The development of UV-LED curing for ink jet printing

The past five years have seen a revolution in ink jet digital printing as the development of LED ‘cold curing’ lamps for UV-cured inks has opened up a much wider range of materials that can be printed onto directly. Mimaki, a renowned and respected Japanese ink jet printer manufacturer, has been a pioneer of LED UV curing since it started development in the last decade. Here Johan Spies, Product Manager Europe, Mimaki EMEA explains the background and potential of UV-LED technology and its use in pioneering printed such as the very compact, low cost UJF-3042 flatbed printer.
Inks that are cured by exposure to ultra violet (UV) light have long been used in the graphic arts, for applications ranging from packaging through to industrial processes, using ‘conventional’ analogue processes including lithography, screen process and flexography.
It took some time for UV curing to appear on digital processes, but the first inkjets to use UV cured inks appeared around 2001. The process was quickly accepted in the sign and display sector because it can be used on such a wide variety of media, with fast curing, little odour and fewer health and environmental issues than solvent based inks. With the latest enhancement of UV-LED lamps, this digital process is expanding its applications even further, especially for industrial use.

Why UV curing?
UV cured ink has long been attractive to printers because of its near-instant drying properties plus the ability to adhere to a wide range of papers and plastics. In addition it has environmentally attractive qualities, especially its lack of emission of volatile organic compounds (VOC). Unlike water or solvent based inks, there is no need to evaporate a large fluid component in order to dry the ink, which both saves on heat energy and means that UV-cured ink is less bulky, which saves on transport and storage requirements.
Originally, metal-halide (MH) lamps were commonly used to cure UV inks. However, these lamps have several problems, such as large calorific value (meaning heavy energy requirements), a short lifespan of 500–1000 hours, the difficulty of turning the lamp on or off, and control of its luminous energy.
Therefore in 2006, Mimaki started the product development of an ink jet printer in which light emitting diodes that emit UV light are used to cure the ink. These UV-LEDs are relatively inexpensive and have long lives compared to MH lamps. They have low energy requirements and can be switched on and off almost instantly. In addition they run much cooler than MH lamps, making it possible to print on a much wider range of potentially heat-sensitive media without distortion.
At the drupa 2008 print show Mimaki announced the launching of our UJV-160, the first LED cured wide format ink jet of its kind in the world. Three years later in 2009, the company introduced a large flatbed LED-UV ink jet printer, the JFX-1631. Additionally, in 2010, Mimaki started the production of UJF-3042, an inexpensive, very compact A3 format flatbed printer. Thanks to its LED curing it is both energy-conservative and able to print on a wide range of materials from plastic instrument panel inserts and wood signage, through to three-dimensional objects such as pens and golf balls.

In this paper we explain the primary technological advancements that were developed for the commercialization of the LED-UV ink jet printers and leading to the development of UJV-3042. We also look to the future for this technology and its expanding applications.

Advantages of UV ink jet printer

Among the reasons for the popularity of UV ink jets are:

1. Excellent media compatibility
UV ink jets can print directly on to various media such as plastic, metal or glass, usually without any special ink-receptive coatings. This is particularly important for industrial printing applications.

2. Functional dissociation-type ink
Until it is exposed to ultra violet light the ink remains as a UV monomer. This means that it remains a liquid with low viscosity. It is a stable liquid within the print head, with little risk of blockages. On the other hand, after it is jetted onto the media the ink is solidified almost immediately by UV photo-irradiation (exposure). The UV light starts to convert the unlinked liquid monomer molecules into a polymer where the molecules rapidly become linked and

tangled to increase viscosity (which stops the ink spreading and blurring the image on the media), and consequently cure completely as a near-solid layer.

The practical result is that the printer can directly and clearly print onto wide range of media without any special coating layers.

In technical terms, this ink is capable of functional dissociation that can satisfy the demands of the low viscosity required for the discharge inside the printer head as well as the high viscosity required to avoid blurring once the ink gets on the media, by controlling UV photo-irradiation.

3. Formation of strong high polymer film

For aqueous ink or solvent inks a resin with relatively small molecular weight of less than 10,000 is normally used as a binder. The fixation of those types of ink is usually conducted by just drying and does not involve any polymerization reactions. Drying takes time, carrying the risk of the ink droplets spreading and blurring the image somewhat before being fixed. The resin remains somewhat soluble in either solvent or water even after printing and drying. By contrast, once a UV ink is applied to the media and exposed to UV light, it starts a polymerization reaction that stops blurring by increasing the viscosity. After the ink is completely cured, the process forms strong high polymer films with high molecular weight. Also, depending on the selection of the polymerized monomer, it's possible to create printed films with different degrees of softness, quality, adhesion and release properties.

