SGIA
Screenprinting & Graphic Imaging Association International

The Theory and Practice of UV Screen Printing

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Michel is one of the "founding fathers" of FESPA (Federation of European Screen Printers Associations) and he is an Associate Member of the Academy of Screen Printing Technology. He is responsible for technical advancements in the area of UV technology and inks, fine line half-tone printing, continuous tone printing, superpositions of transparent inks, and textile printing.

Introduction

Over the last few years, several screen printers and users of screen technology have had to face a difficult problem, considering the evolution of screen printing technology and limitations on the use of solvent inks in certain countries (including restrictions that will come very soon), as well as the limitations of UV technology: Should we invest in UV systems?

This decision implies different economic, technical and industrial considerations, but the basic problem is to find out if the UV option is commercially and qualitatively a good one. To do so we have to first understand:

- What UV is
- Whether we should choose or reject this technique
- What this choice means to a screen printing shop with regard to equipment, technology and the production of screens, artwork, etc.

As happens with every new feature in our industry, the coming of UV has triggered discussions and opinions for or against the various UV methods. Anything that disturbs the routine engenders suspicion, distrust, apprehension and even hostility—but mostly a lot of false ideas. Now 20 years later we find again, in new terms, the dissension which once prevailed concerning "jet air dryers". A colossal amount of articles in professional reviews, books, reports, seminars and discussions have cropped up on both sides of the Atlantic since 1973. Ink and curing unit manufacturers have published "technical handbooks" (more or less valuable) attempting to demonstrate—naturally—that their products and technology are the best for UV applications.

How can the screen printer—the first person concerned with the problem—find his own way in this confusion, and discover the best approach to the UV problem?

The purpose of this article is to review the different theoretical (and above all, practical) problems and to help:

- on one hand, the undecided screen printers to make a decision regarding UV, and
- on the other hand, those already using UV technology to achieve the best profit and quality possible.

Outside of any other considerations, we know that the choice of UV technology entails a few modifications. It does not seem wise for a screen printer, who is supposed to know his job, to instantly turn against the ink or curing unit manufacturer when the expected result is not achieved. Nor is it wise for the ink manufacturer to say "That is the curing unit's fault," or vice versa. More than the inks or the curing unit, the problem many times is due to the technology employed by the screen printer. And more so than with the use of other screen techniques, a certain amount of theoretical knowledge is very necessary with UV technology.

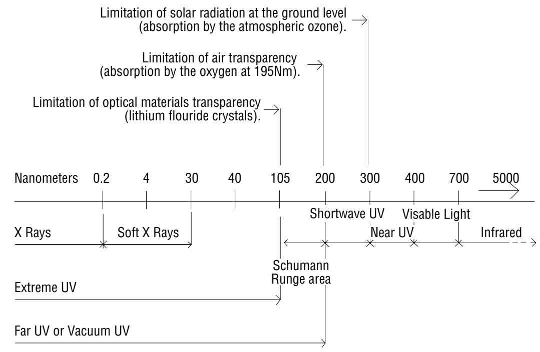
What is UV Printing?

For screen printing, as well as for lithography and flexography in some of their applications, the UV process employs a specially formulated ink, which dries **only** under a source of ultraviolet radiation; the UV dryer can **only** cure a UV ink. This obligatory connection is, for the screen printer, a relatively new idea. To understand the importance of it, let us examine how the "classical" inks—solvent inks—dry in screen printing. Most of the time, those inks dry through the **evaporation of solvents** included in the "wet" condition. The drying speed is a function of different factors: The speed of evaporation of the solvents used; the eventual addition of heat; the speed of air moving at the surface of the ink coat; the thickness of the ink deposit, etc.

In certain more unusual cases, this drying principle is achieved by a reaction of polymerization, either through oxidation (with the glycerophtalic inks) or through catalysis (with the "two-components" inks). With the UV inks (inks without solvents), the "drying" principle is **only a reaction of polymerization.** But this is a very peculiar type of reaction, a phenomenon of "photo-catalysis" or "photo-polymerization" similar in principle to the reaction of hardening direct emulsions used for stencil making.

In other words, we can say that specially formulated inks are peculiarly sensitive to—or absorbent of—a form of radiant energy (emitted in the length of waves named "ultraviolet") and this induces a change of condition—drying—which occurs very quickly. But classical drying is a change of condition based on evaporation; with UV inks, there is no evaporation and, consequently, no "drying." We will therefore speak

Figure 1



Place of UV on the Maxwell Scale

of "polymerization" and of "curing units."

The Theory of UV

UV radiation is, like visible light or the infrared, a form of energy in the electromagnetic spectrum. Actually, all electromagnetic radiations simply represent the different manifestations of a unique phenomenon: The emission of photons. In the theory defined many years ago by Hertz and Maxwell (see Figure 1), radiations differ only through their lengths of wave; that is to say, the "distance" between the highest peaks of their profile of emission, their amplitude of oscillation.

On the Maxwell scale, starting from the shortest radiation and going to the longest, we will find gamma rays (from 0.005 to 0.25 angstroms), X rays (to 0.001 micron), the ultraviolet (from 0.002 to 0.4 microns), visible light (from 0.4 to 0.7 microns), the infrared (from 0.8 to 300 microns), and the radio waves: Short waves (from 30 to 1,600 cycles/second), medium waves (530 to 1,610 kilocycles) and the FM (from 54 to 108 megacycles). Ultraviolet's length of wave takes place between 20 and 400 ten-thousandths of a micron, the micron being itself a thousandth of a millimeter. In order to have a simpler unit to work with, we will use the Nanometer (Nm) which represents 10^{-7}cm, or 10 Angstroms. The really interesting part of UV radiation is located between 200 and 400 nanometers, the "near UV." It takes place just before the visible lightwaves (400 to 700 Nm). But in reality the phenomena having an influence on the behavior of UV inks inscribe themselves in a much more important area of radiation because, taking into account the parasitic radiation emitted by the UV lamps, we must consider (to different degrees) radiation included between 100 and 5,000 Nm:

- 100 to 200 Nm: far UV
- 200 to 300 Nm: medium UV
- 300 to 400 Nm: near UV
- 400 to 700 Nm: visible light
- 700 to 5,000 Nm: infrared.

Despite this fact, the most effective radiations reacting on the photoinitiators included in the UV inks are located between 200 and 270 Nm. Let us also notice that waves between 170 and 210 Nm are the ones producing ozone. This production of ozone, of which we will speak later, characterizes the majority of UV lamps.

UV Radiation: How Does It Work?

In order to understand, it is first necessary to know the composition of UV ink. The easiest way is to take as your starting point something we are familiar with: The solvent inks. Without getting too detailed, we can say that these inks are generally composed of a synthetic resin, in the body of which are mixed colored pigments—the whole being diluted by a high percentage (from 50% to 70%) of solvents. The drying of these inks is a change of condition—the conversion from a liquid to a solid—via a loss of solvents disappearing through natural or forced evaporation with (or without) the addition of heat. This happens with 95% of the inks.

Sometimes this type of drying is completed by a more complex reaction of polymerization (formation of molecular chains), by "fusion" with the substrate (e.g., enamels for glass or ceramics), or by "absorption" (in textile printing with dyes). UV inks consist of oligomers (urethane polyesters and epoxy polyesters, but mostly acrylated polyesters); very liquid monomers (generally acrylates) as "dilution agents" for diminishing the viscosity; pigments for the color; various additives, (stabilizers, thixotropic agents, correctors of surface tension, etc.) and photoinitiators. This last element is very important because it produces the change of condition; in other words the transformation of the liquid (unstable) oligomers and monomers into solid (stable) polymers—"dry" in the sense we consider it.

Action and Effect of Photoinitiators

A photo initiator is a chemical component that absorbs the energy emitted by a source of ultraviolet radiation in different lengths of waves—mostly the energy emitted between 200 and 270 Nm. Under the impact of that radiation, the photo initiator splits and invokes the formation of very unstable free radicals—unsaturated molecules keeping only one electron—which attack the unchained oligomers and monomers, transforming them into a solid, three-dimensional network of stable polymers. This makes the UV ink insoluble in solvents and insensitive to a thermoplastic softening. This reaction spreads in chain at a very high speed (See Figure 2).

Contrary to what happens with the classical solvent inks, this transformation is a "change of condition" without any loss of material.

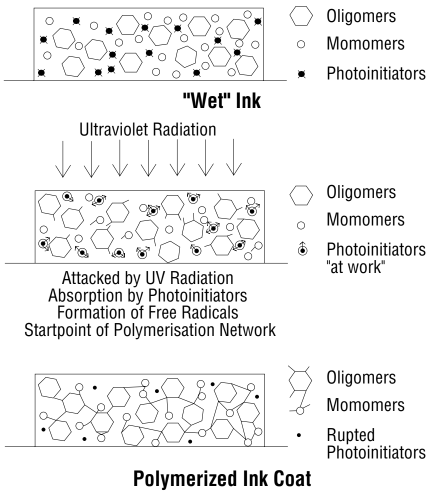
Photoinitiators, then, absorb the UV energy. To do this, they must react to the appropriate length of wave of the emitted radiation. They are very complex substances but, without revealing manufacturers' secrets, we can say that photoinitiators can be classified in three groups: The A group (for example, ethyl 4, dimethylamino benzoic acid esters or the most famous, benzophenone)

The B group (such as acetone ethyl)

The C group (such as 2 ethyl-anthraquinone or 2 chlorothioxan-thenone)

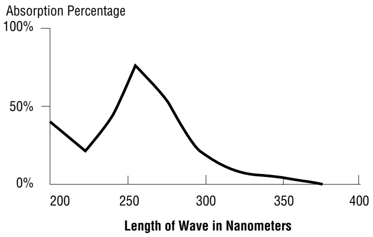
Figures 3 and 4 show the absorption characteristics of two of them, which permits us to see

Figure 2



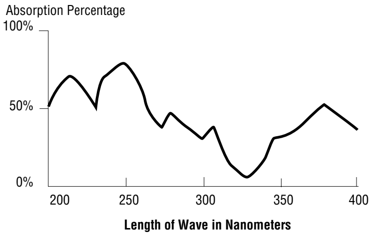
Ink reaction under UV radiation

Figure 3



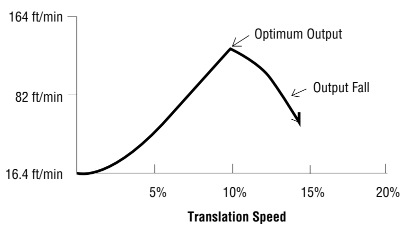
Output of benzophenone

Figure 4



Output of chlorothioxanthenone

Figure 5



Percentage of photoinitiator concentration

immediately to which length of wave they are receptive.

It is interesting to note that a certain form of competition can exist in the absorption of UV-efficient radiation between the photoinitiators and other components of UV inks. Certain pigments are peculiarly receptive to the same length of wave, and sometimes certain monomers are, too. This competition to absorb a very precise range of the emitted spectrum can sometimes delay or retard the polymerization reaction. But contrary to many false ideas, this slackening cannot exceed 10% to 15% of the entire time of reaction.

Their percentage of concentration is very important. The proportion between the mass of oligomers, monomers and even pigments plays a primary role. As a matter of fact, a saturation point of the concentration of photoinitiators exists that must never be exceeded. The addition of supplementary photoinitiators does not increase the speed of reaction, and can even slow it. Generally speaking, the reaction speed of UV ink is proportional to the square root of the concentration of photoinitiators. This means, in theory, that to double the reaction speed (stabilization = “drying”), one must multiply by four the concentration of photoinitiators. This principle is valuable for the lower range of photo initiator concentrations; as soon as the maximum point of concentration is exceeded, the curing reaction retards itself (Figure 5).

If you take into account the other incidental factors, such as the concentration and the absorption relative to different pigments and the effects of complementary agents, additives, etc., you will find that very precise dosing of photoinitiators in quantity and quality is a very delicate matter.

In my opinion, this necessity makes very implausible the precise dosing of this concentration by the user himself, as can happen with some American UV inks. Dosing a solvent with a thinner or a retarder can be done by any screen printer; to dose a percentage of photo initiator exceeds the capacities of 95% of them!

The theoretical knowledge possessed by the screen printer about applied physics does not allow him to make a choice between several types of photoinitiators to find the one with the optimum absorption of a specific length of wave which will prevent the competition with certain pigments or other components of the UV ink. This requires measuring equipment and research which are not practical and may even be undesirable for the screen printer. Once again, this is the role of the UV ink manufacturers. They must assume it and try to avoid any empiricism.

The “Center of Reaction”

The center or sphere of reaction is the physico-chemical space in which this reaction occurs. Has this atmosphere any influence on the photopolymerization reaction which interests us? Here, there is a debate held, mostly in North America, concerning:

- the reaction in a partially active atmosphere; chemically speaking this means in ambient air which contains 18% oxygen (active), 81% of nitrogen (inert) and 1% rare gases, and
- the reaction in totally inert atmosphere, 100% nitrogen; this colorless, odorless and insipid gas constitutes, as we know, the principal component in mass (although inactive) of the air we breathe.

The “inert atmosphere” position in this matter is based on the fact that certain photoinitiators discharge free radicals which can be activated by the oxygen in the air, which then slows or even inhibits the reaction of polymerization. This factor is called “oxygen inhibition;” it seems to be caused by the “oxygen component” of the air concentrating at the level of the ink-coated surface and burning a good part of the photoinitiators before they are able to “do their job” on the mass of oligomers and monomers.

Inert atmosphere system advantages are:

- increase in the curing speed;
- increase in the degree of molecular cohesion of the obtained polymer, from which is effected:
- a higher gloss effect of the ink; and
- an increase in hardness and shock resistance of the ink coat. The disadvantages are more or less corollaries of the above advantages:
- risks of “overcuring effects;”
- poor adhesion to the substrate;
- a lack of flexibility—this can mean problems when cutting or folding or during any post-manipulation;
- higher cost of the curing unit because of its more complicated construction. For example, to maintain the printed substrate in close contact with the conveyor belt, air vacuum systems cannot be used; one must use such expensive systems as the electrostatic. Also, it is necessary to consider buying or leasing a tank for stocking the liquid or gaseous nitrogen;

- supplementary costs engendered by the consumption of nitrogen.

I believe this controversy has developed because of a kind of confusion between UV litho printing and UV screen printing. This oxygen inhibition is a physico-chemical fact, but I believe that the real question is: "Is this fact really important in screen printing?"

In offset lithography, the adhesion to the substrate is not so critical; on the other hand, the applied thickness of the ink coat is only 2 or 3 microns maximum. One generally admits that the oxygen inhibition is effective for a depth of 1 micron; this can mean a risk of a bad cure of perhaps 50% of the UV litho ink coat, which is very important. Secondly, in lithography the curing speed must be considered in feet per second.

