Kirk-Othmer Encyclopedia of Chemical Technology.

PRINTING PROCESSES

Significant change has taken place in printing processes in the latter part of the twentieth century. This change, which embraces electronic technology, involves a shift in the printing and publishing industry to electronic prepress, electronic printing, and alternative media such as compact disk–read only memory (CD-ROM) and multimedia. Meeting the needs of the Electronic Age, these new developments could conceivably rival the cultural and commercial impact of the introduction of printing to the Western world. Just as the fast, economical printing production processes to which Johannes Gutenberg contributed around 1450 served to spread knowledge and advance civilization in the Renaissance, in the 1990s, the tools of electronic printing are helping to enhance global education and change the ways in which information is communicated. Spurred on by the impact of television, printing is demanding more color; shorter press runs, ie, more information flexibility; and a change in workflow integration. Printing and mass distribution are being replaced by electronic distribution of information and local printing for specialized, sometimes even individual, interests.

The role of chemical technology in printing is also changing. Whereas a need exists for hard copy, whether for visual, legal, or historical reasons, the hard copy must meet new standards of performance, including visual and environmental. Many traditional printing processes have become unacceptable in the workplace, and are being replaced by processes that are water-based, dry, desktop, or in some other ways more convenient.

There are four main printing processes: planography or lithography, intaglio or gravure, porous or screen, and relief (flexography or letterpress). Use of letterpress, which once excelled in the reproduction of text and pictures, has rapidly waned as first photolithography, and then electronic prepress systems, have increased in ability to provide text material without the setting of metal type. Although letterpress printing has diminished in importance, the relief image has been revived in the form of flexography using photopolymer elastomeric relief plates. These plates offer significant advantages in process and performance over rubber plates.

In general, the process of printing involves generating two physically different areas: the printing or image area, and the nonprinting or nonimage area. In relief printing, whether flexographic or letterpress, the image or printing area is raised above the nonprinting area. Ink is applied to the raised surface, which is brought into direct contact with the paper (qv) or other surface upon which the print is to appear. The relief printing process is used to print on a variety of paper and plastic packaging materials (qv) as well as for some magazines and newspapers, labels, and business forms. Water-based or solvent inks are used. Letterset describes the use of relatively thin relief plates for printing by the offset principle (see Inks).

In the intaglio process, the nonprinting area is at a common surface level but the printing area is recessed, consisting of wells etched or engraved, usually to different depths. The most typical method of intaglio printing is the gravure process. Solvent inks with the consistency of light cream are transferred to the whole surface and a metal doctor blade is used to remove excess ink from the nonprinting surface. Ink is transferred directly to the substrate, usually with an electrostatic assist. Gravure printing is used to print long-run magazines, mail-order catalogs, newspaper supplements, preprints for newspapers, plastic laminates, floor coverings, etc.

In the planographic or lithographic process, the image and nonimage areas are on the same plane, and the difference between image and nonimage areas is maintained by the physicochemical principle that oil and water do not mix. The image area is oil-receptive and water-repellent; the nonimage area is water-receptive

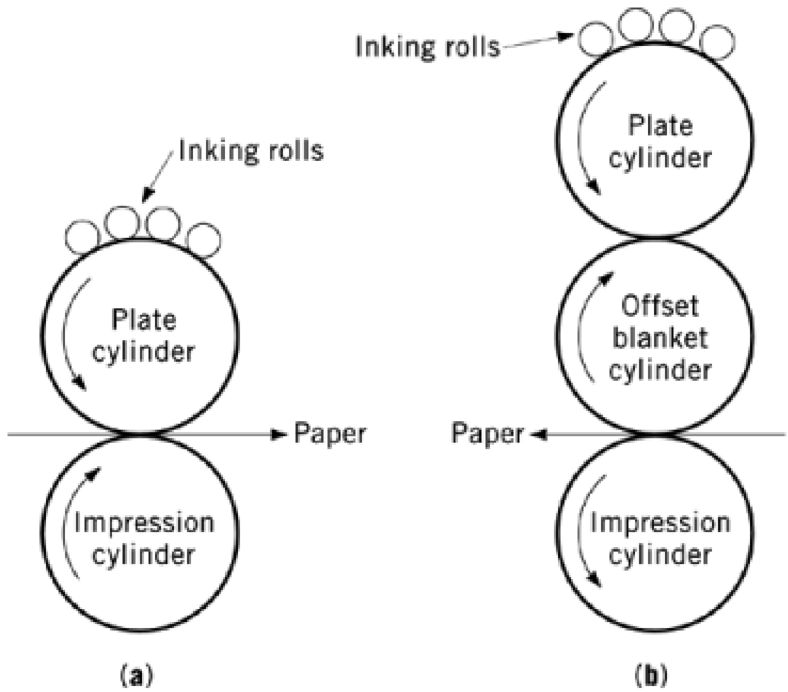


Fig. 1. Printing cycle for (**a**) direct and (**b**) offset printing.

and oil-repellent. Therefore, the ink adheres only to the image areas, from which it is transferred to the surface to be printed, usually by the offset method. This process is used for printing general commercial literature, books, catalogs, greeting cards, letterheads, business forms, checks, maps, art reproductions, labels, packages, etc.

In the stencil or screen printing process, a stencil representing the nonprinting areas is applied to a silk (qv), nylon, or stainless-steel fine-mesh screen to which ink having the consistency of paint is applied and transferred to the surface to be printed by scraping with a rubber squeegee. This process is used for printing displays, posters, signs, instrument dials, wallpaper, textiles, etc.

Direct printing is the transfer of the image directly from the image carrier to the paper. Most letterpress and gravure and all screen printing are done by this method. In indirect or offset printing, the image is transferred from the image carrier to an intermediate rubber-covered blanket cylinder, from which it is transferred to the paper (Fig. 1). Because most lithography is printed in this way, lithography is usually referred to as offset printing. Letterpress and gravure can also be printed by the offset method.

Images are defined for these printing processes in a number of different ways. Letterpress uses cast-metal type for printing. The other processes produce images on a support by manual, chemical, mechanical, or increasingly by electronic imaging means. As of this writing (ca 1995), the greatest number of plates and images are made by photomechanical methods. These systems are characterized by photographic images and light-sensitive coatings that, by using chemical etching or other treatments, lead to the formation of a printing surface. Increasingly, this printing surface is produced directly by electronic imaging without the traditional photographic intermediates. In some cases the final creation of a printing surface is electronic. These processes are termed computer-to-plate or direct-to-press.

A typical workflow involves image creation, capture, assembly, storage, approval, duplication, output, delivery, and distribution. A printing process workflow is shown in Figure 2.

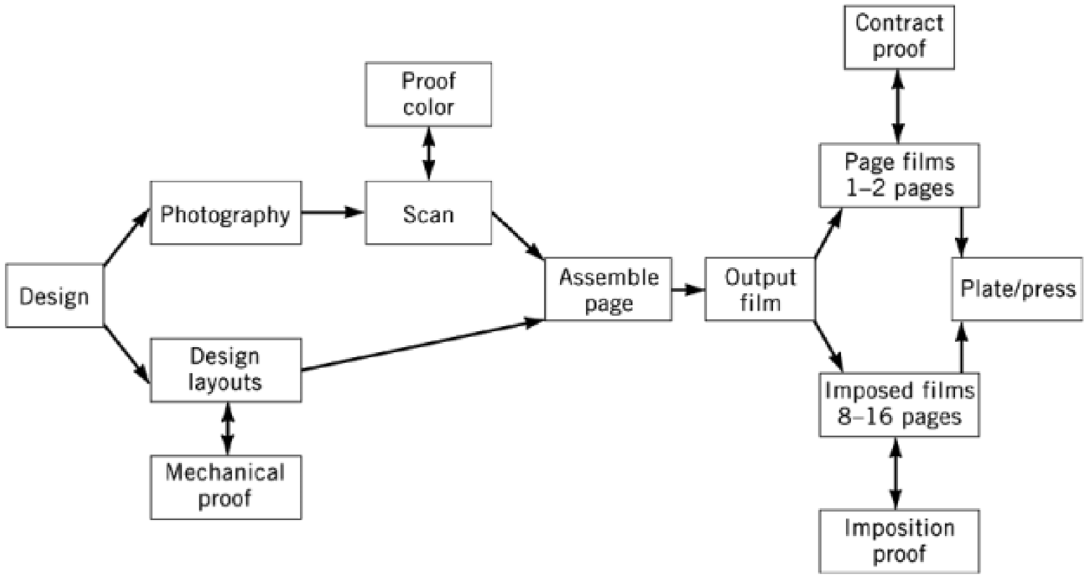


Fig. 2. Printing industry workflow.