4. Layered printing

Once an ink has been UV cured, there is no risk of later blurring or dissolving, even if additional ink is applied on top. This means it's possible to build up multiple layers of ink to produce raised or textured effects, or for Braille printing. It also allows the application of a white layer over or under the coloured inks to act as an undercoat on dark surfaces or a diffusion layer on clear media for backlit graphics. Likewise a clear UV cured ink can be applied over coloured inks either as a protective layer or to give effects such as gloss or matt overall or patterned finishes.

5. User- and environmentally-friendly

Because the ink does not contain any volatile solvents, it eliminates the environmental issues of volatile organic compounds (VOCs), which are increasingly subject to legal restrictions, including the protection of operators against the dangers of inhaling solvent vapors. Some solvent inks still give out a heavy odor for some time after drying, which is not hazardous but many people find it unpleasant, so it restricts the use of such print for indoor use such as POS. However, using UV inks does still require some caution, as there is a small amount of odor that can occur during the curing process with a photo-curing initiator, so extraction and/or activated carbon filtering is advised. Operators must be protected from contacting unreacted liquid monomer prior to UV curing, as this can trigger allergies. This can largely be achieved by careful design of ink containers or cartridges.

With MH lamps there is an issue of ozone being generated from the reaction of particular UV wavelengths with atmospheric oxygen. This needs to be extracted as it is an irritant to human operators. However, UV-LEDs emit different wavelengths and energies, so ozone is not a problem

Development of the UV-LED ink jet printer

This section explains the primary development steps that led to the commercialization of the LED-UV cured ink jet printer. In particular we look at the development of the compact low cost UJF-3042 and present case studies on its use for various digital printing applications.

1. Background of the invention

It was around the end of year 2003 when Mimaki came up with the idea of the UV-LED usage. At that time, the development of high power UV-LEDs had only just started and the UV output was still small. At the time, the price was about 500,000 yen for every Watt of UV output (about 4,700 Euros in 2013 prices).

Furthermore, since the radical polymerization-type ink would often incur curing errors due to oxygen obstruction while being slowly cured under weak UV light, at that time it was feared that the original low-output UV-LEDs would not be suitable for curing ink. However, the subsequent development of two key technologies allowed the development of commercially viable UV-LED printers. One was the appearance of high output UV light emitting diodes. The other was the formulation of high-sensitivity ink that is tuned to respond to the emission wavelength range of such UV-LEDs.

At the start of development the maximum output per UV-LED was only a few milliwatts (mW) to a few dozen mW. The output is presently increased to about dozens of Watts or more even under air-cooled conditions with the UV-LED module, where several chips are installed. Thus, it became possible to instantly cure UV ink.

If a traditional UV cured ink intended for metal-halide lamp curing is used with UV-LEDs, the light energy for a complete cure needs to be several thousand mJ/cm2 or more, which is not practical for commercial use. This is because the absorption wavelength of UV ink made for the MH lamp is different to the luminous wavelength emitted by the UV-LED.

With the development of inks tuned for UV-LED emissions, it became possible to completely cure the ink by using only about 100-300 mJ/cm2 of light energy. Once these technical solutions became available, the development of the LED-UV cured Mimaki UJV-160 printer was started in 2006. The original high cost of UV-LEDs has been reduced by mass production in recent years. So the UV-LED technology is not only superior to MH lamps, but the cost is now less.

2. UV-LED unit

Fig.1 shows a structural drawing of a UV-LED unit used in the Mimaki UJV-160. (a) is the printer's front cross sectional view. (b) is the side view, and there is a cooling fan attached to one side of the unit.