Conversely, in UV screen printing the finest meshes and stencil printing techniques bring, under the best conditions, a minimum ink coat of 6 or 7 microns. Instead of 50%, only 13% to 17% of the ink coat may be adversely affected. And the curing speed must be considered in feet per minute.

Not only can this "superficial" influence be discounted in the entire reaction of polymerization, but also it is good to remember that we need in screen printing (especially on plastics materials and for a good intercoat adhesion) a fair polymerization of the lowest part of the ink coat, parts on which the influence of oxygen is equal to zero.

The Additives

In addition to the main components (base and pigments), every UV ink contains low percentages of different additives.

The classical additives included are agents which, added in very low quantity to the inks, modify their physico-chemical properties, or their "rheology." They can be, for example, surface tension correctors for improving the ink film immediately after printing or to prevent or diminish such phenomena as "bubbling," "orange peel," "cloud effect," etc. They can also be thixotropic agents designed for reducing the intramolecular cohesion (internal cohesion) of the ink—and thus its capillarity and sticking (adhesion to the mesh)—and the flowing or bleeding of the ink after printing. Thixotropy is the physical property of a thick fluid which permits it to become more liquid under agitation and to become almost immediately thicker when at rest. This property is of great value for halftone-dot printing.

In the case of UV inks, specific additives are necessary. They are stabilizing agents designed to inhibit or to delay the reactions of polymerization without the presence of UV radiation. The chemical components of UV inks are in effect highly reactive. Even now, several ink manufacturers face the problem of shelf stability of UV inks before use. The time when the "pot life" did not exceed three months is a recent memory for some ink manufacturers—a "natural" polymerization used to occur even without the presence of any UV radiation. In the best situation this precocious reaction produces a thickening of the ink, and in the worst case creates an almost complete polymerization of a good part of the ink components. Taking into account the relatively high price of UV inks, this is catastrophic, and this phenomenon for a long time prevented stocking of UV inks. But the use of stabilizers now generally permits a conservation of medium duration (several months or up to a full year).

The second specific additive is the "viscosity adjuster". If classical inks were involved, we should speak of "thinners" or "solvents." But let us not forget that a solvent is an agent which, when added to ink, lessens its viscosity and then disappears through evaporation. With UV inks, one does not use "solvents" in their classical state, but rather very liquid monomers designed to become a definitive part of the ink and polymerize with the other components. These liquid monomers are generally very unstable and, therefore, several ink manufacturers do not include photoinitiators in their composition. Have these different additives any influence on the ink reactivity? Let us first recall that the additives are present in the ink at very low percentages:

- Surface tension correctors: 0.5% to 2%, influence = 0.
- Thixotropic agents: 1% to 5%, influence = 0.
- Stabilizers: 1%, slows reaction slightly.
- Liquid monomers: 3% to 10%, slows reaction slightly.

In reality, these additives do not alter or inhibit the reaction. Their presence in the ink is too minimal to play a large part. At the most, together they slow the polymerization reaction down slightly.

Other Factors Influencing the Reaction: The Pigments

The pigments problem is much more complicated with UV inks than with solvent inks:

- first, because of their specific absorption of certain lengths of waves in UV radiation, in the visible light.
- at the same time, because of their own reflective power, based on the fact that a light pigment reflects a part of the radiation it receives, but a dark pigment does not reflect, or can even absorb radiation; one must not confuse the reflectivity of the pigment with that of the substrate below;
- also, because of their specific transparency—which in come cases can mean "lack of transparency," permitting UV radiation to go through the ink coat, then to reflect on the substrate (if it is a reflecting one) and to come back into the ink coat, adding to the effect of direct reactivity an "incident reactivity;"
- and last, because each of the above factors can come

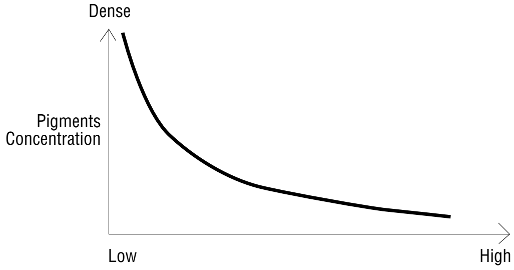
into play—separately or together—according to the thickness of the printed ink coat, the full mass of the pigments has an influence on all three factors!

One can nevertheless observe a basic principle: The thicker the ink coat, the slower the curing speed in the mass of the ink. The effect of these factors of "relative cumulative opacity" is more important than their effect on absorption and reflective power.

This principle makes very necessary **a perfect control of the ink coat thickness** in UV technology.

The curve of the decrease of the UV radiation penetration in the deeper levels of the ink coat is exponential: Doubling the thickness of the ink coat (or the pigment concentration in the layer) amounts to reducing by 8 to 10 times the penetration of UV radiation (Figure 6).

Figure 6



Percentage of radiation passing through

This is not a great factor where transparent UV inks (such as trichromatic inks) are printed. But for clear coating, (contrary to appearances) this is not quite true. In theory, clear coatings are transparent and are supposed to cure rapidly. In practice, some of these clear "varnishes" may polymerize more slowly simply because the manufacturers are obliged to use other, less reactive photoinitiators which limit or eliminate the yellowing of clear coatings.

Incidence of the "UV Factor" on the Characteristics of Inks

When we speak about ink characteristics, we mean on one hand their rheology—their physical properties of use—and on the other hand their qualities resulting from use: The obtained dry film of ink. It is necessary to take into account not only the incidence, but also the "non-incidence" of the UV factor. This point is very important, because among the questions the screen printer asks are: What exactly is the flexibility of UV inks? How long will they hold under sunlight or atmospheric conditions? What is their solidity…their ink mileage…their gloss (luster) or matte…their absorption in the substrate…? Among all those questions it is possible to find different degrees of relation within the UV technology.

No influence of the "UV factor:"

One often-asked question is whether a UV ink is "resistant" to the light (sunlight). The answer is simple and definitive: There is no incidence of UV on this factor, because this resistance—or lack of resistance—is first related to the quality of the pigment itself. If the ink contains pigments of 3 or 4 to the light (let us recall that this factor is measured in 8 degrees from 1 (resistance = 0) to 8 (total resistance to the light) in the "blue wool scale", then the ink will resist light for a short time only. If, however, this ink contains pigments "8 to the light," its resistance to sunlight will be perfect.

Too often, if his print is of a bad quality (due to slurring, bleeding, or with some "omissions"), if the "snapoff" (of the ink from the screen) is too slow, if the fine lines or dots do not print, or if "sawtooth" appears, the screen printer will accuse the ink or (in the case of UV) the entire UV process. But, if it is a fact that UV printing technology demands a careful attention or even the modification of certain elements of our technique, it is unfair to accuse the UV inks of faults which primarily stem from bad stencils, bad choice or stretching of meshes, unsharpened squeegees or printing presses.

Some influence of the "UV factor:"

- Resistance to weather conditions—we discussed the resistance of the pigment itself; let us now look at the solidity of the other components. In this case, the UV factor has an influence. We will see later that there often is observed (chiefly in accelerated weathering tests) a certain yellowing of UV clear coatings after a few months or the equivalent. All the "solvent-bearing" clear coatings have the same tendency. This is an old problem still without a definite solution. With some UV varnishes, this yellowing is directly related to the presence of certain photoinitiators. Even after a complete cure (polymerization) of the ink or varnish, there still remain some "unburned" photoinitiators or residue. Week after week they continue (under the impact of solar UV radiation) their work of catalysis; besides, they have a tendency to become opaque after decomposition, which creates a certain yellowing of the clear coating.

However, this is an inconvenience only when white substrates are clear-coated. On colored substrates, or over ink coats, this yellowing can be negligible. At the same time the "mechanical" resistance—to wind, rain, sand, salt, atmospheric pollution, etc.—is much higher than with solvent inks.

- Hardness, abrasion resistance and solvent resistance—here again, the influence of the UV factor is great. UV inks can be considered "hard" inks.
- Flexibility, or suppleness—here the UV factor is predominant. Although the flexibility qualities of UV inks are now rather good, generally speaking, thus making prints with UV inks easy to fold or die-cut (and even expandable under a continuous traction), the "impact resistance" remains rather poor; in effect, one UV ink characteristic is that polymerization continues even after curing, specifically in the deep layers of the ink coat. The more an ink polymerizes, the more numerous are molecular junctions; then this ink turns "hard" and then brittle. For a print where the ink coat is discontinuous—such as when halftone dots are

Figure 7

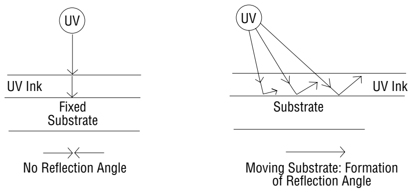


Figure 8

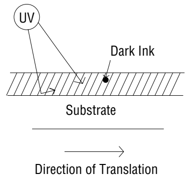


Figure 9

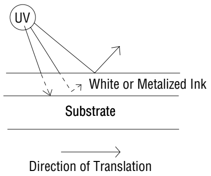


Figure 10

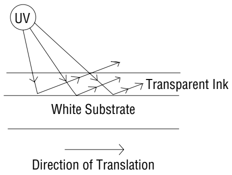


Figure 11

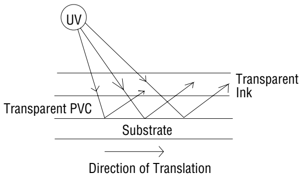
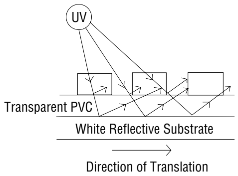


Figure 12



printed—this factor is not so important.

- Adhesion to the substrate—most UV inks essentially hold to the substrate through mechanical adhesion because they do not contain any solvent able to superficially dissolve the printed substrate. In this case, the surface tension of the substrate or of the under ink coat, its "wetting ability," is most important. It is impossible to obtain perfect adhesion of UV ink over a substrate for which the surface tension is under 38 dynes/cm2. By comparison, certain types of solvent inks need a minimal surface tension of only 35-36 dynes/cm2.
- It is also impossible to deny the existence of some chemical influence with the UV inks, because of the high reactivity of the oligomers and monomers used, but this influence can be negligible relative to adhesion to the substrate.
- Ink mileage—here again, for the UV factor to have importance, proper stencil making and printing techniques must be in use. With UV inks, the whole amount of ink passing through the screen lays and stays intact after curing onto the substrate, so UV inks are 100% usable. Thus an extremely thin coat will have a sufficient colorimetric value for an ink and insure a sufficient protection (for a clear coat). In this manner it is possible with UV inks to obtain a mileage of around 1,300 to 1,600 square feet per gallon.

Total influence of the "UV factor"

- Naturally, in first position is the curing (or drying). Once again, UV ink cannot normally be cured without the impact of UV radiation, particularly the wavelengths situated between 250 and 270 nanometers which insure the best activation of photoinitiators.
- The reflectivity of the printed substrates—this factor, very important when drying solvent inks, also counts heavily with UV inks because it can increase or decrease up to 40%. One cannot take this into account without coupling it to the speed of passage of the substrate under the UV lamp. If the printed substrate was motionless, the effect of reflectivity would be practically equal to zero. This is the translation speed which engenders the formation of a reflection angle (Figure 7).

It is also true that this factor is more or less efficient according to the capacity of the UV ink pigments to let a part of the UV radiation go through (their relative transparency or opacity); a dark color or a black will let only some or none of the directly received radiation be reflected by the substrate—even a white one (Figure 8). Using a white or metallized UV ink, the proper reflectivity of those pigments will also prevent the substrate reflectivity action (Figure 9).

But if relatively transparent UV inks are used—and this is the case of the majority of UV inks, particularly primary colors—it is possible to obtain on reflective substrates an interesting effect of "complimentary curing." On a substrate bringing a direct reflection (a white PVC, for example), this will increase curing speed about 20% (Figure 10).

On an "indirectly reflective" substrate (a transparent adhesive PVC mounted on a white substrate, for example), the lessening of the direct radiation coming from the lamp and the lessening of the reflected radiation by the substrate, permits a total utilization of the reflected radiation within the ink coat (Figure 11). The curing speed increase is about 30%. And when "dots" are printed—monochromatic or four-color halftones—the division of the ink coat into fractions permits and favors the utilization of a lot of small incidental radiations; this increases curing speed up to 40%, sometimes even 50% (Figure 12).

What Produces UV Radiation?

To cure UV ink, we have seen that it is necessary to submit it to the impact of UV radiation of a wavelength between 200 and 400 nanometers. What are the sources supplying this type of radiation? Several types of UV lamps are built for this purpose. For practical reasons, and because it usually is necessary to cure along the whole length or breadth of a flat substrate or a more-or-less linear object (such as in bottle printing) the most-used shape for the UV lamp is the tubular one.

Among all the models on the market (some very special applications aside), three types of lamps predominate:

- the most widely used is the medium-pressure mercury vapor lamp, followed by
- the electrodeless lamp excited by microwaves, and
- the pulsed-xenon lamp.

As was the case in inert atmosphere systems, there is a controversy among UV curing systems manufacturers about which is the best lamp. In my opinion, it is up to the printer to choose, according to his needs.

The Lamps

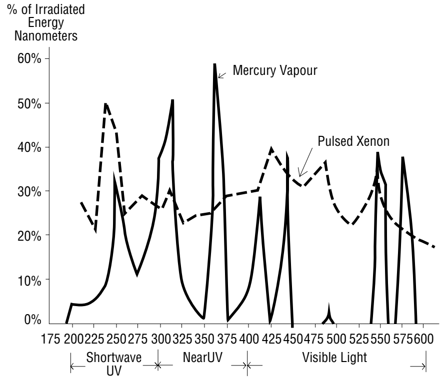
Let's remember that, in relation to what is known concerning the function of the photoinitiators, the required "useful" UV radiation must include the wavelengths situated between 200 and 400 nanometers, the "near" UV. For many photoinitiators, the top reactivity is situated between 258 and 264 nanometers. Whatever the type of UV lamp chosen, it must be one that emits a maximum percentage of its UV radiation in this zone. One can compare the medium-pressure mercury vapor tube which gives a maximum radiation intensity of 200 watts/linear inch, and pulsed xenon. Figure 13 shows the distribution of the "peaks" of intensity of both systems.

We can see that the medium-pressure mercury vapor system has three strong peaks of intensity in the UV—32% at 250 Nm, 52% at 310 Nm and 57% at 360 Nm—and three weaker peaks in visible light—36% at 440 Nm, 40% at 540 Nm and 39% at 570 Nm. The pulsed xenon system has a less erratic curve, with two peaks of intensity in the UV—50% at 225 Nm and 30% at 310 Nm—and three in the visible light—38% at 430 Nm, 37% at 480 Nm and 35% at 540 Nm.