1. Image Creation

1.1. Photography

Most press-printed illustrations are reproductions of photographic originals (1, 2). These originals may include paintings, drawings, or digital image files created using drawing or illustration software. Press-printed photographic images fall into three main photography (qv) categories based on intended use: commercial, editorial, and fine art.

Commercial photography typically illustrates a product or other salable item for a package, advertisement, catalog, or brochure. Commercial originals must be technically excellent and are often retouched to improve or enhance the image, or to remove blemishes. Editorial photography usually illustrates a magazine or newspaper story, thus pictorial content is more important than technical excellence. Fine-art photography is regarded as attractive, collectible, or salable as works of art, and may be press-printed in the form of posters, books, or prints.

Both the camera and the media play a role. The photographer chooses a film and camera, adjusting the camera variables to achieve particular effects and meet the requirements of the project.

1.1.1. Media Types

1.1.1.1. Black-and-White Negative Film. Black-and-white photographs are usually reproduced from photographic prints. To preserve maximum details, eg, in fine-art reproductions, an original black-and-white negative may be scanned directly.

1.1.1.2. Color Film. Most color photographic images reproduced on press are made from positive color transparencies known as slides. Transparencies are preferred over color prints for reproduction because of superior sharpness, tonal contrast, and color saturation (see Color photography).

Photographs made from color negative film are usually reproduced from a color print. These can also be reproduced directly from the negative either to extract the full sharpness and tonal range of the negative or, because negative films develop faster than transparencies, to meet a publication deadline. Color negative film has wider exposure latitude and greater tonal sensitivity range, making it ideal in rapidly changing or high contrast lighting, such as news or sports photography. About 2% of all press-printed images are produced from color prints made from an original color negative or transparency.

1.1.1.3. Common Film Sizes. The most popular photographic film format uses rolls of film 35-mm wide, producing a full-frame image measuring 24 × 36 mm (1 × 1.5 in.). A wide array of 35-mm films are available. Owing to economy, quality, and versatility, about 80% of all press-printed color transparencies are 35 mm. However, the small image size and high enlargements required can challenge lens performance, emulsion technology, and cleanliness. Dust and scratches are also enlarged. Larger originals tend to produce sharper, smoother, and cleaner results.

The next larger film sizes, considered a medium format, are 120-, 220-, and 70-mm roll films. The first two are about 62-mm wide and unperforated; the last is bulk motion-picture stock perforated along both edges. These are also available in a range of emulsion types.

When finest grain structure and maximum image sharpness are required, the original is photographed in a large-format camera using a separate sheet of film for each exposure. These cameras are heavier than roll-film cameras and usually require a tripod and/or a controlled studio environment. Common sheet film sizes include 102 × 127 mm (4 × 5 in.) and 203 × 254 mm (8 × 10 in.).

1.1.2. Camera

Choice of camera and camera settings affects the final appearance of the image. Variables such as the lens, which affects sharpness, magnification, and field of view of the image; lens aperture, which determines the lens opening through which light can reach the film plane; depth of the image field; and shutter speed, which controls the maximum amount of light reaching the film, all combine to produce the desired artistic effect. The other parts of the print process chain must then maintain that effect into the final printed page.

1.1.3. Filmless Photography

A rapidly emerging type of photography is the direct acquisition of monochrome and red–green–blue (RGB) images electronically using digital cameras (3). Digital cameras fall into two categories: those that can stop moving subjects with short shutter speeds or electronic flash, and those that require relatively long, tripod-based exposures and continuous illumination. The latter typically produce superior image quality but can only work with static, ie, nonmoving, subjects.

Digital cameras use two-dimensional charge-coupled device (CCD) arrays to generate instantaneously a digital image, thus substantially shortening the color production process. Both the traditional generation of film-based original artwork and the entire scanning process are eliminated. This technology is in its infancy as of the mid-1990s, but promises to improve rapidly, driven by savings in cost and time.

One digital camera technique uses a high density pixel device consisting of three interwoven arrays representing the primary colors red, green, and blue. Over each of these charge-coupled sensors is deposited a filter that determines its color. This system has the advantage of capturing all three colors simultaneously. Such arrays are difficult to manufacture and therefore expensive for high resolution image capture. An alternative system uses a single array, ie, either a scanned linear device or an area array, and movable filters whereby the system captures the color planes sequentially. This has the advantage of high resolution at a lower cost, but exposure times are longer. A unique variant of area array technology uses a low resolution color video CCD array mounted on a piezoelectric platform the location of which can be incrementally positioned so as to increase the resolution of the video sensor sixfold.

Disadvantages of these technologies include short depth of focus and intense lighting requirements. Moreover, they are not suitable for live models. Alternatively, high density television or vidicon tube technology can be used. This latter technology has the advantage of using standard flash lighting, which increases depth of focus while delivering only moderate resolution.

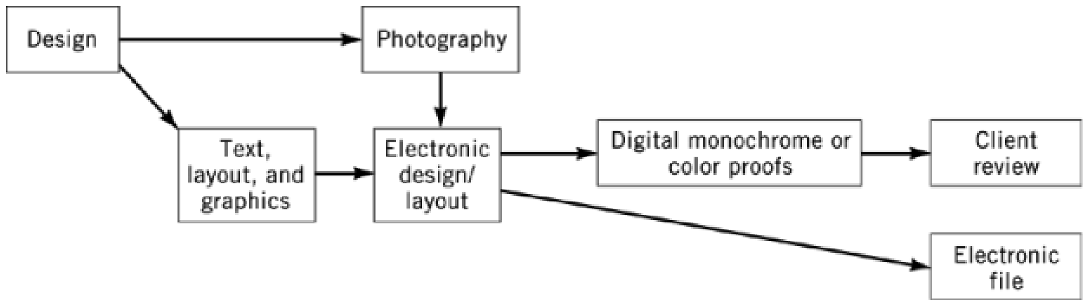


Fig. 3. Creative process workflow steps.

1.2. Creative Processes

Use of computer technology (qv) by designers, artists, illustrators, and photographers involved in the design and layout of printed materials has propelled the printing industry into a new digital era. Work processes have been radically transformed, giving the creators more prepress control of the printing process. More design alternatives can be provided to the client earlier in the process, the final solution can be developed faster and at less cost than previous conventional methods, and a fairly accurate representation of the color layout can be approved prior to release for prepress and printing.

Creative processes (Fig. 3) have four distinct workflow steps: conceptualization, electronic design and initial layout, preparation of graphic and photographic elements, and finalization of electronic mechanical. During conceptualization, one or more creative solutions are generated. Known as loose comprehensives or comps, these solutions representing text, headlines, and graphic elements can be prepared either conventionally, ie, by pen and pencil or color marker sketches, or electronically, by electronic sketches. After the sketches, the creator begins to develop a tight comprehensive of the design. Text and headlines are typeset and placed, along with existing graphics, illustrations, or photographs. This first layout is output in either black and white or representative color for review and approval of the design and layout by the client. In the third step, supporting graphic elements used within the design are created using drawing software applications. Photographs are taken and provided for scanning and placement. In the last step, all text and graphic elements are finalized and placed in position, and an electronic file is prepared for output.

Whereas each step has a unique objective, electronic tools allow the steps to be accomplished totally by the creator, thus changing the roles and responsibilities across the printing supply chain.

1.3. Synthetic Image Creation

Two types of synthetic image creation programs are available: bit map-based and vector-based (object oriented). Ultimately, all digital images are converted into bit-mapped (raster) images for display or output. The distinction between bit-mapped and vector is the form of the image in the creating application or program. Digital image creation can best be understood from the concept of bit-mapped images (4).

