and empty containers as special waste.
- Put used cleaning materials in specially marked containers and empty these containers daily.

Cured UV ink does not pose any sort of hazard whatsoever and can be handled like conventional printing inks.

**Disposal and recycling**

Recycling papers and substrates that have been printed with UV ink pose certain problems. The effectiveness with which UV inks can be removed from the substrate – a process known as “deinking” – depends on the method used. Generally speaking, UV ink can be separated from the paper by means of flotation in water. However, this process can be influenced by many different factors, and based on the information currently available, there is still work to be done before we are capable of achieving results as good as those possible when deinking conventional inks. That said, a huge amount of effort is going into researching the best method for deinking UV inks. Whether or not UV-printed waste has to be collected separately from other paper wastes in the printshop or can be disposed of together with general recovered paper from the graphics industry is governed by municipal waste disposal regulations.