The **medium-pressure mercury vapor lamp**—because of the need for high temperatures to obtain an emission of thermic origin radiation, the arc lamps—carbon arc first, then xenon arc under high pressure (10 to 40 atmospheres)—were the only capable lamps. But this type has the disadvantage of giving mostly infrared and visible light (90%) and only 10% UV.

It is now possible to obtain a better efficiency of UV radiation emission through electronic transition of ions, atoms or molecules excited by continuous or discontinuous discharges within gases or vapors; mercury vapor is most utilized. These discharges are produced inside of a quartz tube, used because its thermal resistance is much greater than that of glass, but also because of its "transparency" to ultraviolet radiations. This transparency is efficient until 170 Nm. An envelope of fluorine permits further efficiency, to 123 Nm; lithium fluorine is the only material permitting the maximum limit of optical materials transparency, 105 nanometers (the limit of extreme UV). However, those shorter wavelengths are not of great utility for the kind of reactions we need.

Figure 13



Peak intensities in mercury vapor and pulsed xenon systems.

For this reason, the "high-pressure" (sometimes more than 100 atmospheres) lamps are not used. They have a strong ray of resonance at 185 nanometers, a wavelength which does not appear to have an effect on most photoinitiators. Other reasons for not using high-pressure lamps include their internal reabsorption of certain wavelengths, higher temperatures, very strong brightness and higher cost.

The "low-pressure" lamp would seem suitable because of lower temperatures and an intensive ray of resonance at 254 nanometers—an excellent zone of reactivity for the photoinitiators. Unfortunately, practice has proven that those lamps do not have a sufficient output for "speed of reaction," because the radiation below 220 Nm and the infrared radiation is produced in insufficient quantities to insure a quick, deep curing of UV inks.

In speaking of the ultraviolet rays, some used to call them "chemical radiation" because their behavior encouraged such reactions as photosynthesis, photovoltaism, oxidation and diverse photopolymerization; whereas, infrared qualified as "thermic." But we must never forget that any electromagnetic radiation is a vector of energy, and energy is always able to become heat.

In practice, and from 10 years of research and experience in litho as well as screen printing, it appears more and more clearly to me that it is better to use a "cocktail" of wavelengths emitted between 200 and 5,000 nanometers, to:

- obtain the maximum speed of curing, and
- be able to use the same lamp to obtain the best possible curing of different oligomers and monomers, mixed with different photoinitiators and printed on different substrates.

Of course, it is quite true that certain lamps using gases or metals other than mercury vapor can give a better curing with individual photoinitiators or substrates, and these lamps can be useful in specialized printing—such as on glass, polyethylene bottles, aluminum, printed circuits etc., but I do not concur in this opinion where a general screen printing shop is concerned. Some UV material manufacturers used to say "Change lamps according to the application." But this is impractical and risky (to handle UV tubes is a delicate business), and means a heavy investment.

Lastly, an important question: What is the lifetime of a medium-pressure mercury vapor lamp? The warranty given by the manufacturer is generally 1,000 hours, full intensity. But if we take into account usage at one-half intensity (or even one-third or one-fourth, if the system permits), and good maintenance, and the number of starts and restarts, it is reasonable to expect an average lifetime of 2,500 hours, or more than one working year.

We have seen that medium-pressure mercury vapor lamps have two disadvantages: They create a lot of heat because on one hand, 50% of their output is situated in the infrared, and on the other hand, preservation of the ionic agitation requires a high-temperature quartz envelope; also the starting or re-lighting periods are relatively long. Fundamentally, the problem is to trigger instantaneously—without prior heating or "cooling plus heating"—the production of UV radiation through the interaction of an electron cluster with an ionized gas. To achieve this, it is possible to start the reaction either with a three-electrode "exploder" (a very hot system), or with an **"electrodeless"** tube in which the reaction is started by the emission of hyperfrequencies.

For hyperfrequency generation, one American firm has chosen the magnetron. A magnetron (we will surely speak again of it in a few years when water-solvent inks will be operational) is a hyperfrequency generator "at crossed fields"; the electrons borne from the cathode move under vacuum and are submitted to an electrical field (HF) and a very strong magnetic field perpendicular to it.

For our purposes, we are interested in the property of magnetron, acting in impulses, to generate an enormous power "in crests" (in peaks). It is the power of this strong impulse that is used to "light," almost instantaneously, the UV lamp. The advantages of this type of "electrodeless" lamp, are:

- a working temperature of about 210°F (99°C); the plasma energized by the hyperfrequencies is very homogeneous, and the infrared emission can be 30% lower;
- the lifetime is much higher (up to 5,000 or 6,000 hours of use) because of the reduction of thermal shocks and the absence of electrodes (with no accompanying risk of oxidation); and
- the startup time is very short—about 12 seconds—as is the restart time (after an intentional or accidental shutoff).

Inconveniences are:

- these lamps exist only in segments of 10.5", each accompanied by a magnetron; they must then be mounted in series to cure large substrates; and
- because of the price of the magnetrons, especially in Europe, the purchase price is high for large units.

In my opinion, this type of lamp is particularly well adapted for UV units designed for curing three-dimensional objects, especially when they are built in "compact" (printing + curing) units.

The **pulsed xenon lamp** is more rarely used, but this type has its supporters in the United States. This source of UV radiation is very popular for photographic work, such as enlargement of big-sized positives. Also numerous are the flash lamps using this system; the principle of the application is that the electrical charge is produced by xenon high-tension condensators. The xenon, one of the "rare gases" comprising the atmosphere, is enclosed in quartz tubes; each discharge ionizes the gases and creates an arc very rich in ultraviolet radiation and visible light.

This type of UV source has as an advantage the ability to emit UV radiation (and also visible light) in cycles of pulsations—flashes—of about 60 per second; the UV emission is less erratic and more continuous than that emitted by mercury vapor systems (see Figure 13). This leaves more possibilities in the choice of photoinitiators (each of them having a very precise optimum "threshold of response") and decreases the risk that the photoinitiators, some pigments and some oligomers or monomers will compete to absorb the UV radiation. The delivery of radiation is also simpler to regulate than in the mercury vapor systems. The lamps are able to receive high-frequency flashes and have longer lifetimes. Lastly, augmentation of intensity translates into augmentation of UV radiation stronger than that of visible light and infrared.

However, while the pulsed xenon gives a relatively valuable "medium" result, it does not seem able to obtain (in some wavelengths) the intensity of mercury vapor lamps, and cannot achieve a total absence of emission in other wavelengths. There ensues a loss of efficiency with several types of photoinitiators. On the other hand, the energy needed by pulsed xenon systems is more important (+ 4 KW, on average) with an equal output. The maximum efficiency of pulsed xenon is situated between 350 and 500 nanometers.

The fact that pulsed energy reaches its maximum level several times per second seems, a priori, advantageous due to the fact that each pulsation increases the effect of the preceding one (a little like a nail driven in the wall by several hammer strokes). This permits breaking through the "threshold" of polymerization initiation, even deep within the ink coating.

But in reality, this element would be more efficient on an immovable substrate. Let us not forget that the printed substrates are moving between 32 and 140 feet/minute on the conveyor belt of the curing unit; thus each quantum of pulsed energy cannot "strike" at the same place (Figure 14).

The Reflectors

To permit UV radiation to reach full intensity, the emitting lamp would need to be only a very short distance from the substrate—from one to two inches generally—because each time the distance is doubled between the lamp and the substrate, the radiation loses three-fourths of its initial intensity. It is impossible, mostly because of the irradiated heat, to put the lamp this close to the substrate. The average distance, which varies according to the type of curing unit, is usually fixed by the manufacturers to be between two and three inches. To counterbalance this loss of radiation intensity, one uses reflection of the laterally-emitted radiation. For this purpose, there are several types of reflectors. Here again, opinions differ concerning focalization onto the substrate surface; focalization between the lamp and the substrate; and no focalization at all.

In the first case, and the most classical, the UV tube has an elliptical reflector which concentrates the whole reflected radiation at the second focus of the ellipse, the elevation of the lamp being calculated in such a manner that this second focus is

Figure 14

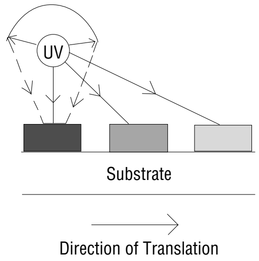
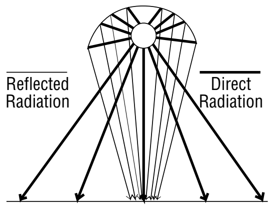


Figure 15



Focal point on the substrate.

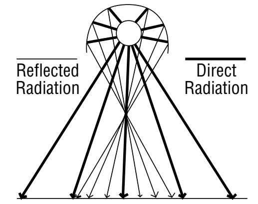
exactly located at the surface of the printed substrate passing under the UV lamp (Figure 15).

In the second case, the curve of the elliptical reflector being more shuttered, the second focal point is situated above the printed substrate, at half of the distance between the lamp and the substrate; the reflected radiation crosses at this focus to then cover a wider area of the printed substrate (Figure 16).

In the third case, the reflector has a flat bottom, its two lateral parts being simply open under an obtuse angle. The radiation is then dispersed over a large surface onto the substrate (Figure 17).

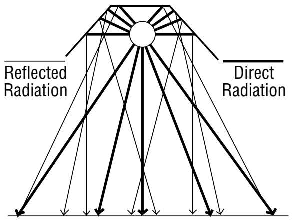
I have used or seen in use these three types of reflector. I did not see very much difference in curing speeds among these three systems. I feel it is more important to take great care concerning the quality of the reflecting surface (its polish and cleanliness). It is wise to clean the surface of these reflectors often; any dust or oxidation traces make them lose up to 70% of the reflecting radiation—between 30% and 40% of the whole emission. Thus, I believe non-oxidizable steel is a better material than the extruded aluminum commonly used for the water-cooled systems where the medium of reaction is very corrosive, especially because of the ozone presence induced by certain wavelengths in the UV.

Figure 16



Focal point over the substrate.

Figure 17



Dispersed radiation.

Additional Problems

The emission of UV radiation creates some problems directly related to this production of UV rays. Two of them are physical; the other two belong more to safety and health concerns. They are, in order of importance: The produced heat; the startup or restart times of lamps; the ozone production; and the danger to eyes and skin from UV radiation.

The produced heat—let us go back to the most usual case, that of the medium-pressure mercury vapor lamps. We saw that besides UV radiation, these lamps produce visible light and a lot of infrared. When we say infrared, this means thermic radiation turning into heat. There is, then, parasitic heat due to the infrared production, but also **necessary** heat, about 1,100°F, needed for the quartz envelope itself to maintain the necessary mercury arc. If this temperature falls, some of the emitted wavelengths will be changed, which is deleterious to the lamp output.

A lot of experience with different models of curing units has proven that if one heat absorber (or infrared filter) were interposed between the lamp and substrate, the output could diminish more than 50%. This additional thermic effect seems quite useful to complete the action of the "radiation cocktail," reacting onto the photoinitiators; as we know, heat is always an activator of polymerization reactions. However, this emitted heat, if one still finds it at the level of the printed substrate to be cured, engenders the same type of disadvantages as from warm jet-air dryers: **Distortion** of the thermosensitive substrates, either by lengthening (with the plastic materials), or by shortening (as with humidity-sensitive substrates such as papers and cardboards). In any case, those dimensional modifications affecting the printed substrates are critical in obtaining a precise register. To mitigate this disadvantage, two methods of action are conceivable in the UV curing units: One is "passive," the other "active." The passive method is very **high-speed** (in comparison with the classical type of dryer) passage under a lamp focusing radiation on a very narrow surface in the direction followed by the printed substrate. Take as an example the case of a lamp where the whole amount of direct or indirect emitted radiation is focused on 50 inches—the printed substrate remains inside the "active" area (then the "warm" area), only two seconds at 20 feet/minute, the lowest speed of the conveyor belt. At the highest speed of translation (165 ft/min) this passage will take only .25 seconds; in both cases, the substrate has little possibility or time to get really hot.

The active method consists of insuring a very strong **cooling** of the lamp reflector, of the printed substrate and sometimes of the lamp itself inside of the limits seen above. Another problem related to the emitted heat, the speed of the belt and sometimes the turbulence created by an improper air-cooling mechanism is that a very light, printed substrate can "fly"; or, if it is a plastic, "swell up" and stick to the lamp. This substrate will be liable to melt or even catch fire. This risk is eliminated through the creation of a very strong vacuum under the conveyor belt to hold down substrates that are too light or too thermosensitive. In the case of curing units working in inert atmosphere (nitrogen), the vacuum must be replaced by an electrostatic system.

Once again, there is no unanimity among manufacturers as to which is the best cooling system for all elements (reflector, lamp, substrate). The systems offered belong to four groups.

- The systems "all by air;"
- the systems using "water circulation around the reflector" + air for the substrate;
- the systems using "water circulation around the lamp" + air for the substrate;
- one of the above systems, with the addition of a "heat pump."

Each of these systems has advantages and disadvantages, so let us have a look at them.

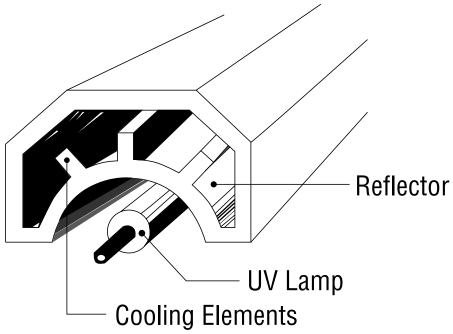
Cooling by air alone—supporters start from the principle that air is necessary (through vacuum) to eject the ozone outside, necessary (through blowing) to cool down the printed substrate after its passage under the lamp and lastly, necessary (through a very strong depression or vacuum) to lay the substrate flat on the conveyor belt.

It can be practical to use the ozone-extraction air stream to cool down the reflector and the metallic parts of the lamp (the electrodes and the contacts) or lamps, and to produce the strong vacuum necessary under the conveyor belt. To do so it is necessary to increase the power of the ventilation to accomplish those tasks, and to study as accurately as possible the whole air circulation with an eye to avoiding the turbulence and obtaining maximum efficiency.

This system has the advantage of a relatively simple construction, security in use and simplicity of connection. But if its design and its construction are not perfect and if the ventilation power is not sufficient, the temperature of the printed substrate (which can reach 160°F when leaving the curing unit) may not be lowered enough.

A curing unit of this type is valuable if, when using only one lamp at full power (200 watts/inch) at a conveyor speed of 50 feet/minute, the temperature of the printed substrate when leaving the curing unit does not exceed 85°F (29°C).

Figure 18



Water-Cooling reflector.