1.3.1. Bit-Mapped Images

A bit map is a grid pattern composed of tiny cells or picture elements called pixels. Each pixel has two attributes: a location and a value or set of values. Location is defined as the address of the cell in a Cartesian, ie, x and y coordinate, system. Value is defined as the color of the pixel in a specified color system. Geometric qualities of images are a function of the location attribute, ie, the finer the grid pattern, the more precisely can the geometric qualities be controlled. Color qualities are a function of the value attribute, ie, the more bytes of computer memory assigned to describe each pixel, the more precisely can the color qualities be controlled.

The fineness of the grid pattern, called resolution, is quantified in terms of pixels per linear distance. Common practice for commercial quality images assumes that photographic images can be reproduced accurately using about 300 pixels per inch (120 pixels/cm).

The number of bytes, each of which contains eight binary bits, assigned to describe each pixel dictates the number of colors that can be represented by the pixel. Assigning one bit to each cell allows two color values, eg, 0 or 1 (black or white). Assigning two bits allows four (2^2) color values, three bits allows eight (2^3), eight bits allows 256, and so on. Whereas 256 is not enough colors for commercially acceptable color photographic images, it is more than enough for commercially acceptable black-and-white photographic images, providing 256 shades of gray.

Assigning three eight-bit bytes, one byte for each of the additive primary colors, red, green, and blue, to a single pixel provides 16,777,216 colors (256^3). This arrangement, called 24-bit color, provides commercially acceptable color photographic images. Hence, depending on the number of bytes assigned to the value, images can be represented from monochrome through true color.

1.3.1.1. Creation. Users create bit-mapped images by accessing each cell in the bit map and assigning a color value to it. Software programs provide users with the tools to accomplish this, making the task easier, faster, and more intuitive. In effect, the user draws on the computer screen, using the electronic equivalent of conventional drawing tools. Because there are only two attributes associated with each cell, ie, location and value, the software tools allow the user to manipulate either the location attribute, the value attribute, or both. So many different tools have been developed that the effects available to the user are limited only by the user's imagination. For example, a program may have a fill tool that allows the user to fill a specified area with a desired color.

1.3.2. Vector Images

Conceptually, a vector image is not an image at all, but a set of equations defined by a user that directs the way a computer creates or alters a raster image. By storing only the equations and not the pixel information, vector images take up much less space than bit-mapped images. Moreover, they are also resolution-independent, because resolution is not specified until the vector image is converted to a raster image. Resolution independence is an advantage when a user desires to enlarge an image, whereas bit-mapped images lose information, ie, become lower resolution, when enlarged.

Vector-based programs provide tools for the user to define the equations in simple, intuitive ways. In fact, most users are unaware that their instructions to the computer are actually being used to define equations. For example, if a user wants a line across the top of the page, the line shows up on the screen as the user expects. However, the software has done more than simply display the line. The vector-based program in effect creates and stores an equation that defines the line. Complex definitions are, of course, required for more complex images. Typographic or typesetting programs are common examples of vector-based graphics.

Software tools are used to modify images in just about any way imaginable. For example, cloning allows a user to copy pixels from one portion of an image and place these in a systematic way in another portion. The principal application of cloning is to remove parts of images. For example, by cloning a background over an undesired image, the subject can be removed from the picture while retaining a natural appearance. Color correction functions allow a user to alter the color of the image. Typically, the user can make the image lighter or darker, or alter the red, blue, and green channels to change the color in a desired way. Sharpen and blur functions allow the user to alter an image to emphasize or de-emphasize portions of it. Images can also be resized, cropped, or inserted into other images.

1.3.3. Natural Images

Natural images typically originate as photographs and are invariably represented in some type of bit-mapped form. They are similar to synthetically created bit-mapped images except they are defined by a scanner that samples the light reflected from a photographic print.

1.3.4. Merger of Natural and Synthetic Images

Natural images and synthetic bit-mapped images can be merged directly to form a single image. A common software tool, for example, allows cutting of images from one file and pasting of the same image into another file. Such tools allow the user to define both the location and the amount to cut and the location to paste.

For a long time, the printing industry struggled to combine text (vector) and graphics (bit-mapped or natural images) capabilities in the same prepress system. This problem was solved with the advent of the PostScript (Adobe Systems, Inc.) page description language, which is capable of handling both bit-mapped and vector images, eg, a page that contains images scanned or created in a bit-mapped program and text or vector-based linework created in a page layout program. The two image types are not merged into a single file, but instead are processed separately as two separate layers until the image is converted to a raster image for final output. At that point, all layers are converted to bit-mapped format and merged together.

1.4. Creative Tools

Software applications, designed to perform specific functions, have changed the methods of producing a layout from conventional cut-and-paste techniques to electronic ones. Image creators are likely to have available powerful desktop publishing capabilities, an array of sophisticated software applications, and digital monochrome or color printers for digital proofing and review. Software applications allow the creator to produce illustrations and graphics, retouch photographs, compose and create page layouts, and perform prepress techniques such as placing high resolution images and other graphic elements into a page design or layout. Photographs and illustrations provided as hard copy can also be scanned and placed within the page layout as low resolution images and output to a digital printer.

2. Image Capture

2.1. Color and Color Separation

In 1860, James Clerk Maxwell discovered that all visible colors could be matched by appropriate combinations of three primary colors, red, green, and blue (RGB). His experiment involved mixtures of colored lights added together to produce other colors or white light. This additive color is well represented by the primaries RGB. Indeed, human color vision is trichromatic, ie, human visual response approximates receptors for the colors recognized as red, green, and blue (see Color).

Printers use colored materials, eg, inks (qv), that absorb or subtract regions of the visible spectrum from white light. Subtractive color is usually represented by the three printer's primaries: cyan, magenta, and yellow (CMY). Cyan absorbs red light, magenta absorbs green, and yellow absorbs blue light.

The nature of printing is such that each color of the primary set must be printed sequentially, one on top of the other, building up a color image one color at a time. The basic task of color prepress work is converting a color image into color separations that represent each of the CMY color components of an image. In addition, the color planes must be adjusted for the characteristics of the printing system. Inks used in printing do not represent the ideal CMY primaries. The inks are made from real pigments and must satisfy many other requirements, not the least of which is cost. The colors show overlap in their visible spectra, referred to as color contamination. Thus areas that are printed by using equal amounts of CMY, instead of appearing neutral, ie, grey or black, are actually colored. Also, the maximum amount of ink that can be printed plays a role. Ink quantity does not allow for a true deep black. In addition, it restricts the color gamut that can be achieved on a press.

Some of the color deficiencies can be overcome by using a fourth ink, black, which allows printing neutral tones and dark blacks and colors. Black also improves the contrast of an image and its apparent sharpness. Black, usually referred to as K to distinguish it from blue, makes up the fourth member of the printer's primaries, CMYK.

Although adding black increases the color gamut somewhat in the darker colors, it does not help in other regions of the spectrum. Compensation is made in the color-separation process by adjusting the tone of an image to provide a pleasing rendition, but not necessarily matching the original color.

Color contamination is another factor that needs to be considered. For example, a small amount of cyan commonly contaminates magenta. Thus, adding magenta to color-correct an image also adds cyan, which must be removed for compensation.

The color-separation process, then, becomes one of taking an image, usually analyzed in the RGB primary color space, and converting that image to the CMYK primary color space, while accommodating the deficiencies of the printing process. This is a highly nonlinear problem, which, because of the four channels, does not have a unique solution. Much effort has been expended, both in the traditional photomechanical process of color separation, and in the newer electronic systems, to achieve a goal of press-ready separations. Much of the workflow in a prepress shop is centered around separating color and checking the accuracy and suitability of the separations for printing. Reviews of color reproduction in printing (5) and electronic color separation (6, 7) are available.

2.2. Color Scanning

Historically, the process of color separation was done by using a process camera. A colored original was placed in a copy frame and photographed three times, once through each of a red, a green, and a blue filter. The red filter image produced the cyan plate, the green produced the magenta, and the blue the yellow. An additional image is created to make a black plate using white light (8, 9).