Fig.1 Composition of the UV-LED Unit

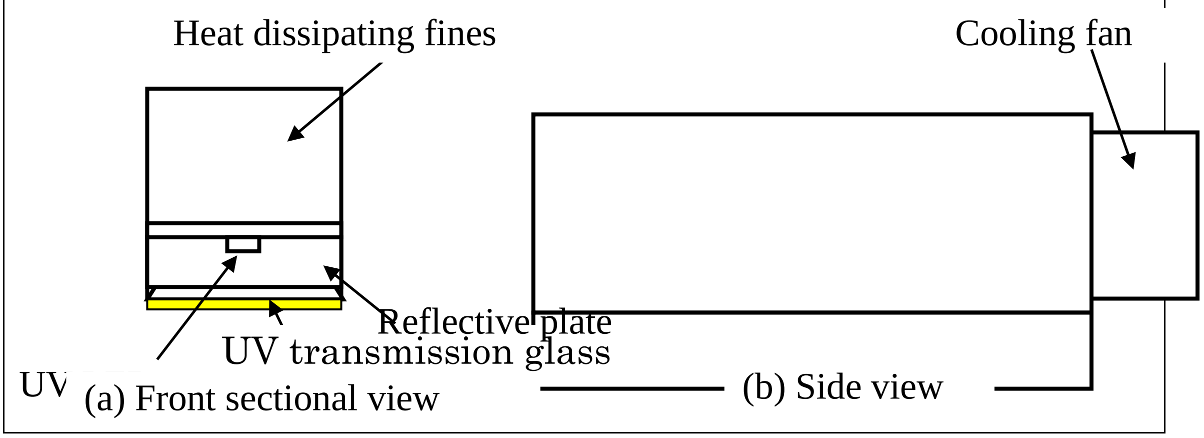
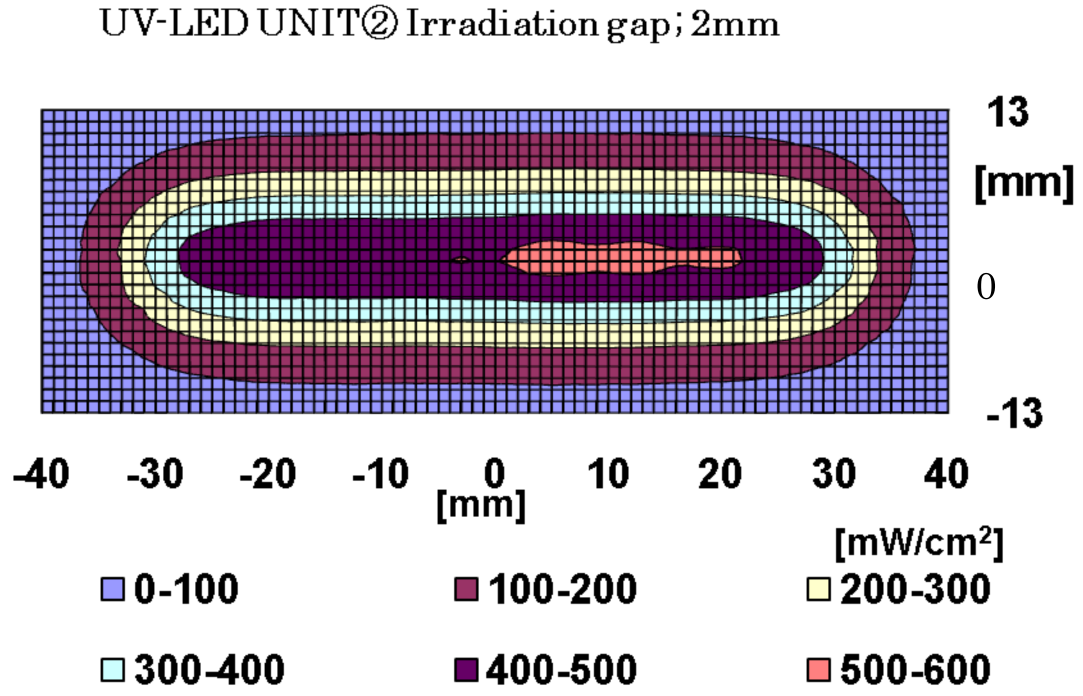


Fig.2 indicates the distribution of the UV light intensity at a position 2mm directly below the UV-LED unit. As seen in the distribution, irradiation intensity of over 300-400 mW/cm2 was obtained in a slit of about 60x10 mm. The width covers the ink jet head, which is about 50mm.

Fig.2 The distribution of the irradiation light intensity at a position of 2 mm from the UV-LED unit.