Cooling by water circulation around the reflector—if running water is a better heat exchanger than air, it is possible to imagine that a strong water circulation around and on the top of the reflector will be a good solution. It will be possible, then, to extrude the reflector from aluminum with a system of internal vanes, assuming a large increase of surface is cooled through convection (Figure 18). However, this solution does not include ventilation, so it is necessary to plan for a strong-enough water supply—and it is a situation calling for caution when high-tension equipment, heat and cold-water systems are put close to each other.

Cooling by water circulation around the lamp—in this case, the water is asked to play a double role: Cooling the lamp directly, and acting as a filter of infrared rays—for which 1/2 inch of water is very efficient as a heat absorber. This solution is quite popular for some UV curing manufacturers. However, in my opinion, there are some "buts" with this system. First of all, the water cannot be in direct contact with the quartz envelope of the lamp itself because the cooling would be too effective—one must not forget the necessity for the ionized gaseous mixture to remain at a temperature of about 1,100°F. An intermediary quartz envelope is thus necessary around the lamp, with the water circulating inside a second envelope (Figure 19).

The emitted radiation will be obliged to go through three thicknesses of quartz and one of water; it will of course, lose the greatest part of the infrared wavelengths. Unfortunately, it will also lose almost 30% of its efficient UV radiation! There are two ways to curtail this loss: Either reduce the speed of the conveyor belt, or passage of the printed substrate under the lamp. This can be done without any risk of over-heating because of the efficiency of the infrared filtering, but there will be loss of printing press efficiency. Or, you can increase the power of the lamp from 200 to 300W/inch. But once again, this solution not only increases the energy cost, but the increase of UV output is not proportional—for a power increase of 50%, the UV emission increase is only 20%. Lastly, the cost of the curing unit is higher in comparison with an air-cooled curing unit.

One of the above systems with the addition of a "heat pump"—in reality, a heat pump (a relatively false term, because heat is a fluid which cannot be pumped) is a system able to capture some heat from a cold source and convey this heat to another source. The thermodynamic system is the same as that of a refrigerator, permitting you to recoup heat instead of cold; an "inverted" refrigerator. When passing from one source to the other, a part of the heat is used to produce a mechanical function.

In several curing units using the water-cooling systems, either for the reflector or a lamp or both, instead of having a constant supply of cold tap water from external sources, the system works in a "closed circuit." The water heated after its passage near the UV lamp is refrigerated by passing through an exchanger, where it leaves its calories by contact with tubes containing a highly compressed gas (such as freon). This water then comes back to cool down the lamp or the reflector, and the whole process starts again.

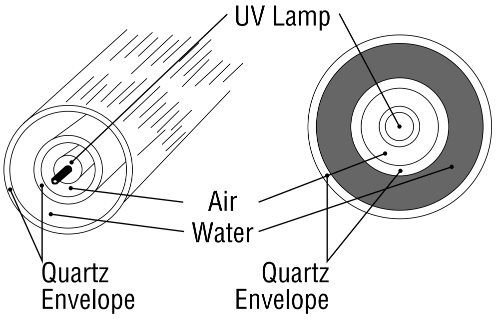
The advantage of this system is that, once started, it becomes **self-maintaining**. As a matter of fact, the proper term would be "cooling through a thermic motor." The action of the pump moving the water and of the compressor used to cool the gas is supplied by the use of some of the heat when it is transferred.

The disadvantages are the necessity to employ high electrical power to start the system (sometimes about 25 amps) and the creation of a lot of condensation close to the curing unit. This condensation increases the humidity, aggravating the oxidation reaction already engendered by UV radiation and the presence of ozone.

The start and restart times of the lamps—as screen printers know who use mercury vapor or metal halide lamps for exposing the stencil, those types of lamps need a certain time before they reach their full intensity. This "starting time" can vary between 90 seconds and 5 minutes, according to the types and trademarks of the lamps.

Exciting the atoms of enclosed mercury vapor (ionization) is not an instantaneous action. The gas must be heated to a sufficient degree to engender the electrical arc which generates intensive UV radiation. Otherwise, if the arc is interrupted—voluntarily or by cutting the electrical energy—the molecular agitation must stop completely to permit the ionization to restart in a "cold" lamp, and 5 to 12 minutes will be necessary to let the lamp reach its full intensity again. It is then easy to conceive how disturbing it can be from a production point of view: If an unplanned stop occurs while printing, it will be necessary to wait—that is to say, lose production—for several minutes to restart the whole printing and curing unit.

Figure 19



Besides, with only one exception to my knowledge, the UV curing units are not equipped with VPE (variation of power emitted) systems, working either at full power (5 amperes for 200 W/inch) or half power (2.5 A for 100W/inch). In case of interruption (planned this time) of less than 15 minutes, it is necessary to keep the lamp at half-power during the waiting period. In this case, it is also impossible to interrupt the cooling system or the conveyor belt which could, if stopped, be damaged by the emitted heat. This means non-productive costs for energy. Such a problem is well known with the metal halide lamps where stencil exposure may be maintained the whole day at half power behind a metallic shutter—that is to say, seven hours of energization for only one hour of full-power work during one working day.

This disadvantage is, of course, cited by supporters of electrodeless or pulsed xenon systems, for which the startup time is almost instantaneous. For some industrial applications, such as bottle printing, impulses or short, intensive emissions of UV radiation separated by periods of complete extinction can be preferable. This is the favorite domain of electrodeless lamps. Concerning the classical graphic applications in screen printing, it is necessary to work with "what we have" and to utilize UV systems as they are.

Ozone production—a lot of screen printers incorrectly exaggerate estimations of ozone produced by UV curing units. What exactly is ozone? No more and no less than an allotropic variety of oxygen—very oxidizing, engendered by the ultraviolet wavelengths situated between 170 and 200 nanometers. Ozone is a poison for the human body in very high doses; serving as a catalyst of oxidation facing the oxygen it accompanies, it can occasion an over-oxygenation of blood hemacytes. The threshold of maximum acceptable concentration is .000007 O_3/35 cubic feet (0.2 milligram/m^3). It is ironic to note that this is a concentration equal to the ozone layer in the high atmosphere which protects us from the sun's ultraviolet rays. How to eliminate this ozone?

There are two ways to eliminate ozone—produce none, or evacuate it. To not produce the ozone seems the most simple and evident solution; it is only necessary to stop the UV radiation from 170 to 200 nanometers. There exists slightly translucent quartz for this purpose. Unfortunately, as we saw with the elimination of other wavelengths of emitted radiations, the output efficiency reduces again from 10% to 15%, which means curing speed will slow by the same percentages. However, with UV curing systems working in inert atmosphere, this type of solution is obligatory, because it would be impossible to evacuate the ozone without also evacuating the nitrogen.

In all other cases, the simplest solution still is to evacuate (through vacuum systems), the produced ozone to the outside of the printing plant. The air used for this evacuation is also used for cooling the lamp or its reflector. The ozone, produced only in very small quantity by UV lamps, is a very unstable gas; in some milliseconds, the third atom leaves the molecule (O_3) which returns to oxygen (O_2); the ozone self-destructs almost immediately.

Eye and skin protection—we all know that ultraviolet radiation received in too large quantities can damage the eyes and the skin. If the UV curing units have been designed and built by serious manufacturers, all those risks are eliminated. There are safety equipment and devices to instantaneously shut off the UV emission if the doors of the curing unit body are opened accidentally or voluntarily; smoked glasses or plastic shields prevent the dispersion of direct or reflected radiations outside of the curing unit. Because of the above dangers, I am personally quite against the UV curing system "kits" as they are offered by some manufacturers. If you want to avoid grave accidents, don't do it yourself.

The conveyor belt—in relation to the problems occurring because of oxidation and heating, the nature of the conveyor belt is very important. In all cases metallic belts must not be used unless they are "nonoxidizing," because one must not forget that the conjunction of UV radiation and ozone creates an extremely high oxidation for unprotected metals or, simply because they are built of metal, even if this metal is stainless steel (to prevent oxidation). Metal is typically a conductor and an accumulator of heat, and inside of a UV curing unit each detail, each element of the construction must contribute to elimination of heat (because excess heat is undesirable for maintaining the dimensional stability of the printed substrate).

The solution adopted by most of the manufacturers is to use fiberglass woven in large meshes and coated with Teflon. For the inert atmosphere systems, the weaving must be tightened to prevent escape of nitrogen outside the unit treatment chamber. In this type of curing unit, it is often necessary to cool down the belt by passing it over a metallic surface cooled by water circulation underneath.

Advantages and Disadvantages of UV Inks

According to the options considered thus far—economic, technical or in direct relation with screen printing—and after an examination of UV theory, it is vital for the screen printer to know all the facts in order to choose the UV option or to reject it.

Although it can sometimes be very difficult to make a clear separation between the technical advantages or disadvantages and the economic ones, I shall try to do so as clearly as possible—first at the inks level and then for the curing units, without forgetting that they are connected.

And we must also remember a more general point: Nothing permits us to predict that in 5 or 10 years from now, the whole industry will not be obliged to adopt UV technology! We must not, in effect, keep some dangerous illusions about the future of "standard" screen printing inks. Solvent inks may someday be simple "prohibited"—or have so many restrictions that, in practice, they can hardly be used.

Another solution may arrive via water-based inks dried with a flux of electrons engendered by hyperfrequency generators (such as the magnetron) but this technique, although it is already in use in some areas, will not be available for screen printing of all substrates (particularly papers and cardboards) for several years. So at present, the only reliable option is UV technology.

A. Technical and screen printing advantages

If UV inks are not, unfortunately, the "universal panacea"—able to be printed on any kind of substrate—they are (considering the level of our screen technology) the best approach. Some ink advantages:

- There is no risk of drying into the meshes of the screen. Because UV inks can only dry under a direct emission of UV radiation, they merely need to be kept out of the sun. From this advantage comes the possibility to print with exceptional fineness—lines of .002 or .003 inch width and halftone printing of 175 or even 200 lines per inch, if the stencil process in use has a sufficient resolution power. UV inks also eliminate the need to wash or clean the screen if you stop printing, even for a long period of time.
- The "curing" (or drying, if you prefer this conventional term) is almost instantaneous: It can, under the best circumstances and with the lamp at full power, be done at speeds up to 160 feet/minute; in time about 1/10th of a second at the application point of the radiation.
- Because adhesion is purely mechanical and curing is very quick, penetration inside of the substrate is minimal. It is then possible to obtain an excellent definition of the image even on very absorbent substrates.
- The high speed of translation inside of the curing unit limits the risk of distortion of the substrate, even if it is a very thermosensitive one—and this is true despite the heating caused by the lamp. In UV curing units of the "cold" type (those from which the printed and cured substrate emerges at a maximum of 86°F), the distortion is one-half that produced by the least warm types of "jet-dryers."
- Taking into account the total absence of solvents in UV inks, there are, in the case of overprinting of ink coats, no risks of re-wetting of the already-printed undercoats, whether the undercoats are UV inks or not. For the same reason, and if curing of the UV ink is achieved, there are no risks of offsetting or tackiness between sheets; stacking can be done immediately after curing, even if the printed substrate is "heavy" (thick cardboards, metal plates, acrylics or polystyrenes) and printed on both sides.
- The lack of solvents also eliminates colorimetric variations while printing. This phenomenon occurs many times with solvent inks; unfortunately it is very important when printing four-color halftone inks (or any transparent inks). The "solvents" part of the ink partially evaporates out of the screen when the inks are shifted by the quick movement of the squeegee and of the flood bar. The ink density generally tends to change (usually getting darker), and to clear up again when fresh ink is added.
- Lastly, there is no emission of solvents in the interior or exterior atmosphere, which reduces fire hazards.

B. Economic Advantages

These are, of course, directly related to the technical advantages. I believe the greatest advantages of UV technology are evident in a potential decrease in fabrication costs and an increase in profits of 10% to 25%.

- The ink mileage can be, under certain circumstances, very high; up to four times that of a solvent ink if the correct meshes are utilized for the screen. In effect, a "standard" ink contains between 40% and 70% solvents which disappear through evaporation when drying. But UV ink contains 100% of "dry extract" (solids). So materials going through the screen remain, in their entire thickness, on the printed substrate after drying (or curing). It is then possible to achieve continuity of colorimetric value; by leaving less ink on the substrate with proper meshes, i.e., the calendered ones, it is possible to reach a mileage of 4,000 square feet per gallon of ink.
- One realizes that a real economy of inks and solvents includes better quality, because it is not necessary to clean the screen during printing (because of blocking of meshes by dry inks), nei-

ther when locating the screen for a good register nor when searching for the exact color, nor after an interruption of printing—even for a whole weekend, if a long run is unfinished. The screen is washed only when the printing is completed.

- Some UV inks have multiple uses. The same UV ink can, under certain circumstances, be printed on paper as well as on PVC, regardless of whether it is adhesive-backed or not. Another type can be printed on plastic materials of a different chemical composition.
- Some UV inks can be ultra-glossy, even when used on very absorbent substrates, which permits elimination of varnishing or laminating. Similarly, a good UV varnish has a "gloss-index" which can be as good as a lamination: It can be used for overprinting on litho or screen prints (either printed with standard or UV inks) for a smaller cost. In the United States, where the cost of UV inks or clears are lower than in Europe, profit gains can reach 50%.
- Its great surface hardness makes some UV ink ideal for printing the decoration of diverse elements submitted to great constraints after printing (folding, cutting, etc.) This is the case with glossy UV inks or those with a satin finish; matte-finish UV inks generally are as fragile as matte solvent inks.
- UV ink resists very well almost all solvents, which permit its use for marking or decoration of containers or bottles (in perfumery or chemical industries) or decoration of any element that will come in contact with solvents or chemical products.
- In addition to speed of curing and fine definition, the excellent resistance of UV varnishes to several acids makes them peculiarly well adapted to print as resists for the fabrication of printed circuits in the electronics industry.
- Accumulation of the diverse advantages of UV inks results in production safety, which translates into profits. The screen, washed less or not at all while printing, is less damaged (an important point when fine lines or halftones are printed); waste through offset in stacking is eliminated; dust deposits have no time to develop because of the curing speed; the register is better than with a standard jet-air dryer; the risk of colors "bleeding through" (wetting of the underprinted colors) is eliminated; the stability of colors and the graphic quality (no drying into the meshes) are better. All those elements together can represent a savings of about 20% in production costs each year.
- The lack of solvents in UV inks increases their flashpoint considerably; it is 70 to 95F degrees higher than that of solvent inks. This can mean a substantial decrease in insurance costs.
- The advantages of UV inks as seen above, added to those of UV curing units, permit an important shortening of delivery times, which opens up new markets for which the "delivery time" element is primary.