The color-separation process has been automated through the use of electronic color scanners. These devices convert color images to electronic data, which are used either to image directly monochrome photographic film that represents the cyan, magenta, yellow, and black content, or to provide CMYK or RGB image data files to computer-based pagination and retouching systems.

Color scanning technology can be grouped into two principal categories: photomultiplier or linear charged-coupled device (CCD) array. These are the actual components within the scanners that convert light to voltage (see Photodetectors). White light is passed through a spot or line on a transparency or reflected from a photographic print. The resulting light, which has been altered, taking on the color of the spot through which it has passed, is then passed through red, green, and blue filters and onto either photomultipliers or a CCD array where a voltage, proportional to the amount of color in the pixel being analyzed, is generated. These voltages are converted to dot percentages that range from 0 to 100%, where 0% represents no color, ie, white, and 100% represents a solid color. The spot or line of light is moved (scanned) across the entire image. After scanning, the image ends up as a rasterized array of numerical values representing the color value of each pixel in a file typically containing 32 bits (eight bits per color) of data per pixel (10–12).

One of the benefits of color scanning equipment is that is allows corrections to be made to an image during the image capture process. As each pixel is analyzed it is passed through a series of look-up tables or mathematical algorithms that alter the amount of each color (CMYK) based on operator instructions. The benefit of this process is that color can be adjusted as the image is captured, thus dispensing with the need for post-scan processing.

2.3. Process Camera

Although replaced by the digital scanner and imagesetter to a large extent, a process camera is still used in many shops to convert originals to film. The camera consists of a movable glass-covered copyboard to hold the original, a movable lens board, and a stationary vacuum back to hold the film. A bellows connects the lens board to the vacuum back. The degree of enlargement or reduction is governed by the lens and the distance from copyboard to lens and lens to film plane. The camera may be set up vertically or horizontally. The vertical camera's optical axis is perpendicular to the floor and has the advantage of compactness over the horizontal camera, in which the optical axis is parallel. Owing to a larger range of copyboard movement, however, the horizontal camera has a greater range of enlargement and reduction and is usually designed for larger original and film sizes (13, 14).

3. Image Assembly

3.1. Page Creation

3.1.1. Traditional Methods

In the preparatory stages of printing, the traditional process starts with one or more originals in the form of written matter, line art (diagrams, drawings), and photographs (1, 14). These originals are photographed to make films that, in a final step, are used to expose a printing plate. The conversion process often includes changing the size of the original to the size required on the page. Because most printing processes cannot print continuous-tone photographs directly, these photographs are converted to halftones in which the intermediate tones of the original are represented by solid dots on the film, which are spaced equally but vary in area (Fig. 4).

3.1.1.1. Halftone Screens. Halftone screens are used in cameras to convert a continuous-tone photograph to halftone dots (Fig. 5). Most screens, sometimes called contact screens, are made from film and consist of evenly spaced rows of vignetted dots. The screen ruling, usually expressed in lines per centimeter, governs the level of detail of the printed halftone. Finer rulings give greater detail. Newspaper halftones are generally produced by using a screen ruling between 25 and 50 lines per centimeter. Magazine halftones are produced with screen rulings between 50 and 60 lines per centimeter. Screen rulings up to 120 lines per centimeter may be used for special purposes.

Besides changing size, additional photographic steps may be required to achieve the desired effect on the printed page. For halftone images, the color balance may have to be changed to achieve a visual match with original art work. Line art and text images may have to be manipulated to allow for registration variance on the printing press.

If the line art and text originals are sized correctly in relation to one another, these can be assembled together onto a stiff paper or acetate base to form a paste-up or mechanical and photographed as a unit. Line art or text that is not sized correctly is enlarged or reduced on the camera and assembly is done at a later stage. Continuous-tone originals are treated separately and assembled later.

To create the halftone image, the screen is contacted against the film in the camera. Exposure of the original through this screen creates a pattern of dots on the film that correspond in size to the different tonal areas in the original. The lightest tones of the original reflect the highest percentage of light, which penetrates most of the screen dot's vignette. In this area, a large dot is formed on the film. Darker tones reflect less light and penetrate less of the screen dot's vignette and result in a smaller dot being formed on the film.

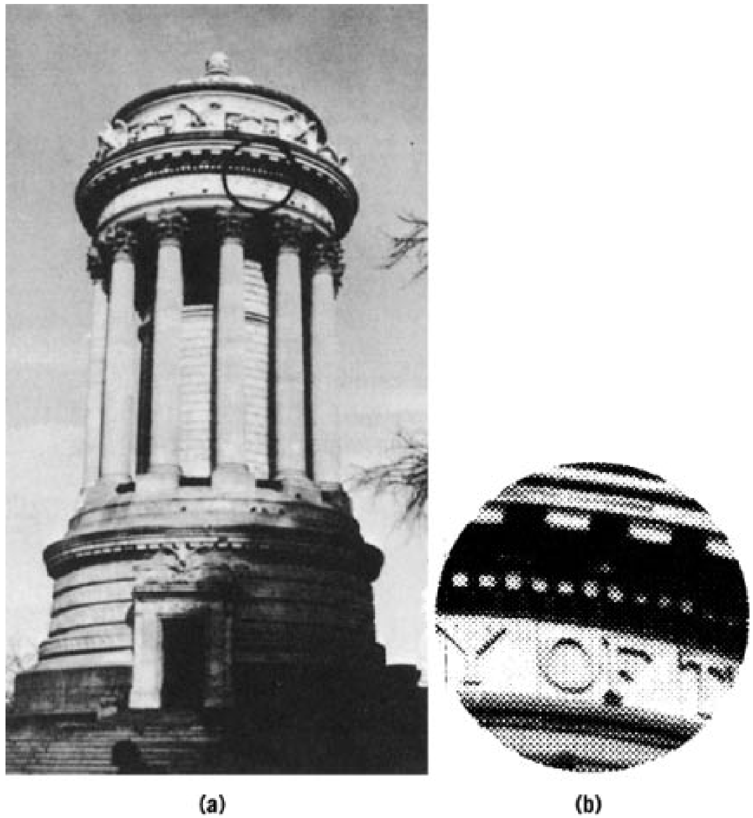


Fig. 4. Example of a halftone illustration. The circle in (**a**) indicates the enlarged area shown in (**b**), which reveals the image to be composed of halftone dots.

3.1.2. Typesetting

Typesetting or typography is the process of arranging, composing, and placing type onto the printed page. Typesetting has evolved through three important stages: hot metal, phototypesetting, and electronic (8, 13). The roots of typesetting began in hot metal with Gutenberg, who cast the earliest metal type used in Western civilization. Prior to metal, type for each individual printed piece was carved in wood, a slow and precise craft. Wooden type deteriorated after brief use.

Gutenberg developed a hand-held mold for casting individual type characters. These cast or blocks were then arranged, composed, and placed in the printing press (a letterpress). These metal casts made more impressions than wood before deteriorating, and new casts were quickly made. Lead alloys were the easiest and cheapest metal for use, and could be reused. Because each block resembled a single typeface and size, each different size and typeface required a mold and casting. Most of the terminology used in typesetting was derived from the hot-metal process, including face, feet, shoulders, body, and character.

The basic hot-metal process remained in use from Gutenberg's time to the late 1960s, but over the centuries became automated with the advent of equipment such as the Mergenthaler Linotype. This equipment allowed an operator to enter characters through a typewriter-like keyboard, which caused type to be cast one line at a time. These lines, or slugs, were then placed together to form a page.

Phototypesetting represented an easier way to compose type. Early phototypesetters used an optical process, whereby a disk of characters, in different sizes and typefaces, was spun under computer control.