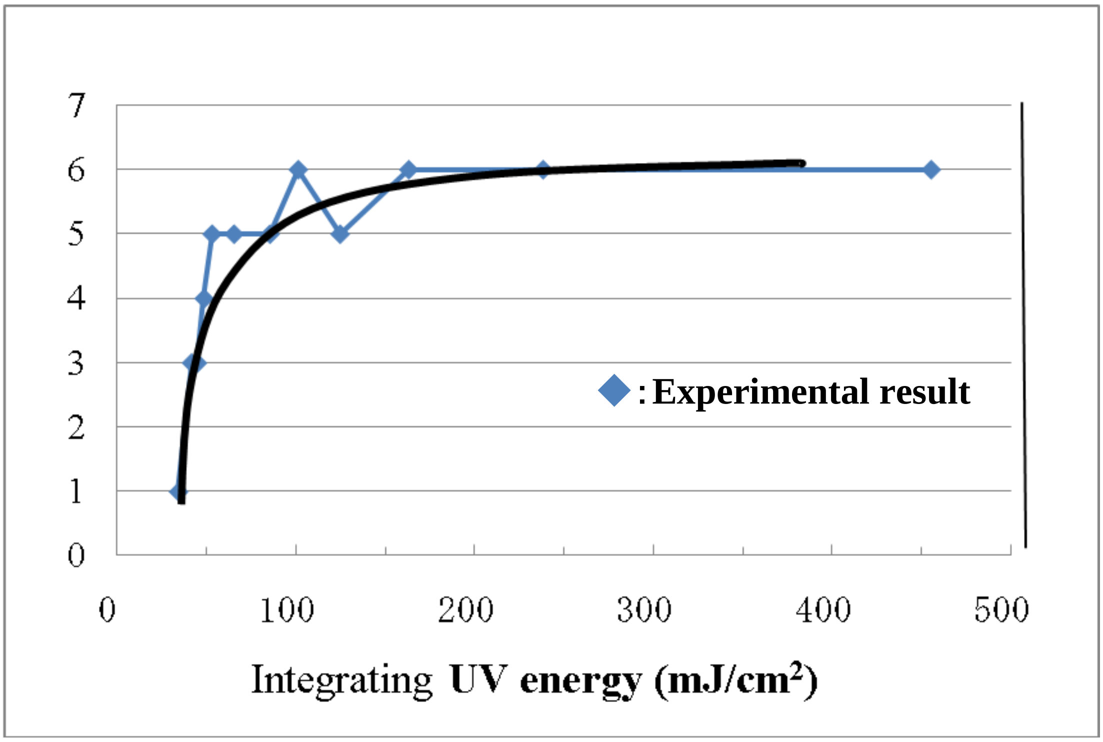


3. High-sensitivity ink for UV-LED use

Traditional UV cured ink was designed to be cured efficiently under UV light with short wavelengths of less than 350nm, suited for MH lamps. When the generic UV ink was cured under UV-LED with longer wavelengths of 365-400nm, several thousand mJ/cm2 of energy was required because the UV ink could not effectively absorb the UV-LED light.

Fig.3 shows the hardening sensitivity characteristics of high-sensitivity ink for UV-LED, which is a newly developed radical polymerization-type ink.

Fig.3 The hardening sensitivity characteristic of the high sensitivity ink for UV-LED