C. Technical and Screen Printing Disadvantages

The principal characteristic of any exhaustive list of UV inks disadvantages is the list's tendency to shrink month by month: I remember some 1976 technical articles in which this list was three or four times longer. For example, only recently it was impossible to overprint solvent inks (on top of) UV inks—especially the glossy ones—because of a lack of adhesion; this was disturbing when printing double-face decals for which the printing of white backgrounds and the opacity coat must still be done (for opacity reasons) with solvent inks. This is not true anymore. But to be perfectly objective, it is necessary to admit that while many disadvantages disappeared for some ink manufacturers, many still exist for others. The most characteristic ones are:

- First is UV inks' lack of opacity. In principle, the cumulative mass of pigments (and each of them separately) must maintain a certain "transparency" that allows the penetration of UV radiation and permits the polymerization reaction, or curing. Here it is necessary to refine such a relative notion as "opacity". The only really "opaque" inks in screen printing are the glycerophtallic ones (glossy or matte), sometimes improperly called "cold enamels;" only with this type of ink is it possible to find yellows, oranges, bright reds or greens without a weakening of their primary coloration, when printing on dark substrates.

But even with this type of ink not all colors retain full color intensity, and it is necessary to use meshes permitting a sufficient ink thickness to go through. Actually, the opacity of UV inks is simply equal to that of vinyl inks for PVC, or the "jet-type" inks. It is possible to find good-quality UV inks on the market in blacks, whites and even golds or silvers, with opacity and reflection which seem not to favor the passage of UV radiation. This last fact indicates that the opacity of UV inks will very soon be improved.

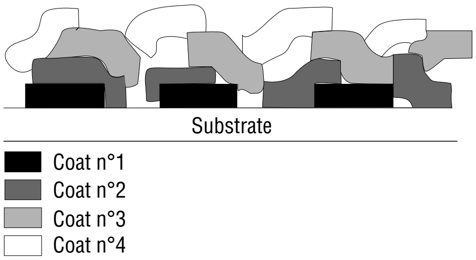
- A direct corollary of this relative transparency is the necessity of a precise register in order to come very close to the litho technique and to avoid the overlapping and wide "color traps" which have facilitated the work of screen printers so much historically.
- Some UV inks are irritating to skin and eyes in cases of direct contact. This "irritating" capacity is not systematic or automatic. On one hand, the reactions are mostly "allergenic"—some bodies are more sensitive than others. On the other hand, ink manufacturers are working unceasingly on this problem and little by little, through testing thousands of possible combinations of oligomers and monomers, they have made UV inks less irritating to the skin.

There is a scale for measuring the irritation called the Draize scale or Draize patch system, graduated from 1 (no irritation at all) to 8 (strong irritation), which assigns (through dermic tests, generally on rabbits' skin), a certain coefficient of irritability to any chemical product.

Right now, most UV inks can be classified between 1 and 2 on this scale, and thus are considered only "slightly irritating." Only those designed to be printed on polystyrene remain rather irritating (6-7 on the Draize scale). Generally speaking, it is necessary to be more careful with UV inks than with solvent inks, especially while washing screens or squeegees. However, UV inks do not disperse any solvents in the air during printing or polymerization. This means a reduction of the breathing hazards which, even if you do not "see" them, are very real in the use of solvent inks.

- UV inks produce a relatively high thickness of the ink coat even when cured, because there is no "loss through solvent evaporation"—all ink going through the screen remains integrally on the printed substrate after curing. This thickness of the ink deposit has effects both economical and technical. It can be troublesome mostly in four-color halftone printing. When it is time to print the third or fourth coat of "halftone dots," those impeded by the dots of the first and second colors (See Figure 20) reach the substrate only with difficulty (or not at all). They can also "slip" over the others and give images of a bad quality. We will see that when printing with UV inks, all factors must contribute to reducing the ink coat deposit through the use of very fine calendered meshes and appropriate screen printing techniques.

Figure 20



D. Economic Disadvantages

Disadvantages here are mostly related to the relatively high cost of UV inks. It can be double or triple that of solvent inks, for example, because these inks contain only "solids" and not 50% to 70% of solvents as in the standard inks. And the chemical products used are themselves quite expensive.

It is possible, with appropriate techniques, to turn this relative disadvantage to an economic advantage, because three or four times more surface can be covered than with solvent inks—resulting in a "cost-per-square-foot" savings.

Advantages and Disadvantages of UV Curing Units

A direct comparison with traditional drying systems is difficult because it is hard to conceive of the UV differently from an "integrated" system and an obligatory complementary one—ink + reactor (curing unit). Those two elements are direct corollaries and have to be; it follows that advantages or disadvantages of the curing units are dependent to some degree on the advantages or disadvantages of UV inks. However, at the "economic" level, a comparison can be made with the standard systems (warm or lukewarm jet-air, infrared, wicket-dryers), keeping in mind that a UV curing unit can "dry" only UV inks.

A. Technical and Screen Printing Advantages

I see two main technical advantages: Curing speed and the low heating of the printed substrate; all the other advantages, speed included, are economic.

- The speed of curing can reach 195 feet/minute. For example, with a 20" x 27" four-color halftone print on poster (coated or offset) paper, cardboard or even PVC for decals, it will be possible to cure the four colors at a speed of 130 feet/minute using one UV lamp of 200 W/inch at full power; this means it will be possible to print on a cylinder press and then cure 4,500 sheets/hour, which exceeds the printing capacities of the highest-speed screen printing presses of similar size. At half-power, the speed will be of 3,000 sheets/hour. In the case of a 40" x 60" outdoor poster and under the same conditions as above, the possible speeds can be 2,200 and 1,400 sheets/hour, respectively.
- The low degree of heating, mostly due to the high speed of passage under the lamp and the short length of the heating zone, is an advantage that is all the more evident if the cooling devices of the curing unit are efficient. In comparison with a standard jet-dryer, this advantage is very important with regard to register.

B. Economic Advantages

The speed, then, is a great advantage because this "curing" principle permits use of any screen printing press at its higher speed of production. But other points are also important, such as:

- Little floor space is needed. This factor is certainly important when you consider a plant's per-square-foot cost. The length of the curing chamber itself—for a one- or two-lamp UV curing unit—is rarely more than 40". Only some units working in inert atmosphere (nitrogen) exceed this length at 8'. To this curing chamber length it is necessary to add the length of the conveyor belt (varying as a function of the size of the sheets or objects to be cured, or of peculiar specification by the printer). But generally speaking, the whole UV curing unit occupies three to four times less floor space than a standard jet-air dryer.
- Low energy cost is of primary importance. The UV curing unit needs two or three times less energy, even under full power, than a warm or lukewarm jet-air dryer. But inert atmosphere UV curing units, even if they do not need more energy, consume nitrogen, whose cost/hour can be considerable. In this case, and only in this case,

the operating cost is about two times higher than for a jet-air dryer.

Considering that it is not always necessary to work at full power (either through a judicious choice of UV inks, or because the press speed is not sufficient), it should be noted that it is possible to cure using the lamps at half-power; the economy realized will increase 25% to 30%. There is a device called VPE (variation of power emitted) by which the power of UV emission can be reduced to 1/4 of the maximum value, or to any value between 5 amps (200 W/inch) and 1.25 amps (50 W/inch). This type of unit, (if the press allows its use) can increase the economy to 50%. In this last case, and still in comparison with a jet-air dryer, the UV curing unit will use six to eight times less energy.

Very complicated financial studies have been done (especially in the United States) concerning the annual costs of all UV materials. Some manufacturers indicate exactly how much money a UV curing unit will cost you each year. But I feel that a really precise and exact financial analysis would require so much data (even when considering only United States information; without integrating data from European countries) that the computer integration alone would take months, and that practical experience and accumulation of results from the manufacturers, screen printers and screen industrial departments would take years.

Once again, I believe it is up to the screen printer to develop his own financial prospectus from elements supplied by manufacturers; his own technical, commercial and financial structures; and, eventually, such articles as these. Large screen printing plants usually have efficient financial departments able to develop such a prospectus. Smaller shops need only to supply their accountant with necessary elements to obtain a study of "cost and profit" precise enough to help them to decide.

Nevertheless, it seems reasonable for me to supply ranges for percentage of "profit" increase (savings) realized because of UV technology use, compared to conventional systems:

- profit in energy cost; 60% to 80%
- profit in equipment and installation cost; 20% to 40%
- profit in floor space; 60% to 85%
- profit in maintenance and depreciation cost; 10% to 20%
- profit in operation safety; 5% to 20%
- profit in increased production; 20% to 60%

As a matter of fact, if we consider the notion of "profit" as being the most important, it is possible to write that while the profits engendered through the use of UV technology are important (in the actual worldwide screen printing context), the importance of those profits is going to increase in proportion with the increase of energy costs.

C. Technical Disadvantages

There are no "economic disadvantages" except perhaps with the inert atmosphere curing units. But there do exist a few disadvantages, more from a general point of view than from a really technical one.

- Heating of the substrate, especially with "cold-type" UV curing units, is low and is limited by the curing speed. But if the emitted infrared radiation (main cause of heating) is diminished too much through intensive cooling (which must not affect the lamp's quartz envelope so much that the UV radiation emission is interrupted) or through interposition of a heat filter or infrared filter, the curing efficiency is noticeably reduced. So, weak or not, this substrate heating has to exist and, from the screen printer's point of view, this is always a disadvantage which is liable to cause distortion of the substrate and register problems.
- Ozone production, for UV curing units in which the quartz of the lamp envelope does not block the wavelength producing such an emission, can also be a disadvantage. Stopping this emission affects the efficiency of curing. It is then necessary to evacuate the ozone outside of the printing plant, where it dissipates almost immediately. This evacuation obligation is a constraint, although less so than evacuation of the solvents-loaded air from a jet-air or wicket dryer.
- One estimate generally gives the lifetime of one UV lamp as a warranted minimum of 1,000 hours at full power; thus it is theoretically necessary to change those lamps every six or seven months. But of course, if the lamps are used at half-power or less (with the VPE systems), their lifetime will more than double. It is also very important to clean the quartz envelope of the lamps and the reflector with alcohol about every two weeks—this takes five minutes. You must be very careful **never to touch the lamp with naked hands.** The contact of greasy or moist fingers can damage the quartz.
- Because UV radiation is dangerous to the eyes and skin, it is necessary that the lamp (or lamps) be very well enclosed. But this responsibility rests with the manufacturer, so the user is simply obliged to refuse any UV curing unit which does not offer all the warranties desirable at this level.
- The UV curing unit cures only UV inks, although recent experiences have established that, with some UV lamps especially rich in infrared emissions, it is possible to dry some solvent inks. But generally the screen printer using a UV curing unit is obliged to follow a printing line and to always use UV inks on this line. However, there are numerous movable UV curing units; they can be shifted from one line to another inside the plant.

Also, two European manufacturers build units which are dual purpose; heating elements of a normal jet-air dryer are equipped to be used as UV curing units, too. For screen printers using both the standard techniques and UV on the same line of production, this formula has the advantage of adding inside of the drying unit body a UV curing unit which then does not need any supplementary floor space. This mix makes this drying unit multifunctional for either drying solvent inks or curing UV inks.

What Are We Able To Print With UV Technology?

The main question that the screen printer is likely to ask when he is interested in UV technology is: "Is it possible to print everything with UV inks?" or: "What exactly can we print with UV inks?"

In fact:

—UV inks are not the "miraculous, universal ink".
—It is not possible, today, to print "all" we are used to printing through screen printing.
—But 90% of what is normally printed in a screen printing plant with solvent inks can be printed with UV inks.

Furthermore, we must not forget that this relatively new technique is progressing all the time; the "impossible" of yesterday does not exist anymore today, and the "impossible" today may not exist tomorrow. Also, as an important point in favor of UV, we must consider that things impossible or difficult to print with standard techniques can become possible or easier to print with UV inks.

The simplest approach is to examine what, in the actual possibilities of UV technology, we **cannot** print with UV inks.

- It is impossible to print really opaque colors, either matte or glossy. This prevents what is often an advantage of screen printing: The printing of bright and light colors on dark backgrounds or dark substrates, whatever their chemical composition. Simply using the UV curing unit at full power and slow translation speed, we can actually obtain whites, golds and silvers that nearly cover. This remains impossible with oranges, yellows, bright reds and greens, and some blues.
- The adhesion of UV inks to the substrate being purely mechanical (and not chemical through attacking the substrate surface with solvents), substrates for which the surface tension is less than 38 dynes (chrome, nickel, stainless steel, polyethylene and untreated polyesters, for example) cannot be UV-printed if a very good adhesion is needed.
- UV inks, not being "thermoplastic" (softening under heat action), cannot be used for printing of polystyrene, PVC or acrylics before vacuum forming. The UV inks would "crack" under vacuum depression of the plastic substrate, especially if the depression is significant. The reason belongs to the principle of UV polymerization itself; this "cross-linked" polymerization, in three dimensions, does not have the suspension of the "linear" (in extensible chains) polymerization of the solvent inks.
- There is one last area where the success of UV printing has not yet been demonstrated—direct printing (or placement of vitrifiable decals) on glass or ceramic (porcelain, etc.). What characterizes this type of printing, in which the metal oxides "blend" together variously at 932°F, 1,472°F or more than 2,012°F with the material itself, is a "burning" of the resin base which carried the pigments during the printing operation and, in the case of decals, a burning of the varnish supporting the image before it is put onto the object to be decorated.

Numerous experiments and research have shown the impossibility for several UV bases and varnishes to "burn" and completely disappear through sublimation without leaving any traces. A certain yellowing or even brown traces appear which have a bad effect on white or light surfaces; those phenomena are almost imperceptible and negligible on colored backgrounds.

The most spectacular applications for which UV inks offer the screen printer the greatest facilities are certainly in four-color halftone printing.

- Halftone screen printing is no longer the privilege of a few very clever screen printers. For very large outdoor poster printing with very coarse dots (less than 45 lines/inch), and even for more sophisticated works in small size, there are numerous screen printers (mostly in Europe) now able to print 120- or 133-line halftones. The lack of drying into the mesh facilitates the printing of very fine halftone dots. By staying within the resolution power of screen techniques, and if (above their own specific properties) the UV inks have sufficient thixotropic qualities, four-color halftone printing of 150, 175 and even 200 lines/inch becomes quite possible.
- Besides, because of the very even absorption of UV inks into the substrate, one can use—with very good results—papers or cardboards that were impossible to print properly with solvent inks because they were too absorbent.
- The qualities of transparency of UV inks makes them especially able to be used for transparent color overprints. This technique, even without joining to it the halftone or "Benday" (manual halftone), produces an enormous number of "resulting" tonalities. I briefly recall this principle: 2 overprinted colors give 3 tonalities; 3 colors give 7 tonalities; 4 colors, 15 tonalities; 6 colors, 63 tonalities; 9 colors, 511 tonalities, and so on...This special technique needs only a perfect register.
- In the area of printed circuits, mostly microcircuits, UV resists permit printing of exceptional

fineness—up to lines of 20 microns. UV inks' curing speed in bottle printing allows production that is impossible to attain with solvent inks; 8,000 milk bottles/hour instead of 5,000, for example.