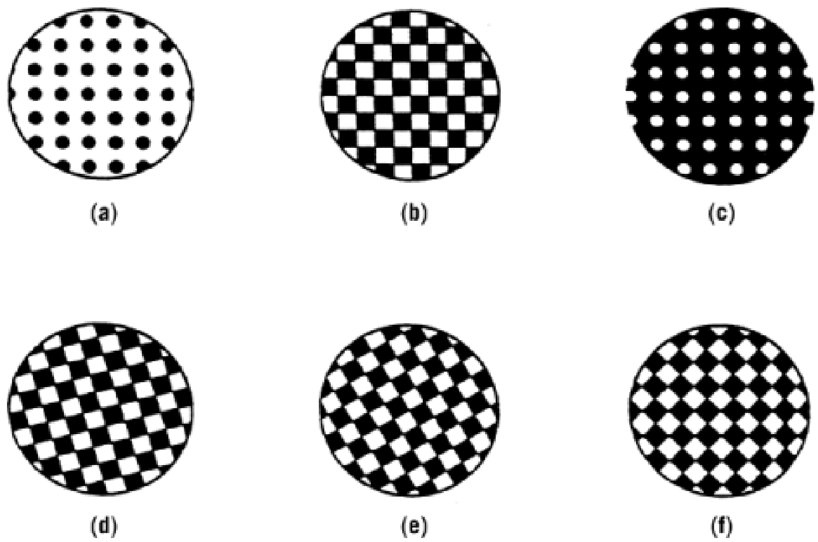


Fig. 5. Halftone dots magnified: (**a**), (**b**), and (**c**) are 20, 50, and 80% dots at 0°, respectively; (**d**), (**e**), and (**f**) are 50% dots at 15, 30, and 45°, respectively.

Each character was projected in turn onto photosensitive film or paper. This was followed by systems where characters drawn on a cathode ray tube (CRT) exposed the photosensitive material. In each case, the operator interacted with the system at a video screen that only showed the characters of the text (the information content) and codes that indicated how the characters were to look on paper. An experienced operator was required to obtain high quality results.

Conventional typesetting has been largely superseded by electronic typesetting using the PostScript page description language. Fonts and typefaces in PostScript, as well as in a similar system, TrueType (Microsoft Corporation), actually exist as mathematical descriptions of the characters. This allows each character to be rendered at arbitrary sizes and resolutions for different output devices. Electronic typographic programs are usually implemented in such a way that the operator sees a close approximation of the final output on a computer screen, ie, what you see is what you get (WYSIWYG). The operator can visually compose a page, making best use of the myriad fonts at his disposal.

The page layout program, which is used to prepare the text, generates a representation of the printed page, including text in the PostScript language. A PostScript raster image processor (RIP) interprets the PostScript commands and renders the image into a bit map, which can then be output on a printer or imagesetter.

3.2. Digital Page Creation

Historically, designers created the page, a layout artist recreated the page to exact specification as a mechanical, and then the prepress house, referred to as a trade shop, created the films for producing the printing plates. Individual page elements, type, and photographic images were transferred to color-separated film by the use of cameras. Strippers in the trade shop gathered the pieces of film for a given page and recomposed them for plate creation, one for each color printing plate that needed to be generated. As of the mid-1990s, many shops still use this technique, but usually the film has been electronically generated (8).

Using color scanners, photographs are digitized directly onto a computer system. These digital images are then positioned in an electronic page layout document that contains type and other page elements, created by the designer or production artist. Finally, the page is imaged to color-separation film or directly to the printing plate (4).

The pioneers of electronic page layout, ie, Du Pont-Crosfield, Linotype-Hell, Scitex, and Dai Nippon Screen, developed proprietary pagination systems to compose pages for color separation. Initially, only the largest commercial trade shops and printers used these complex, expensive systems. The conventional mechanical is sent to the prepress house, along with any photographic and type elements used in composing the page. Scanner operators input text, photographs, and other design elements into the pagination system. The operator digitizes the page by using the mechanical as an exact reference. Photographic images are scanned and added to the layout. Once the page layout has been established, it is imaged to film using an output recorder or imagesetter that exposes the individual colors to separation film or digital printing plates. The real electronic boom came as designers began generating final electronic pages using desktop personal computers.

Many of the tasks once performed only in a high end electronic pagination system, often called color electronic prepress systems (CEPS), are possible by using personal computers and work stations. Pages are composed on screen, and the results are output typically as PostScript files. The data are transferred over a network to the final output device.

4. Image Storage and Movement

4.1. Electronic Data Storage

Images in the prepress industry range from one megabyte to hundreds of megabytes, thus data storage capacity is a primary concern. Modern color electronic prepress systems rely on high capacity magnetic hard disks for quick data storage and retrievel. These drives reach capacities of several gigabytes (see Information storage materials, magnetic).

Many different types of removable storage media are also used. These have the advantage of utilizing a relatively inexpensive storage medium used in the more expensive drive equipment. Removable media storage systems also have the advantage of providing a simple means of moving large data files from place to place. These systems typically have capacities of tens to low hundreds of megabytes for magnetically based media, and close to a gigabyte for optically based media.

Compact disk–read only memory (CD-ROM), employing technology similar to that of consumer audio compact disks, has become a commonly used medium for the distribution of large image files because of their large data capacity and low manufacturing costs. Magnetic tape is still used for inexpensive long-term bulk storage and backup of files stored on other media (see Magnetic materials). Computer storage technologies are changing rapidly. A good source for information to remain current is any of a number of computer oriented magazines (15).

4.2. Networks

Image files are typically transferred among many different stages in the prepress process. This is most often done over a network that connects the various computer work stations used in the process. Although the subject of networks is beyond the scope of this article, some discussion is useful in understanding prepress workflow. The literature contains a more complete description (16).

At the lowest level, the network is the physical medium that connects the various pieces of equipment. This can be copper wire, often known as Ethernet, or optical fiber, ie, fiber-distributed data interface (FDDI). Networks allow transmission of data at nominal speeds of 10 to 100 megabits per second, depending on the physical medium used.

The next level is the protocol that governs how the data are transmitted over the wire. Many protocols are in use. A typical installation may have multiple protocols running simultaneously on the same physical network. Vendors of network hardware and software develop protocols that are optimized for the type of application for which their product is targeted. Among the protocols commonly seen in a prepress network are Apple Computer's AppleTalk and EtherTalk, and TCP/IP used by many UNIX work station vendors. The application software a user employs automatically uses whatever protocol is necessary to move information over the network.

The same concepts of a network as the local area network (LAN) in an office can be extended over a broader area, eg, wide area network (WAN), effectively to extend the network around the world. This type of network is becoming more important as prepress operations try to work more cooperatively with their clients, by accepting digital files over the network, or passing finished work back for approval.

The physical medium that links the LAN at each end of the network is typically supplied by a telecommunications provider. This can range from private networks, where the telecommunications company maintains physical links among the desired locations, to switched services such as switched multimegabit data services (SMDS), where high speed data links are made and broken as needed, much like conventional telephone connections. These services can range in speed from a few kilobits per second up to about 45 megabits per second. Again, these represent the physical link layer, and may support multiple transmission protocols such as frame relay or asynchronous transfer mode (ATM). In any case, to the user the result is an extended network that appears to be directly connected to the local network. The user is able to move images among locations as easily as moving them on a personal computer.

4.3. Image Compression

Despite the increasing capacity of storage media and speed of LANs and WANs, storing and transmitting large image files represent a significant expense. Many schemes to compress image files have been developed. Data compression encodes the information contained so that the resulting file is smaller. Two general types of compression are used.

Lossless compression preserves all of the information in a file, so the original file can be reconstructed bit for bit. This is usually accomplished by replacing data redundancies by tokens that represent the data. An example would be an image where much of the background is white. Most of the white pixels could be substituted by tokens representing the number of white pixels replaced. Because the tokens are much smaller than the runs of white pixels, the file is compressed. Lossless compression, represented by run length encoding (17) or Lempel-Ziv-Welch methods (18), are capable of moderate levels of compression, often about two or three to one. These do not provide much compression of natural images, which often do not contain much redundant information.

Lossy methods, on the other hand, do not preserve all the information. The original file cannot be reconstructed bit for bit. Lossy compression takes advantage of the insensitivity of the human eye to rapid changes in color in an image. These methods deliberately remove high frequency color information, but maintain all of the luminance (lightness) information where the eye is most sensitive. These methods, the best known of which is called JPEG, for the Joint Photographic Experts Group that developed the standard, are capable of compression ratios of twenty to one or more, depending on the amount of image quality degradation that can be tolerated (19).

4.4. Image Files

Only the physical problem of moving or storing files has been discussed herein. The format in which the data is actually stored or transmitted is another part of the process. There are a number of file formats, many of which are proprietary, developed to suit the needs of a particular computer platform or software application.