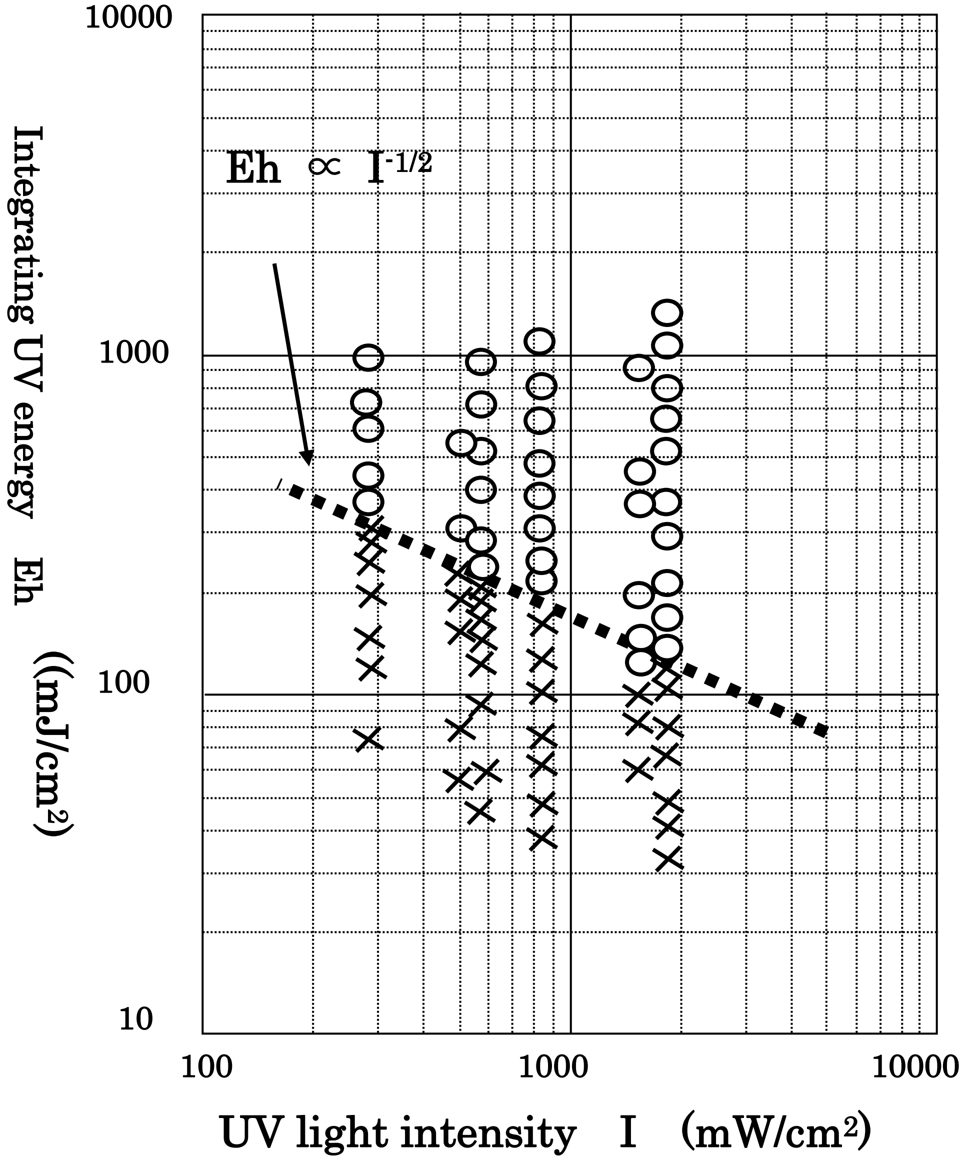
The hardening sensitivity was evaluated by a pencil hardness test. It was found that the ink could be completely cured by UV-LED light energy of about 150m J/cm2. The emission wavelength was 380nm. A sensitizer with about 350-390nm absorption capability was added to the ink.

It is known that the following relation exists between radical polymerization's reaction velocity V and irradiation light intensity I 3).

$$V \propto I^{1/2} \qquad (1)$$

Fig.4 shows the amount of UV energy necessary for a complete cure, depending on various UV-LED light intensity I. The result shows the characteristics of a typical radical polymerization-type ink. Namely, as the UV light intensity I increases according to I to the power of -1/2, the UV energy Eh required for the cure goes down and the sensitivity goes up. Since UV-LED, which has strong directivity, can easily concentrate lights, radical polymerization-type ink that has characteristics similar to what is shown in Fig.4 is suitable for the high-speed cure by UV-LED, which has excellent light-harvesting capability. The ink used for the measurement is LH-100.

Fig.4 Relation between UV energy required to curing and UV light intensity. ○ ; Hardening , × ; No hardening or imperfect hardening.



Furthermore, a UV-LED with wavelengths that enable less absorption by pigments added to the ink was chosen, in order to obtain high-sensitivity and sufficiently cure not only the surface but also the inside.

As seen from Fig. 3, it was found that the LED-UV cured ink developed under the above concepts could be completely cured through UV-LED photoirradiation with about 150mJ/ cm2 of integrating light energy.