- Any kind of line work, flat colors or halftone work can be printed on papers, cardboard and practically all plastic materials (treated, if it is polyester or polyethylene), all self-adhesive PVC, treated or coated iron plates, anodized aluminum, copper, glasses and some textiles.
- Substrates can be used in sizes up to 47" x 72". Above this size, it is necessary to build special units with a battery of lamps mounted diagonally or in quincunx to the belt. In band (or strip) printing with continuous or spaced images, substrates up to a width of 65" can be used (special fabrications excepted once again).
- Substrates can be used for any shape and size for cylindrical, conical and oval objects.
- It is possible to print in UV about 90% of all actual screen printed jobs, including:
  - —All posters with line, flat areas or halftones, including the very large outdoor posters of 120" x 160" in several sections, or even larger;
  - —All advertising at point-of-purchase, window elements, pictures, exhibition counters, banners, decals, etc., used inside or outside of stores (the vacuum-formed excepted).
  - —Record covers and bookcovers—**except** if the basic material (paper, cardboard, textile or plastic) is too dark:
  - —Banners, flags, armbands, caps (decorative and for advertisements)—again excepting the dark textiles;
  - —All types of pressure-sensitive decals in sheets or rolls and labels if the substrates are white, transparent, metallicized or of light colors. For double-face adhesive decals (for glass doors or windows), whites for backgrounds and the opacity coat have to be printed with opaque solvent inks;
  - —Mirrors, if the prints are done after silvering. UV inks for glass generally have a poor resistance to the chemical silvering treatment;
  - —Water-type decals, for decoration or advertising; also "dry" adhesive decals;
  - —The coating of clears (in effect practically as glossy as laminates) over screen prints as over the lithographs, UV or not, if the litho inks do not contain waxes or silicones, which cause poor adhesion to the coated print;
  - —Plastic bottles (injected, extruded, centrifugated, etc.) in polyethylene, polystyrene, PVC, acrylics or even some polyamides;
  - —Backlighted vacuum-formed plates (acrylics, PVC or polystyrene), if they are printed **after** vacuum forming—meaning of course, their shape must be convenient;
  - —Wall coverings, pressure-sensitive or pasted of paper, plastics and textiles;
  - —Printed circuits, from large-size circuits to some microcircuits (conductors of a minimum width of 20 microns);
  - —Art serigraphs; any original or reproduction print based on transparencies or continuous tones (halftones without dots), as well as four-color halftones for art posters.

The "Three Big Questions" About UV

For the screen printer who must and can make an investment in the installation of a supplementary line—with a system of forced drying—or an investment in his first line, the problem during the 1980's can be put in the following terms:

Some very specialized applications of screen printing, e.g., labeling or electronics applications for which the needs are clearly determined, automatically carry their own answer. But, for the average screen printer who owns or manages a large plant or a small multifunctional shop (and who works by necessity or by taste on very different substrates), we must try to define an "approach" or a "standard attitude" concerning UV.

In practice, the three key questions are:

1. Regarding the technical possibilities, but also the limitations, should you choose or reject UV?
2. Is UV printing "qualitatively" and "commercially" satisfactory?
3. What does UV technology mean in terms of modifications in material and equipment in your plant, and in the level of the training for your staff and employees?

A. Whether to Accept or Reject UV

To answer this question let us review some facts. To choose, we must take into account the following elements:

- In a small printing shop having (or willing to have) only one semiautomatic or fully automatic printing line, the question is crucial because if UV is chosen, the whole printing line may be unusable for drying standard solvent inks. Conversely, if the line is equipped with a standard jet-air dryer, UV printing and curing will be impossible.
- The purchase prices of a jet-dryer and a UV curing unit are generally very similar. But the speed and ability of curing, the floor space needed and the energy costs entirely favor UV systems (except if they are inert atmosphere types). But the amount of the investment is high enough to oblige the screen printer (who is rarely able to adopt both of them at the same time) to weigh his choice with great care. At the same time, one must not forget that even if UV technology does not bring a definitive solution to any screen printing problems, it does offer a very good "intermediate" solution for the coming years, until the water-

based inks will be fully operational.

- Considering graphic possibilities, we must not forget that when it comes to opacity, UV inks cannot replace matte or gloss glycerophtallic inks. This means, graphically speaking, that UV requires more precise preparation work. There is also the inability to overprint certain colors and the necessity to limit to the maximum possible (for esthetic reasons) the overlapping (partial or only for the edges) of one color over another. All these factors oblige the screen printer to work with an almost "edge-to-edge" register, or with an edge overlapping of only 0.3 to 0.5 millimeters (+ or - 1/64"). These requirements necessitate not only a more accurate job in the preparation of films, photographically or by hand-cutting, but also a much better register control when printing on the press. But this is, after all, a good thing—and litho printers are obliged to do it all the time. More graphic and mechanical accuracy must become not the exception but the general rule.

But, for those usually printing sophisticated work (halftones in one or several colors, overprints of transparent inks, fine lines) or work with risks (cardboards printed on both sides, very plasticized PVC, registers of less than 1/64", printing of plastic substrates on which static electricity problems can occur during drying), UV technology insures a remarkable safety element.

My Own Opinion:

- For a large plant (more than 20 workers) which owns several printing and drying lines and would like to buy a new one: Yes to UV, without any restrictions.
- For a medium-sized plant (8 to 20 workers) which owns at least one line with a jet or other type of dryer, or maybe two lines, and which desires to increase its capacities of production with a second or third line: Yes, as well.
- For a small shop (less than 8 workers) the problem is not so easy to solve. Most times, this complete line will be the first one. Those shops usually hand-print or own one or two semiautomatic presses, and dry with racks. When they have to decide whether to buy a drying system to follow an existing or new semiautomatic press, the choice between any type of standard automatic dryer and a UV curing system can be very difficult. In this case, I would also say Yes to UV, with the provision that the shop closely review existing or potential clients and the kind of jobs they normally ask for. If at least 70% of those jobs can be handled with UV technology, it is wise to choose UV.

B. Is UV Printing "Qualitatively" and "Commercially" Satisfactory?

Qualitatively, the answer is Yes because, if it is true that at present some substrates still have problems (poor adhesion, fish-eyes)—as also occurs many times with solvent inks—it is easy to verify that the quality of UV printed jobs in several countries is often much higher than that of solvent ink-printed jobs.

Commercially, the answer is also Yes because:

- If the correct meshes are utilized (calendered meshes, for example)—together with an adapted technique of screen making and printing—ink mileage is very important (it can reach more than 4,000 square feet per gallon of UV ink). And in that case, in spite of the high purchase price of those inks, the "relative" price (in comparison to that of solvent inks for PVC) is lower and, if compared with jet-type inks for paper, similar.
- Large economies are realized with elimination of "cleaning solvents," which cause damage to screens (especially with indirect stencils, which turn fragile if used with several types of solvent inks) through too many screen washings during printing—washings caused by the need to open the mesh obstructed by drying solvent inks. With UV, there is no need for screen washing at lunchtime, in the evening or before a weekend if a long run is on the press.
- For the same reasons, there are no problems in starting the press while looking for the correct register or color. All this can be done without the slightest risk of ink drying into the meshes—and this means increased "profits" (savings) in time and improvement in quality.
- Risks of **offsetting** or **tacking** of the ink in stacked sheets disappear. This is important when piling sheets printed on both sides. There is no risk of partial finish dulling on pressure-sensitive PVC, as often occurs with solvent inks.
- The specific advantages of UV inks permit the screen printer to approach more delicate and difficult prints. This allows the screen printer to offer customers a larger scale of production. This is, of course, a way to increase the number of clients and the size of their jobs.
- The speed of curing, with the resulting decrease in "dead time," permits an increase in daily production.
- Lastly, I note once again that UV energy cost is two to four times less than with a jet-air dryer. This constitutes, in my opinion, a major commercial element—because nothing, unfortunately, indicates that energy costs will decrease in the coming years.

C. What Exactly Does UV Technology Mean to Modifications of Materials, Products and Training in the Plant?

When they hear about UV, numerous managers of screen printing plants (large or small) ask themselves if they will be obliged to make a full conversion of their plant—to change all equipment and presses, to use new products and to re-teach their whole staff. If the question alarms them, it is generally because of a lack of correct information. In fact, modifications of technology and material are **not** insurmountable tasks. And I would add that it is very good to be obliged from time to time to shake up the routine and those habits which, by blocking technical progression, wind up bringing regression—"He who does not progress moves back."

1. **Equipment**

- All equipment for stencil making is usable with UV: Screen stretchers, self-stretching frames, coating equipment, exposing and photographic equipment: No change.
- For printing, all types of manual, semiautomatic, flatbed automatic and cylinder objects presses are suitable: No change.
- For drying, a UV curing unit is necessary.
- For stacking, cutting, folding, etc., any classical equipment works perfectly: No changes.

2. **Materials**

- For the screens, it is necessary to use either very fine meshes or special meshes known as "UV calendered." For stencilmaking, you must use techniques producing thin coats.
- For printing, UV inks, of course. If it is necessary to diminish their viscosity (use of solvent is not suitable), the manufacturers of UV inks supply "thinner" which is, in fact, very liquid monomers.
- For cleaning screens and squeegees, either special solvents sold by UV ink manufacturers or ethyl acetate or toluol may be used, according to regulations governing your operation.
- Squeegee blades must be of polyurethane or synthetic rubber and must be very accurately sharpened, but here again special fabrications are not needed.

3. **Training**

- I must presume that screen printing plants versed in forced drying, whether standard or UV, have reached a certain technical level. If so, between three and five days of accelerated training is enough for both staff members and technical operators—if the training technician or consultant knows quite well the subtleties of the UV technique in use.

I have been asked if there is an almost universal rule regarding UV screen printing. After several years of experience in this I think that, as a matter of fact, there is one:

Everything, from stencil making to printing, must contribute in reducing the thickness of the ink coat.

I believe this is the 'Golden Rule,' both for commercial and technical reasons. To achieve this, one must learn the "why" and the "how." The "why" has been sufficiently explained by all the technical and commercial reasons given thus far.

This is also necessary due to the relatively high price of UV inks, which obliges the user to obtain the greatest possible mileage to make the whole process successful and profitable; and, for halftone printing, there is a technical necessity to obtain the thinnest possible ink coat to prevent problems resulting from excessive dot-over-dot thickness. To define the "how" will constitute the essential part of this next section.

The Choice of Mesh

Among the factors which determine the thickness of the ink deposit in screen printing, the mesh is without doubt the most important. If the pressure, durometer, sharpness and printing angle of the squeegee are so vital as may not be neglected, these factors affect not more than 30% of the ink deposit, and must be compared with the influence of the stencil (20%) and with the choice of meshes (50%).

The first proposal brought forth by mesh manufacturers was the use of thinner meshes for UV screen printing. Instead of 192, 225, 275 or 300 threads/inch—T or HD—it was recommended to use 350, 412, 450 or even 500 threads/inch in T or S diameters. But these meshes are quite expensive and (curiously) deemed very fragile by most screen printers. I believe this last opinion is false, because the entire polyester or nylon mass (if one compares, for example, a 250 threads/inch to that of 500 threads/inch) is nearly more for 500 than for 250, in spite of the difference in diameter of the respective threads (ø 50 microns for a 250 T, against ø 32 microns for a 500 T); it follows that a 500 mesh fabric is more "solid" than a 250! However, the factory price being quite relevant at this point, it is easy to understand the reticence of screen printers.

With UV, the ink going through the mesh will remain integral on the substrate after curing. If, for example, a 225 T allows a UV ink deposit of 20 microns in thickness, those 20 microns will exactly remain once cured (polymerized). If a solvent ink was used instead, after evaporation of those solvents the remaining "dry" ink coat would only be 9 to 12 microns in thickness.

If, graphically and colorimetrically, 6 or 7 microns of ink are sufficient to obtain the desired effect, whatever amount exceeds this thickness will be unnecessary as well as expensive. When printing three- or four-color halftones, the relative thicknesses of the first two ink coats will make the printing of the third and fourth coats risky, hindering them in reaching the substrate in some places, and causing "cloud" effects or print omissions prejudicial to a good final quality of the image.

Then, in order to have each ink coat of the necessary **minimum**, one must utilize very fine meshes, knowing that the finest (and the most expensive) on the market is actually 525 threads/inch, which deposits (under normal printing conditions) an ink coat of 9 microns; this may still be too thick in many circumstances. So, for UV printing, it is necessary to choose meshes permitting equivalent or thinner ink deposits under less expensive conditions.

UV Calendered Meshes

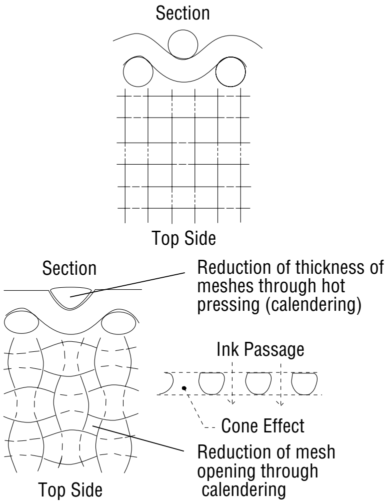
The Swiss fabric manufacturers, specializing in this very peculiar type of weaving of fabrics for screen printing, have been looking for a good method for reducing the thickness of their fabrics since 1976.

For this purpose they began from their experience with fabrics for textile printing, which were calendered in some cases. But, taking into account the kind of fabrics used—generally less than 170 threads/inch with a thread diameter of more than 60 microns—the precision of calendering was not sufficient for fabrics of from 225 to 500 threads/inch, which normally are used for graphic or technical screen printing. A lot of time and money has been necessary to solve this problem, but the desired degree of precision—to the micron—required such an effort.

After some experiences with heated calendering (at 176°F to 203°F) between two hard rollers, it was observed that those fabrics thus flattened on both sides did not allow ink to go through the mesh correctly, under squeegee pressure. It was promptly concluded that the fabric must be calendered on only one side, the squeegee side of the screen; the lower calendering cylinder then becoming a supple countercylinder rather than a hard one.

With these fabrics, the overall thickness of the mesh (including the crossed and superposed threads) is reduced and, because the mass of material itself does not vary, the mesh-opening reduces also. The "cone effect" obtained from the top (squeegee) side to the lower (substrate) side helped to obtain a correct ink path through the mesh, as well as increasing the surface for films or emulsions to hold on to. (See Figure 21).