There has been some effort to standardize to a few file types, but many others are in use. A thorough discussion of graphics file formats is available (20).

5. Image Manipulation

After creating the set of halftones, line art, and type for a given page, the craftsperson may have to manipulate the images to produce the page as designed. These manipulations, which depend on the type of printing plate and press to be used, include changing negatives to positives or vice versa, combining images, duplicating images, changing image orientation from right reading to wrong reading or vice versa, correcting color balance, and making line or text images thicker or thinner to provide overlap between colors during printing (14).

Most often the manipulations require making contacts by placing unexposed film with the film to be contacted into a vacuum frame. Contact is maintained between the two films by evacuating the air between a plate covered with a corrugated rubber blanket and a sheet of plate glass (qv). Originally, orthochromatic films exposed with low power tungsten lamps under red safelight conditions were used. To enhance productivity and worker comfort, films are now formulated to work under bright yellow or white light in normal room conditions. Metal halide or quartz halogen lamps having high ultraviolet output are used as exposure sources. Negative working contact films and positive working duplicating films are available.

Once films corresponding to all of the separate components of a page, eg, text, line art, and halftone images, have been made in their final forms, they are assembled onto a carrier sheet to create a flat. More than one flat are necessary for complex or multicolor pages. This stage of image assembly is commonly known as stripping, because this process at one time involved stripping film emulsions from a glass plate (8). The flat is used to expose the printing plate to form a printable image. For negative working printing plates, negative film images are set into windows of a plastic carrier sheet to create the negative flat. The carrier sheet is colored to block actinic light so that only the clear areas of the film appear as images on the plate. For positive working printing plates, positive film images are positioned onto a clear plastic base to create the positive flat.

Positioning the various pieces of film is critical. Stripping tables are used to provide an illuminated surface to position films on the carrier sheet. The working surface is usually a sheet of plate glass frosted to diffuse light from fluorescent tubes underneath the glass. Often the edges of the stripping table are machined to provide straight edges for T-squares. For more critical work, precision layout tables having micrometer-adjustable straight edges are used. Flat-to-flat registration is provided by pin punch systems.

A special form of image assembly, used especially in label making, involves creating one image as a flat and using that image to make multiple identical images on different places of either a film or the printing plate itself. Step-and-repeat or photocomposing machines automate this task (13).

5.1. Electronic Film Output

Imagesetters are precision electromechanical devices that image monochromatic color separations onto photographic film or paper. Each separation is used to expose a printing plate for a single ink color (4).

5.1.1. Imagesetters

All modern imagesetters use a laser light source to expose the media. Imagesetters should not be confused with color film recorders, which use similar technology to expose full-color images onto a single piece of film. Many different laser technologies are in use, each requiring different media sensitivities (see Lasers). Helium neon, HeNe, lasers produce a visible red light (633 nm) and use media that must be handled under green safelight conditions. Argon ion, Ar^+, lasers produce blue light (488 nm) and allow more convenient amber safelights to be used. Other laser sources include far red laser diodes (785 nm), frequency-doubled yttrium aluminum garnet (YAG) lasers (532 nm), and infrared laser diodes (826 nm). The light produced by these lasers is focused to a tiny spot and modulated to control the placement of marks on the medium. In general, laser diodes can be modulated directly by controlling current flow to the diode, whereas gas lasers, eg, argon ion, require external beam modulation through an acousto-optic modulator (AOM) or similar device (see Light generation).

Three principal imaging technologies are in use as of the mid-1990s. External drum imagesetters use vacuum or mechanical means to affix a sheet of media to a cylinder. The cylinder rotates at a high speed, typically 300–1000 rpm, while the laser head slowly traverses the width of the drum. An advantage of external drum imagesetters is that multiple laser beams can easily be fitted to the imaging head, thus increasing the film exposure speed.

Internal drum imagesetters affix the film to the inside of a semicircular shape. The film typically covers between a 180 and 270° arc. Both the drum and the film remain stationary during the imaging process. A single laser beam is aimed down the axis of the drum at right angles to a spinning mirror, which deflects the beam onto the medium. The spinning mirror slowly traverses the length of the cylinder to allow exposure of the complete sheet of film or paper.

Capstan imagesetters, the third common technology, slowly advance the film or paper across a flat surface. A single laser beam is scanned across the width of the medium by a rotating polygon or resonant mirror.

All of these technologies require careful attention to the film transport mechanism to avoid imaging defects. The sizes of the features produced on the film, typically resolution of 1000 spots/cm or greater, and the accuracy of spot placement both require high precision equipment. Even minute misplacements of spots can produce objectionable visible artifacts.

5.1.2. PostScript

Designers use electronic page composition systems to create pages, but imagesetters plot only monochromatic film separations. Imagesetter output requires that the data be converted from full-color pictorial information to its individual color components. Additionally, the data must undergo a significant format conversion. Electronic page composition systems represent data in a relatively low resolution format, typically 120 pixels per centimeter for desktop printing and 28 pixels per centimeter for video monitors, using eight bits each of cyan, magenta, yellow, and black data for each pixel. Because most imagesetter lasers are binary devices, where the laser beam is either on or off, the data must be converted to monochromatic format with only one bit representing each pixel. Imagesetters compensate for the loss of binary levels by operating at a much higher resolution, up to 2000 spots per centimeter, and using area coverage algorithms to represent different shades of gray as dots of varying area. These rows of dots, made up of the much smaller imagesetter spots, are referred to as screens for historical reasons. Screens typically consist of rows of dots having a resolution of 33 to 120 lines per centimeter.

The PostScript page description language was developed by Adobe Systems, Inc. in the 1980s to provide a common format for describing page contents (21). It has been adopted almost universally by desktop publishing vendors, and many of the high end proprietary page makeup systems (Du Pont-Crosfield, Scitex, Linotype-Hell, Dai Nippon Screen) also support PostScript.

PostScript, an intermediate language, is converted into the appropriate imagesetter data stream by a device called the raster image processor (RIP). The RIP, which can be either a dedicated hardware device or a software program that runs on a standard computing platform, typically operates in two stages. First, it processes the entire PostScript file and builds a display list of all images, text, and linework elements that comprise the page. This display list is independent of the characteristics of the imagesetter. Then, the display list is screened at the resolution required for the imagesetter, and a binary data stream (bit map) is created for each color separation.

5.1.3. Conventional Screening

The primary objective of screening is to use area coverage algorithms to represent different shades of color, despite the fact that the imagesetter laser is typically a binary (on/off) device. The biggest difficulty in screening is the prevention of moiré patterns, which are interference patterns that occur when two or more color separations overlap.

It can be mathematically shown that no moiré patterns occur when the rows of dots in each color separation are rotated exactly 30° apart. Color printing, however, is a four-color process. Only three colors can be assigned screens that are exactly 30° apart, because a screen at 120° is the same as a screen at 30°. One color must be assigned an angle that is only 15° apart from two other screens. This introduces a moiré pattern. The yellow plate is usually assigned this angle because its lighter moiré patterns are less objectionable than moiré patterns in the cyan, magenta, or black plates (22). A typical set of screen angles is therefore 0, 15, 45, and 75° (see Fig. 5). Another problem is that these angles do not line up exactly with the rectangular grid of spots that is exposed by the imagesetter. Complex screening algorithms are used to minimize artifacts from the mismatch between the recorder grid and the desired angles (4).

5.1.4. Stochastic Screening

Stochastic screening (23), also called frequency-modulated (FM) screening, is another way to eliminate problems with moiré. Instead of using a fixed angle for each screen and varying the size of each dot, a random distribution of small, fixed-size dots is used. Different amounts of color are represented by more or fewer dots in a particular region.

Stochastic screening can produce images that rival photographs in their quality level. However, the small dots used by stochastic screening can cause problems in proofing, plate-making, and printing. It remains to be seen whether stochastic screening is to become a permanent part of the printing process.

6. Image Approval

At this stage of the printing process, it is desirable to check the position and appearance of the text and color images. The process check can also serve as the standard by which customer approval of the completed print order is defined. This step in the overall process is called proofing and can be carried out by analogue or digital methods, depending on the overall printing process steps in use.