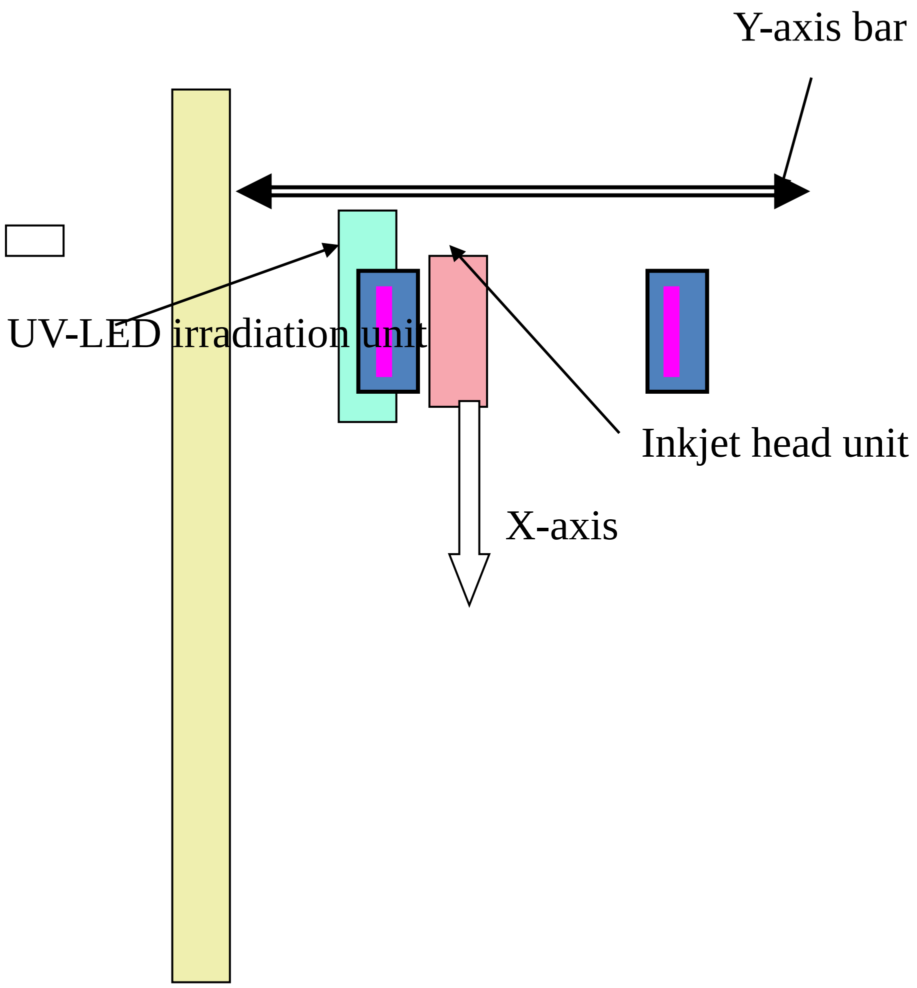
4. Structure and advantages of LED-UV ink jet printer

1. Structure of UV-LED printer

Fig.5 shows the basic structure of a UV ink jet printer. In order to be able to do bi-directional printing, a UV-LED lamp unit is placed on each side of the ink jet head, which travels sideways along the Y-axis. The media are transported in the direction of X-axis.

For single-directional printing, it is only necessary to use the lamps on the trailing side of the head direction, i.e. after the inks are applied.

Fig.5 Arrangement of inkjet print head and UV-LED irradiation units in the UV-LED inkjet printer.



2. Advantages of UV-LED printers

Compared to traditional UV ink jet printers using MH lamps, LED-UV printers have the following advantages:

2. 1. Low power consumption

The UV-LED unit in Fig. 1 consumes about 60W of electricity solely for the UV-LED of the module. It also consumes approximately additional 20W for the cooling fan and the output control circuit, etc. Thus, the total power dissipation by the UV-LED unit is about 80W. Also, the total emission of UV light energy from the unit is about 10W. Meanwhile, the total power consumption of the traditional MH lamp is about 1.2KW/lamp. Solely comparing the exposure system, the power consumption of MH lamp is about 15 times as much as the UV-LED curing system. In addition, because UV-LED is capable of instantly switching on and off the light output, printers only need to switch them on during the actual printing cycle. On the other hand, once it has been turned off, a MH lamp cannot be turned on again until the lamp cools down. Thus, it is generally left on constantly while the printer is in use. This makes the difference of actual power consumption between UV-LED and MH lamp even bigger. At a 50% operation rate, solely comparing the exposure system, a MH lamp on average consumes over 30 times as much electricity as UV-LED.