Figure 21



Expect as a consequence a longer life for the stencils (especially indirect), and the possibility of longer runs. An unexpected result is the possibility, against all the rules concerning the relationship between the number of threads and the number of halftone dots, to print, say, 133 dot lines with a 225 T calendered mesh. This implies a line/mesh relationship less than 1.7, when generally 3.5 is considered as a minimum.

The first really satisfactory tests and resulting measurements were made during 1978 in Switzerland, and after those tests, the commercial products began to appear on the European market during May 1979 and, later, on the American market.

Very recently, after some controversy over the real utility of calendered meshes in the reduction of the ink deposit, we made extremely precise tests in Switzerland and France by mechanical and electronic examination, to study comparatively the thicknesses of the ink coat with normal and UV calendered fabrics. These measurements were made keeping absolutely constant all the printing and stencil elements: off-contact distance; printing speed; angle, pressure and durometer of the squeegee; temperature and humidity of the printing room; fabric stretching tension; stencil methods. The only variable then was, of course, the meshes used. The tests were made with 5 successive coats (after curing of each coat of UV ink) to obtain a total measurement, then divided by five, and compared with only one coat on nonabsorbent polyester substrates.

The results permit us now, with justification, to confirm that the UV calendered fabrics allow a minimum of 20% to 30 % in reduced thickness of the ink coat.

The following chart shows results from three much-used types of fabric, the printed UV being always strictly the same. These measurements can be considered absolute only so far as giving a reduction percentage of the ink coat thickness.

This ink coat thickness will, of course, vary from one ink to another, a variation of the ink thixotropy. The ink coat of a very thixotropic ink will always be thicker than that of a more "fluid" ink (See Figure 22), the difference being perhaps 3 microns.

This is a purely physical phenomenon: Inks—UV or otherwise—have a tendency to "spread out" simply due to gravity, if they are not thixotropic. The greater amount of ink put down under the mesh opening extends itself in the direction of the lesser amount put down under the thread-crossings; and so, the overall thickness of the ink coat reduces itself. A thixotropic ink will with a given fabric, yield a thickness of say, 10 microns. With the same fabric, a non-thixotropic ink might result in only 7 microns. But, in both cases, the percentage of reduction will remain unchanged, as indicated in the chart below.

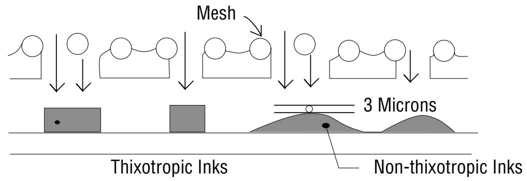
Mesh Count	Thread Diameter	Thickness of Ink (uncalendered)	Thickness of Ink (calendered)	% Decrease
300T	37 microns	13 microns	10 microns	22%
412M	32 microns	12 microns	8 microns	32%
450T	32 microns	10 microns	7 microns	30%

Screen Making (Stencils)

As with the choice of fabric, a very important point contributing also to reducing the thickness of the ink coat is the method used to prepare the stencil.

We all know that there currently exist three main types of stencils in screen printing: The direct, the indirect and the direct-indirect methods. The direct-indirect is the most recent of the three methods (this being relative, since this method was started during 1967). The majority of screen printing plants in the world use either the direct or the indirect method or both techniques. Curiously, and often contrary to any commercial or technical necessity, this is a kind of "national habit:" Germany, France and Italy use in majority the direct method; Great Britain and the Scandinavian countries use the indirect method.

Figure 22



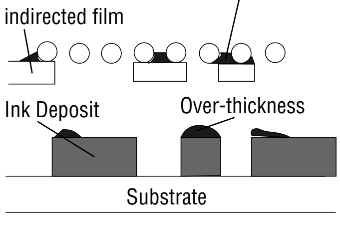
Of course, as often occurs in screen printing, there are unconditional supporters of one or the other technique. My own position is much more balanced; I believe we have to use the less expensive and more resistant direct method as often as possible. But, whatever is said about the resolution and line definition, for fine-line printing from 30 to 300 microns, or mostly for halftone printing between 100 and 175 lines/inch, some indirect films give much better results than the direct method. This does not mean it is impossible to print lines of 30 microns, or 133 line halftones, with a good diazo direct emulsion; but the result, the quality of image, the fidelity of the line or of the dot shape will be inferior, simply because the mesh interference is greater with the direct method. For UV printing, always abide by the "Golden Rule:" Use only thin coating techniques.

The Direct-Indirect Method

Let us consider this first, in order to dismiss it.

This stencil technique characteristically adds a thick coat of emulsion to a films which is thick in itself—consequently, a heavy deposit of ink follows. Generally speaking, even when using direct-indirect techniques with thin film we will obtain an ink deposit two to six times greater than by other methods, with the same mesh count. This is peculiarly true when printing lines finer than 1/12th of an inch; when printing flat areas of color, starting from 1/6th of an inch from the printing edges , the fineness of the mesh will become preponderant, an 'overthickness' of ink remaining along the edges (See Figure 23).

Figure 23



The danger, when printing with UV inks, comes from the fact that the UV lamp intensity and belt speed are adjusted to obtain a perfect curing of the centers of color areas—thus will not be sufficient for the edges of the printed color, where 'overthickness' exists. If, on the contrary, one increases the intensity of the UV lamp or slows down the belt speed, curing will be good along the edges but the centers of color areas will be overcured. This can mean poor adhesion of the ink to the substrate or between the ink coats.

However, there exist occasions when the direct-indirect can be used: for instance, where an important relief effect or a very precise thickness of the ink coat are necessary without the need for taking into account the price of the ink or the curing speed. This can be for practical reasons, such as the printing of Braille signs for example; for technical reasons, such as resists for printed circuits; or for esthetic reasons—texts or line in relief, etc.

The Direct Method

The general reasons for using direct stencils are the same for UV as for solvent inks. It is preferable to avoid light dispersion among the threads by using colored meshes—the best being the gold/orange ones—knowing that the calendered fabrics are also manufactured in this color.

You must not be led too much by manufacturers pretending to sell you special "UV emulsions." As a matter of fact, most of the bichromate or diazo emulsions on the market are quite suitable for UV printing, allowing for qualitative differences from one type or label to the other.

But the coating technique must be slightly different. As always, the rule remains to avoid thick deposits of emulsion, which favor a thick ink deposit. This means first that, under any circumstance and particularly for the screen printing of halftones and fine lines, the multi-coat process must be banished. This is also valuable for certain types of printing with solvent inks.

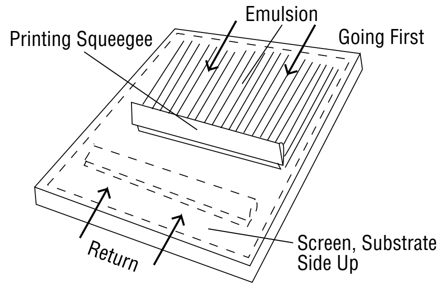
For me, the best technique for UV printing is the following:

(1) If a moderately resistant screen is needed (for 10,000 to 15,000 prints), proceed as follows: Put the screen on a horizontal table, the substrate side being turned upside. Put some emulsion on at the shorter side of the frame. Using a manual printing squeegee (with a very sharp polyurethane blade of 65° Shore), and without too much pressure, apply the emulsion as if it was ink (See Figure 24). Allow it to dry and expose the screen.

(2) If a very solid screen is needed (for 15,000 to 100,000 prints), it is necessary to proceed a little differently: The screen being in its printing position, that is to say with the squeegee side turned up (placed on four blocks of wood so

that the fabric does not touch the table), proceed as in (1)— across and return—but this time "inside" the screen. Let it dry, turn the screen upside down, and this time on the substrate side, add one simple coat of emulsion with printing squeegee. Allow to dry again and expose it.

Figure 24



One often underestimates the chemical and mechanical resistance of the emulsions; when I explain this stencil technique, several people used to exclaim, "It will never hold!" As a matter of fact, if the emulsion is a good one and if the fabric is correctly prepared, these direct screens will be just as solid as if they were coated four or five times. Even with the highest performance diazo emulsions, those "cutting the mesh," the thin coating process has the disadvantage of leaving more of the 'sawtooth' effect; but, as it is necessary to print UV inks with very thin or calendered meshes, the sawteeth are practically invisible to the human eye. A 5X or 6X magnifier is necessary to perceive these sawteeth.

Concerning the proper exposure, I propose two rules:

(1) First, and even more than for solvent ink screen printing, the film positives must be perfectly clean. The smallest dust, the smallest traces of mounting tape (according, of course, to the resolution power of the emulsion) will be repeated on the screen. With solvent inks, this phenomenon occurs too, but the partial ink drying into the screen mesh prohibits the reproduction of those traces on the printed sheet. Absolutely no drying into the mesh with UV inks, then, allows reproduction of the smallest fault.

(2) For this reason of non-drying into the meshes, it is better to increase the exposure time from 15% to 20% (according to the density of the film, of course).

All small retouches after drying (as also with solvent ink screen printing) must preferably be done on the substrate side of the screen. This avoids filler over-thicknesses which, if they are inside the screen, promptly deteriorate the squeegee blade. UV inks being relatively transparent, those squeegee "blade marks" are more apparent than with opaque inks.

The Indirect Method

The basic principles remain the same—don't use thick films; choose thin and very supple films or film types. Any films offering these characteristics are convenient. The lack of solvents or necessity of any cleaning of the screen while printing UV inks, or during interruptions, present great advantage for the user of indirect stencils, especially when printing fine halftone dots; it will be possible to print two- or three-times higher runs than with solvent inks.

However, "some" UV inks designed for "some" types of substrates contain chemically active monomers which may deteriorate "some" films. It is very difficult to be more precise about this point, because:

(1) One UV ink brand designed to print polystyrene substrates will damage one specific brand of film, but not another; with another brand of ink it may be exactly the contrary.

(2) A manufacturer having, for example, UV inks for the printing of polystyrene which do not attack any type of stencil film, might make UV inks for paper or PVC capable of damaging one or several types of film.

(3) But, in all cases and for all the manufacturers of UV inks, research is ongoing and the improvement of products never stops. If, as happens many times, the UV ink manufacturer does not know which type of his inks damage which type of film, it is up to the screen printer to make his own tests with the UV inks he will use.

The suppleness of the film is also a very important factor. Some screen printers using UV inks and indirect stencil methods have remarked that, after about 100 prints, some ink was going through the film, even in the most "closed" parts. This problem is most usually said to be on account of a chemical attack of the film by the reactive components of the UV ink. That is generally a false opinion: This problem is a physical one of relative elasticity.

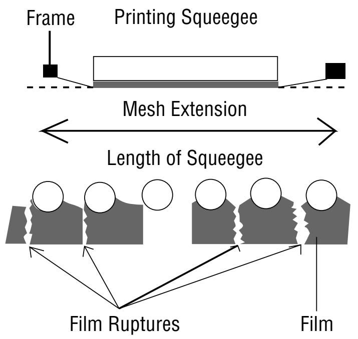
Confronted with this problem three years ago, I proceeded to a microscopic analysis during stretching tests. Continuous and discontinuous tractions were used to produce the movement of the fabric under squeegee pressure. Those tests permitted me to establish that the suppleness of the film was 2.3% lower than that of the polyester mesh. Starting from this point, it was easy to find through an integration of the "permanent off-contact" factor (more important with a flat-bed press than with a cylinder press) that the differences in flexibility induce, mostly in the lateral dimension of the screen, "cracking" or pinholes that allow UV ink to pass through the film, even if they are less than 5 microns in size (See Figure 25).

Of course, for the same reasons and in the same manner, this phenomenon occurs with solvent inks, but is "obliterated" by the drying of ink inside the meshes. This drying while printing obstructs those microscopic holes or cracks, but does not occur with UV inks.

The conclusion is that it is very important that the flexibility of the film be as close as possible to that of the fabric. This is also why it is better to use polyester fabrics than nylon, of which the elasticity coefficient is almost three times higher. (This is also better for register.)

Even more than with the direct method, the indirect films generally have a high resolution power, making it very important to have as clean as possible film positive. Otherwise, it will be necessary to use those stencil films having a weak resolution (thereby obliterating the mounting tape lines), which is not valuable if we have to reproduce lines finer than 300 microns in width. The use of very sensitive films implicates, if mounted films are in use, duplicating them to hide the mounting traces on the intermediary negative.

Figure 25



Concerning the light source, a correct calculation of the exposure time is not so easy. An underexposed stencil film, if it remains generally flexible, will have a poor chemical and physical resistance. Overexposed, it will be at the same time too thick and "crack," which will cause the problem seen above. The margin of maneuverability is then more narrow than with the direct method, and here again there are precise tests made by the screen printer himself which will give him the correct basis for the work he has to do, as a function of the products he uses.

The Halftone Plate (Stencil) For UV Printing

Each screen printer who has at some time tried to print very fine halftones has realized that, if he starts from color separations made according to litho contrasts and densities, it is almost impossible to obtain a good image quality when screen printing. To say precisely what I mean by "fine halftones," I should say that it is a question of 100, 120, 133, 150 and 175 lines/inch.

The screen printer and the film manufacturers too often forget that we superimpose onto the film dots another complex of lines created by the fabric itself. Generally, they take this problem into account only because of the moiré effect.

It is, of course, well understood that the very small dots can be placed under one or several threads (or thread-crossings) of the fabric and lose a good part of their initial surface. On the other end of the gray scale, small "negative dots" in the dark areas can hold only onto one thread or might even be placed within a mesh-opening. Because of this, the dot disappears when rinsing the screen in direct stencils or when peeling the backing sheet in the indirect method. The dots which are just barely holding-on will disappear after only a few prints. The result of those two facts is that the contrast of the image increases quite a lot: The light areas of the image will become too clear, the dark areas, too dark.

By a certain type of logic, one solution was to increase the dot size which resulted in the famous rule of the "15% to 85%" (instead of 0% to 100%), meaning that when making films one must confine the density closely to the center of the scale. This rule is much too simple, not only for fine halftones, but also for halftones with coarser dots (65 lines/inch, for example).

Besides, whatever the halftone screen utilized, there exists in screen printing important variables due to:

- The stencil method: In the direct method, the dot "splits" slightly following the fabric meshes and this induces an increase in the image density. With the indirect method, the dot keeps its shape; but the more difficult ink passage through a double thickness (film + fabric) reduces its size.
- The substrate: On an absorbent substrate, the dot has a tendency to spread out, causing the image to become darker. On a non-absorbent substrate (such as gloss or matte coated paper or plastic), the dot keeps its shape, but the contrast increases.
- The physico-chemical properties of the ink: These act mostly because of the "thixotropic factor," already explained.

With UV inks the fine dots are fully printed, at least what remains of them due to the fabric and the resolution power of the emulsion or film. There are fewer losses than with solvent inks. The conservation of the shape and surface of the "negative dots" remains in relation both to the thixotropic factor and with the "holding" of dots onto the fabric.