For both analogue and digital prepress processes it is frequently necessary to check the appearance of an image and then to gain customer approval to proceed with the expensive step of image duplication by printing. For this purpose, proofs are made at several steps of the workflow (see Fig. 2).

6.1. Analogue Proofing

Analogue proofing can be described as the process of making an image, either monochrome or color, by photomechanical methods for the following purposes. (*1*) Production or quality control within the shop. Production procedures prior to plate-making, such as scanning and stripping, are areas of frequent change or opportunities for error in the printing process. A proof can be used to evaluate these procedures and errors can be corrected prior to the expensive process of making final plates for the press. Internal uses within the printing operation for analogue proofs include scanner setup, color correction, check on stripping procedures, press guides, quality assurance, and bindery operation setup. (*2*) Communications medium between the trade shop, printer, and customer who desires the print job. The parties producing and desiring a printed image often need a means of visualizing and understanding what is said. A proof is a tool that can be used to bridge the communications gap and ensure that the printer is producing what the customer wants. (*3*) Contract or contract proof between the parties producing the print and the customer. The proof, a representation of the appearance of the final image off-press, can serve as a contract to protect all parties should a significant discrepancy occur in the final image from the press. Photomechanical off-press proofing systems yielding halftone proofs have enjoyed wide usage as a result of their consistency and accuracy in predicting the color obtained from the press and the high cost of press proofing in terms of materials, labor, and press ready-time to make color images on a press. In addition, the ready acceptance and confidence of the customer base, in viewing and evaluating off-press proofs as an integral feature in the image approval process, has steadily progressed over time.

6.2. Color-Proofing Methods

There are three principal analogue color-proofing methods commonly used in the industry. (*1*) Monochrome proofing. A monochrome proof is a single-color image on paper or polyester film that depicts image placement, imposition, limited registration detail, and production errors. Some commercially available monochrome systems are Dylux (Du Pont), CopiArt CP-3 (Fuji), and Dry Silver (3M). (*2*) Overlay proofing. The proofs are an assembly of individual monochrome images on individual polyester film sheets, typically yellow, magenta, cyan, and black colors, which can be overlaid in register to produce a four-color image representing information from each color separation generated from the scanner. The proofs can be used as progressives by the printer in the form of one-, two-, or three-color overlays; checks on registration by the stripper; and for lower quality color approval work. Distortions in color perception arising from light reflections off the polyester image-bearing sheet detract from overlay proofing as a tool for accurate color prediction. Some commercially available overlay systems include Color Key (3M), Cromacheck (Du Pont), and NAPS/PAPS (Hoechst-Celanese). (*3*) Surprint proofing. These proofs are the highest quality four-color images available for off-press proofing uses. The proofs are assembled in such a way that the individual colored images lie directly in contact with one another and, unlike overlay proofs, are not capable of being leafed through or pulled apart into individual images after the assembly process. Surprint proofs provide the best print prediction or simulation of color obtainable from the press and are used extensively in the color approval process as the contract proof between the trade shop, printer, and customer. Some representative, commercially available surprint proofing systems are MatchPrint (3M), Cromalin (Du Pont), WaterProof (Du Pont), Color Art (Fuji), and PressMatch (Hoechst-Celanese). A proof can be made in the printing operation anytime a question arises as to the appearance or quality of the image to be produced by the press. The proof approval process can be complicated because of the many iterations for color acceptance by the customer. The separations used to make the proof can be color-corrected many times before it is shown to a customer; even then the customer can request more changes, which may necessitate the remake of the separations. In any event, the product of the process is a set of final film separations to make the printing plates and a final proof to be used as the guide and contract for the printing process.

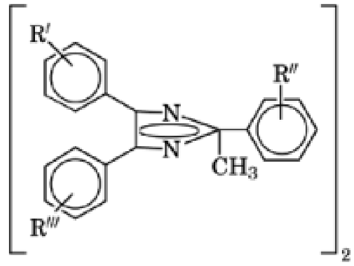
6.3. Monochrome Proofing

Several monochrome photoimaging systems can be used to produce a single color for proofing applications. The photoimaging ingredients are coated on paper and/or film and can be used for proofing and/or as a registration master. The chemistries used for color formation are complex reaction schemes involving the oxidation of leuco dyes by a biimidazole dimer or the photolysis of polyhalogenated compounds upon exposure to uv light (360 nm). Du Pont's Dylux is typical of the oxidation of a leuco dye and the key reactions can be represented by the following, where L_2 is a biimidazole dimer **(1)**; $L^{\bullet}$, the biimidazole radical; RH, a leuco dye **(2)**; and R^+, a dye.

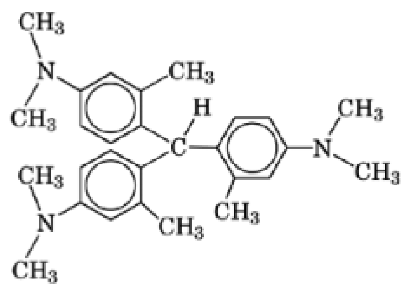
$$L_2 \xrightarrow{h\nu} 2\,L^{\cdot}$$

$$L^{\cdot} + RH \longrightarrow RH^{\dagger} + L^-$$

$$2\,RH^{\dagger} \longrightarrow R^+ + RH + H^+$$



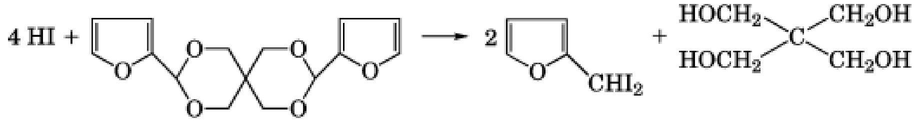
(1)



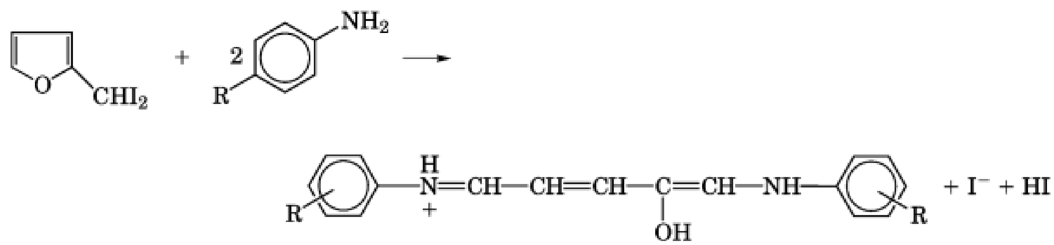
(2)

After imagewise exposure to uv light through a negative separation, a deactivation (or fixing) exposure using only visible light is recommended to stabilize the image by the photoreduction of quinone. The photo-oxidation of the leuco dye and photoreduction schemes have been described (24–28). A unique feature of Dylux is the dual response, which can be used to generate both positive and negative images in either a deep blue or gray color. The intensity of the color image is controlled by the amount of exposure. Thus color breaks, ie, simulation of two or three density levels in a multicolor job, can be performed by the customer. Some other important characteristics of this monochrome proofing system include an intense, blue image to aid register and alignment; an image on paper that can be folded and marked; and room-light handling.