Furthermore, during continuous printing, there is a non-printing overrun area at both sides of the ink jet printer to slow down and reaccelerate after reversing the printing direction. Because UV-LED printers can immediately turn off the UV-LED once it passes the printing area, the difference of the power consumption would be further enlarged.

In reality, both types of printers have common elements such as media transportation motor, electric circuit, and the ink supply system. So the actual difference of power consumption of the entire printer would be a little bit smaller. Comparing both types of printers that operate at an identical speed, the printer with a MH lamp consumes three to ten times as much electricity as the one with UV-LED.

2.2. Miniaturization
Since a MH lamp consumes a lot of energy, it needs a powerful cooling fan or cooling fins to prevent overheating. For that reason, a MH lamp housing has to be big. Also, the lighting power source has to have high capacity, which inevitably makes it bigger.
UV-LEDs are physically small so can be made into compact arrays. Because they are energy efficient, they do not need major cooling or large housings.
In addition, because UV-LEDs do not generate hazardous ozone, only a little ventilation is needed, to eliminate odor during the ink cure. Thus, the ventilation system can also be downsized.
Using UV-LED as the light source for curing means the overall size of the printer can be smaller than a printer using a MH lamp.

2.3. Long service life
The lamp life of a MH lamp is normally considered to be about 1000 hours if measured up to the time of 30% light reduction. For instance, with 1000 hours service life, if the lamp operates for 8 hours a day, it will have to be replaced in 125 days (about 6 months with 20 operation days/month).
The service life of a single chip with UV-LED is about 10,000–15,000 hours depending on the heat dissipation. If a UV-LED operates for 8 hours a day, with 10,000 hours service life, it lasts for 1,250 days (about 5 years with 250 operation days/year). Furthermore, since UV-LED is turned off in non-printing mode during the uptime, the actual service life would be longer. It’s likely that most UV-LEDs would never need replacement during the service life of the printer.

2.4. Freely adjustable light volume
Inside the discharge tube of a MH lamp the electric current must be kept above a fixed value in order to maintain the discharge. This restricts the amount of dimming control available. Because ink jet printers can vary in speed by two to four times, some sort of dimmer control is necessary to maintain a constant cure regardless of the printing mode.
With UV-LED, the light volume can be constantly controlled between zero and the maximum rated output, either by varying the current or selectively switching or pulsing the individual LEDs. Thus, UV-LED can set the optimal light volume for irradiation depending on the printing mode.

2.5. No overheating of media
With the traditional MH lamp, the glass surface of the lamp gets extremely hot. Furthermore, not only UV light but also excessive visible light, infrared light and far-infrared radiation are emitted, to the point that some types of media can be overheated and distort.
With UV-LED, the temperature of the UV-LED chip itself barely goes up. In addition, only UV light that has its peak at 365-390nm is emitted. Printers using UV-LED can be used with media that are vulnerable to heat with MH lamps.

2.6. Ozone-free
UV-LED does not contain any UV lights with the short wavelength components of less than 280nm that belong to UV-C, which cause ozone generation. Therefore, UV-LED does not generate ozone. For that reason, there is no need to arrange a special ventilation to eliminate ozone.

--- END ---

About Mimaki

Mimaki is a leading manufacturer of wide-format inkjet printers and cutting machines for the sign/graphics, industrial and textile/apparel markets. Mimaki develops the complete product range for each group; hardware, software and the associated consumable items, such as inks and cutting blades. Mimaki excels in offering innovative, high quality and high reliability products, based upon its aqueous, solvent and UV-curable inkjet technology. In order to meet a wide range of applications in the market, Mimaki pursues the development of advanced on-demand digital printing solutions. Mimaki Engineering Co. Ltd., (President: Mikio Noguchi) Nagano (Japan), is publicly listed on the JASDAQ Securities Exchange, Inc.

Contact details:

Ivan Lesmana, Marketing Communications, Mimaki Europe B.V.,
Tel. +31 20 462 76 42, E-mail: i.lesmana@mimakieurope.com

Mike Horsten, Marketing Manager, Mimaki Europe B.V.,
Tel. +31 20 462 76 42, E-mail: m.horsten@mimakieurope.com

Press contact:

Maya Staels, duomedia
Tel. +32 487 98 21 61, E-mail: maya.s@duomedia.com