What we might call the "whole density" of the film—is always compared with halftone films for lithography; one finds that the film makers have a tendency to prepare very "light" films. We know that, when exposing the screen in screen printing, it is necessary to obtain a minimum hardening of the emulsion. This requires a minimum time of exposure to the light. With film positives made for lithography, to insure this minimum exposure will require such a long time that the smallest dots will disappear through "closing themselves." It is then necessary to ask the film maker to prepare films 15% to 20% more dense in their totality, as compared with litho films. It is, in fact, possible for the screen printer to increase the exposure time when making the stencil to take the dot size to its correct dimension, but it is impossible to reduce this exposure time under the threshold of minimum polymerization of the indirect film or emulsion.

As a matter of fact, the success in printing halftones depends on the quality of the film positives; it is up to the film maker when making the halftone positive to take into account the problems specifically related to the screen printing technique. To illustrate this problem, and to make it understandable to a film maker, I began from a study of the range of densities in a "gray scale," starting from the pure white (0%) to the black (100%), and going through grays from 10% to 90%.

Figure 26

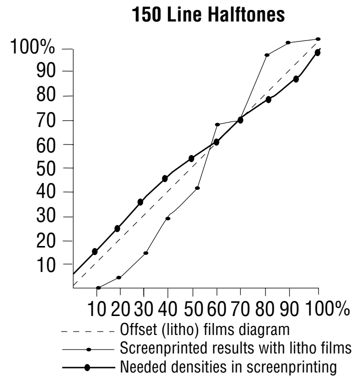


Figure 27

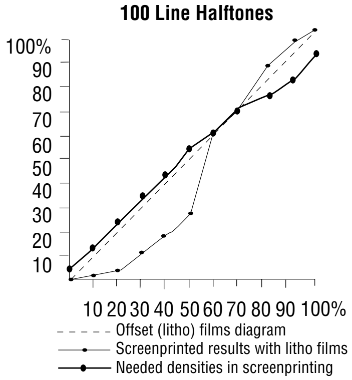
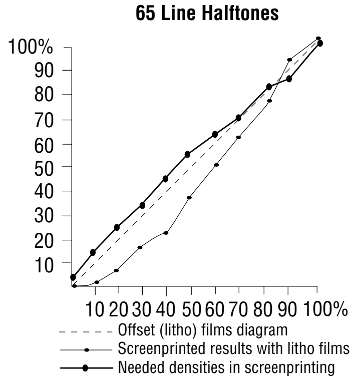


Figure 28



Using a good gray scale in 150 line halftone, the lithographic reproduction will be almost perfect, region by region, with only a loss of about 2% in the very light densities.

The same gray scale reproduced through screen printing on coated paper with a very good indirect film and a 425 threads/inch fabric, and with a good thixotropic **solvent type** ink will yield:
instead of 10% = 0%
instead of 60% = 65%
instead of 20% = 5%
70% = 70%
instead of 30% = 15%
instead of 80% = 95%
instead of 40% = 30%
instead of 90% = 100%
instead of 50% = 40%

The reproduced image of the gray scale will then be much too contrasted and very unfaithful.

It is interesting to note that this terrible "mid-range jump" (one passes from 40% to 65% in one step), which is also a problem in lithography, becomes a major problem in screen printing. Numerous are the screen printers who, while printing the reproduction of a face, have seen the light areas—many times too light—jump brutally to a greenish or reddish shadow, causing a disastrous effect! Partly because of this "jump," and to reduce it, the elliptical dot screen has been created. This dot shape softens the passage between 40% and 60%. I always recommend using it for screen printing positive films.

If we now print the same gray scale under the same conditions as above, but with a very thixotropic **UV ink**, we will obtain the following percentages:
instead of 10% =6%
instead of 60% =65%
instead of 20% =13%
70% =70%
instead of 30% =21%
instead of 80% =94%
instead of 40% =32%
instead of 90% =98%
instead of 50% =44%

A "reconciliation" with the ideal begins mostly in the light grays, but remains insufficient.

It is then necessary, region by region, to modify the densities of the positive film to obtain, while printing, a result as near as possible to the initial scale: That is, the specific fabric and conditions which will permit the restitution of the image according to its initial values. If your film maker is cooperative and has access to a scanner, with which it is possible to program the gray scale "step by step," it will be easy for him to make your color separations according to the following norms. To illustrate these modifications of the film positive, I give three examples with 150, 100, and 65 lines/inch.

150 Lines

For a print using thixotropic UV inks, T quality polyester fabric of 425 threads/inch, "fine" indirect film, and coated paper, the halftone film must be produced according to the following norms:
To obtain 10%, it is necessary to make 16%
To obtain 20%, it is necessary to make 26%
To obtain 30%, it is necessary to make 36%
To obtain 40%, it is necessary to make 46%
To obtain 50%, it is necessary to make 54%
To obtain 60%, it is necessary to make 58%
To obtain 70%, it is necessary to make 70%
To obtain 80%, it is necessary to make 78%
To obtain 90%, it is necessary to make 85%

100 Lines

Again, UV thixotropic ink, but using polyester (T) fabric of 350 threads/inch, a fine direct stencil with a very good emulsion, and coated paper:
To obtain 10%, it is necessary to make 14%
To obtain 20%, it is necessary to make 24%
To obtain 30%, it is necessary to make 35%
To obtain 40%, it is necessary to make 44%
To obtain 50%, it is necessary to make 56%
To obtain 60%, it is necessary to make 60%
To obtain 70%, it is necessary to make 70%
To obtain 80%, it is necessary to make 75%
To obtain 90%, it is necessary to make 82%

65 Lines

Using UV thixotropic ink, polyester (T) fabric of 300 threads/inch, fine direct stencil with a very good emulsion, and coated paper:
To obtain 10%, it is necessary to make 14%
To obtain 20%, it is necessary to make 23%
To obtain 30%, it is necessary to make 34%
To obtain 40%, it is necessary to make 45%
To obtain 50%, it is necessary to make 55%
To obtain 60%, it is necessary to make 64%
To obtain 70%, it is necessary to make 72%
To obtain 80%, it is necessary to make 78%
To obtain 90%, it is necessary to make 86%

It might seem quite strange to require more density with coarse halftone dots—65 lines—than with 100 lines, but coarser dots are cut by more threads of the fabric and a very thixotropic ink reproduces the interruptions due to the threads because it does not spread.

We have noticed that a very thixotropic UV ink will make a deposit thicker by 2 to 3 microns than that obtained with a non-thixotropic UV ink. The latter, even without any liquid monomer, will partly spread by capillarity under the threads of the fabric during the printing action, and also by gravity during the short amount of time between printing and passing under the UV lamp (See Figure 22). It is then necessary to ask the ink manufacturer to dose the thixotropic agent percentage in relation to the kind of work and the fabric, in order to have both a good image quality and the least possible ink coat thickness.

Figures 26, 27 and 28 illustrate the result obtained without any modifications to the halftone film (of litho densities), and give the needed modifications in each of the three cases seen above.

I should like to take this occasion to say that it is useless for the screen printer using fine line halftones to ask the film maker to give him scales and color proofs. If the films have been made according to the above norms, their being printed on a litho proofing press will have no relation at all to what the screen printer will obtain. It is up to the screen printer to make his own proofs through screen printing, and to eventually ask modifications of the film in accordance with his tests.

Screen preparation and stencil making should be made as indicated above, taking the simple precautions necessary for halftone screens: reduce dust; coat the screen without any trace or mark; films washed-out completely; exposure times reduced according to the halftone dots fineness; etc.

Printing

At this step, there are not so many elements influencing the thickness of the ink deposit. Of most concern is the printing squeegee and, to a lesser degree, the flood bar.

For the printing squeegee, three points are important:

- suppleness (Shore degree or durometer);
- printing angle;
- sharpness.

and a fourth point less determinant,

- the applied pressure and speed of application.

For the flood bar:

- sharpness
- its pressure on the screen fabric.

The Printing Squeegee

Of first concern is, of course, the flexible part of the squeegee, the blade, which generally is made of polyurethane or synthetic rubber.

Schematically, one can generally say that a soft squeegee, printing flat (under an angle less than 50°), rounded in profile, favors a thick ink deposit. Likewise, a hard squeegee, sharp, under a more vertical angle, will give a thin ink coat.

Excepting some special applications requiring a thick ink deposit, one estimates that for accurate and fine reproduction of image or text, a squeegee blade must be very sharp (square profile), have a suppleness of 65° Shore and print at an angle of 65° for

solvent inks.

In UV printing (always trying to reduce the ink deposit), a little harder blade is necessary; for instance, on a flat-bed press, 70° or 75° Shore durometer, and on a cylinder press, 75° or 80° Shore durometer. Concerning the squeegee printing angle, 70° to 75° will be convenient on a flatbed press and 75° to 80° on a cylinder press. From this coincidence (75° Shore/75° angle), it is possible to make a ‘rule’ for UV printing, also taking into account less pressure on the squeegee.

The speed of printing depends on the physical properties of the ink, such as consistency and thixotrophy—and of the substrate, whether absorbent or not; smooth or grainy surface; etc. But most of the time you can print at a higher speed with UV inks.

Concerning the sharpness, it will have to be as perfect as possible:

- First, because a well sharpened, correctly angled blade engenders a thinner ink coat on the substrate.
- Second, because the UV inks are to varying degrees generally transparent, and the smallest trace of damage to the blade edge is much more apparent than with an opaque ink.

With the band-sharpeners, the grain must be between 165 and 190. With a grindstone sharpener, the finest compatible with polyurethane or rubber grain is necessary.

The Flood Bar

The principles are similar to these for the printing squeegee:

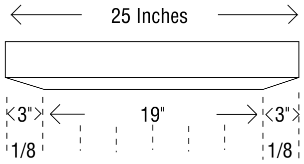
- thick flooding, without pressure on the screen = thick deposit of ink on the substrate;
- thin flooding, filling just the meshes (with some pressure) = thin deposit of ink.

Despite the “apparent risks,” both with solvent inks (especially for halftone printing) and more so with UV inks, I prefer to use very fine and sharpened flood bars. Steel blades of .001 to .0015 are preferable to rounded aluminum blades of 1 to .05 inch.

The sharpening must of course be perfect. The smallest “tooth” or “notch” irreversibly damages the screen fabric; the best sharpening is insured with an oiled grindstone (extra-fine grain). The blade edges and angles must be rounded, or even better softened following a gradual declivity on each extremity over about 1/8th of the total length of the blade (See Figure 29).

A word again about the printing speed. We have seen it does not relate directly with the UV factor

Figure 29



Flooding Blade

except as may be through its matching the curing speed; but, with a good adjustment of the lamp (or lamps) intensity and the conveyor belt speed, the possible curing speed actually exceeds the possibilities of screen printing presses—flatbeds, cylinder or objects—if the rule about the thin ink deposit is respected.

Lastly, a precaution to take if the printing of a long run is interrupted for one night or a weekend, is to cover the screen with a piece of cardboard to prevent both the fall of dust inside the screen and a partial polymerization due to the daylight and/or direct or incident solar radiation. However, because of the reactivity of some UV inks, it is better to wash the squeegee properly.

Hygiene and Worker Protection

With UV printing, screen printers are generally confronted with two types of problems in the matter of occupational medicine and environmental protection.

- the risks in relation to the UV curing unit itself;
- the risks in relation to the UV inks.

On the contrary, one problem is completely eliminated: the risks due to solvent vapor inhalation.

Risks with Regard to the UV Curing Unit

Essentially these are related to the ozone production (when it exists) and the emission of radiation out of the curing chamber, which must not exist.

The solution to these two problems depends upon the manufacturer. Concerning the ozone production, you only have to foresee its evacuation out of the printing plant. This gas will almost instantaneously destroy itself through oxidation in the ambient air outside.

Regarding the radiation leaking out from inside the curing chamber, or in case of an accidental opening of the chamber doors—if these happen, the design and construction of the curing unit is not good. It is then absolutely necessary to refuse to buy such an unsafe curing unit.

Risks Involving the UV Inks

If pollution or irritations are eliminated from the pulmonary point of view with UV inks (and this is a great advantage), it remains quite true that some of these UV inks can be irritating to the skin or the mucous membranes (eyes, tongue, inside of the mouth, etc.).

This form of irritation is not general concerning all UV inks and not general concerning all human bodies. This potential irritation is never systematic but belongs to the group of allergies. This means that, either naturally or through cumulative sensitization, reactions vary according to the individuals from absolutely no irritation, to either light or strong irritation.

The risks of reaction are higher when washing the screens or squeegee manually; also at this time, the risks of splashes (into the eyes, for example) are greater.

It is better to take some precautions, which are very general and, as a matter of fact, would be useful with solvent inks, too. We have to accept the fact that in screen printing, as with any other technique, there are persons who always work in a clean, safe manner and others who cannot or do not know how to do it. This is basically a question of training and education.

Before starting to work with UV inks, just as before the use of any other type of ink, it is a good idea to apply to hands and forearms one of the protective pastes (soluble in soap and water). Because the dilution of UV inks in solvents or cleaning agents favor their penetration into the skin, it is better to wear long gloves, that is, the type protecting also the forearms, when preparing and mixing UV inks, and
especially when cleaning the screens and squeegees.

If some UV ink is spilled on the skin, do not wash with solvents; they do not dissolve the inks, but disperse them. A good cleaning with soap and water is much preferable.

If it happens that the UV ink splashes reach the eyes, wash the eye immediately with a lot of fresh water and, if the irritation does not stop, you must see a doctor at once. Concerning safety eyewear, you cannot force people to wear them all the time against splashes, and protection against UV radiation is not necessary if the curing unit is well built.

General advice

As a kind of general rule, I should say that it is necessary to know exactly what you hope and expect from the UV technique of screen printing.

Then, I should like to add that it is a good idea anyway to listen to the advice and information that the manufacturers are—or should be—able to give you. This technique is in a continuous evolution, and the manufacturers are at the heart of the problem and have the capabilities of analysis and fabrication. They are able to solve the problems with regard to the basic technology, in the physical and chemical fields.

Within this framework I believe that, in the actual state of our knowledge about UV, it is necessary when you have to print an unusual substrate to make preliminary tests and to ask one or several of the manufacturers to adapt (or even formulate) one of the inks to the specific problem. None of them withhold the whole technology or the whole truth, but some of the manufacturers overcome certain aspects of the problem better than the others; it is up to you to find them. They will also advise you on the curing speed, the best ink viscosity, this or that type of press, the regulation of the UV curing unit, etc.

But these manufacturers cannot give advice about the stencilmaking or the printing itself: Screen printing is before everything else your technique, for you are screen printers and it is up to you to find your own solutions.

I shall be happy if this article can have helped you in that way. ■