The photolysis of polyhalogenated compounds forms the basis for another monochrome system. Iodoform can undergo photolysis to produce hydrogen iodide, which subsequently reacts with a di(2-furfuryl) derivative **(3)** and aromatic amines to produce a colored dye adduct **(4)** (29). The photolysis scheme and subsequent reactions can be shown by the following:



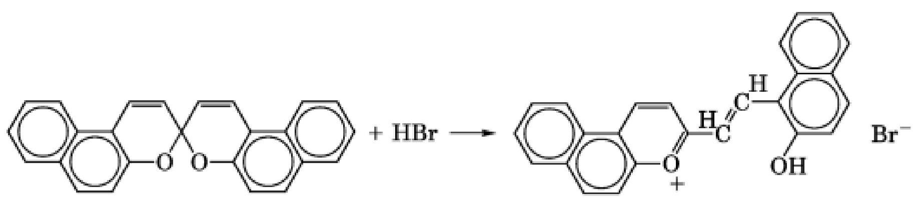
(3)



(**4**)

Another halogenated photolysis (30), using carbon tetrabromide to produce hydrogen bromide and subsequent reaction with spiropyran **(5)**, produces a highly colored spiropyrilium bromide salt.

$$CBr_4 \xrightarrow{h\nu} CBr_3^{\bullet} + Br^{\bullet} \xrightarrow{[H]} HBr + HCBr_3$$



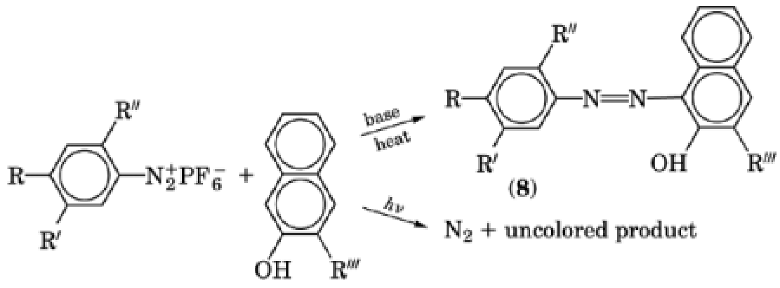
(**5**)

Thermally processed silver systems can also be used as monochrome proofing products. Dry Silver papers and films, as developed by 3M, are exposed to light to form a stable, invisible latent image, which upon heat processing at 126–138°C for about 20 seconds produces a high resolution black image. The chemistry involves the reduction of silver ion in the latent image by hydroquinone or a similar substance. Several references are available that detail the chemistry (31–34). Dry Silver coatings can be applied to paper and polyester films to provide opaque or translucent images.

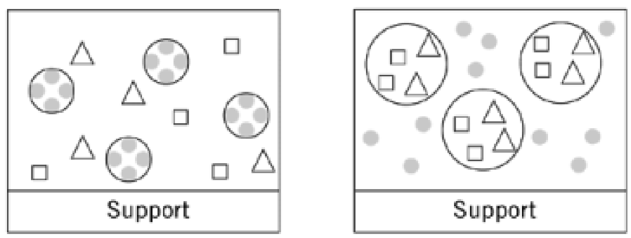
The Fuji CopiArt monochrome proofing system is based on the photogeneration of color from leuco dyes or diazo-coupling (35). CopiArt includes both positive and negative working systems (Fig. 6). For the positive working system, a diazo compound (**6**) reacts with a coupler (**7**) as shown. Compound (**8**) is an azo dye (see Azo dyes). The color-forming ingredients in the positive imaging system are microencapsulated and diazo-based. During imagewise exposure through a positive separation, nitrogen is released from the diazo compound so that coupling, which gives rise to color, cannot occur in the areas struck by light. Further heat processing allows the coupling agent, which is outside the microcapsules, to interact in unexposed areas to form a color image.

The negative system incorporates a coating containing microencapsulated image-forming ingredients applied to paper. The colored image is formed by the oxidation of a leuco dye within the microcapsules upon imagewise exposure through a negative separation. The image is further processed by heating to stabilize (fix) the system. Heating allows the nonencapsulated fixing agents to stabilize the image.

Chemical reactions for the negative systems in CopiArt can be generalized by the reaction of the leuco form **(9)** of crystal violet [548-62-9] to produce the colored form **(10)**.

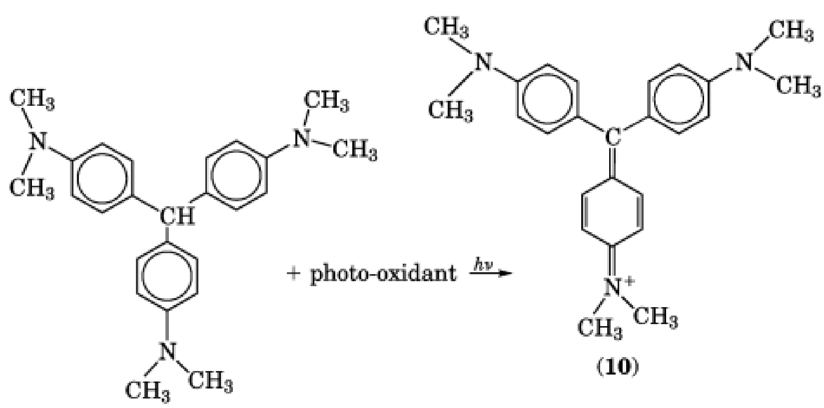


(6) (7)



(a) (b)

Fig. 6. CopiArt proofing system: (**a**) structure of positive working system, where △=organic base, □=coupler, ○=microcapsule, and● =diazo compound; and (**b**) structure of negative working system, where △=photoinitiator, □=leuco dye, ○=microcapsule, and● =radical quencher.



(9)

6.4. Overlay Proofing

Overlay proofing systems can be categorized as wet- or dry-processed systems. The negative working wet-processed systems are generally composed of polymeric diazo resin salts (halides or heavy metal), which after photolysis form an insoluble adduct.

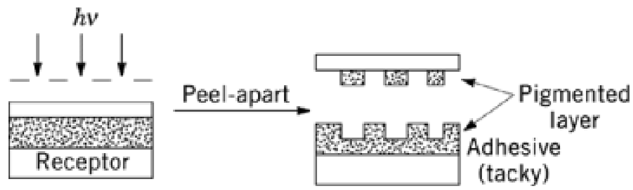
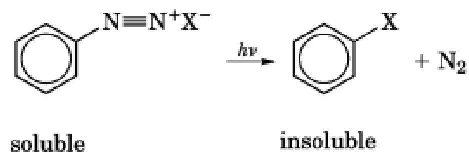


Fig. 7. Image development process.



Wet-processed systems (36–38), such as Color Key (3M) and NAPS (negative-acting proofing system) (Hoechst-Celanese), are comprised of films containing pigments and/or dyes that are dispersed in nonreactive, film-forming polymer systems along with the diazo polymer resin. After exposure to uv light, through a negative separation, the film sample undergoes a wash-off process of the unexposed material using an aqueous solvent or aqueous alkaline developer, yielding the desired negative image. Each process color, ie, yellow, magenta, cyan, or black, on a polyester support is processed in the manner described and overlaid in register to form the overlay proof.

The negative working dry-processed Cromacheck overlay proofing system from Du Pont (39) is based on adhesion balance. After exposure and peel-apart development, the exposed areas of the pigmented photopolymer layer become selectively attached to the polyester coversheet by cohesively breaking away from the integral pigmented photopolymer layer. After peeling apart, the unexposed pigmented photopolymer layer remains on the tacky adhesive. Figure 7 illustrates the image development process.

The right-reading, pigmented photopolymer image from the negative separation remains attached to the polyester coversheet. A simple exposure, through the appropriate separations followed by peel development and overlay of the polyester sheets in register, gives rise to the overlay proof. The dry-processed system is convenient, easy to use, and environmentally friendly. Disposal of waste developer is not an issue.

6.5. Surprint Proofing

The high quality surprint proofing systems used by the printing industry generally give rise to a laminated structure on a paper or plastic receptor bearing the colored image. The laminated structures are composed of four individual laminations, one for each process color, plus, in some instances, a protective topcoat. Surprint proofing systems can be either positive or negative working and wet- or dry-processed to yield the desired high quality four-color image. Du Pont pioneered the development of dry-processed photopolymer surprint proofing systems, Cromalin, using colored, powdered toners to represent the printed image. The positive system relies on a difference of tack between the exposed and unexposed photopolymer areas and the acceptance of toner by the tacky areas to yield a positive colored image (40) as shown in Figure 8**a**. Sequential laminations, exposures through the appropriate separations, and application of the process-colored toners provide a positive proof. The photopolymer layer contains a complex mixture of monomers, plasticizers (qv), initiators, sensitizers, and polymeric binders to achieve the necessary tack/adhesion balance.

The photopolymerization process taking place within a representative mixture of sensitizer, initiator, chain-transfer agent, and monomer, typical of positive Cromalin, has been studied in detail (41, 42). The exact mechanism is still controversial, but a generalized reaction scheme can be postulated as follows,

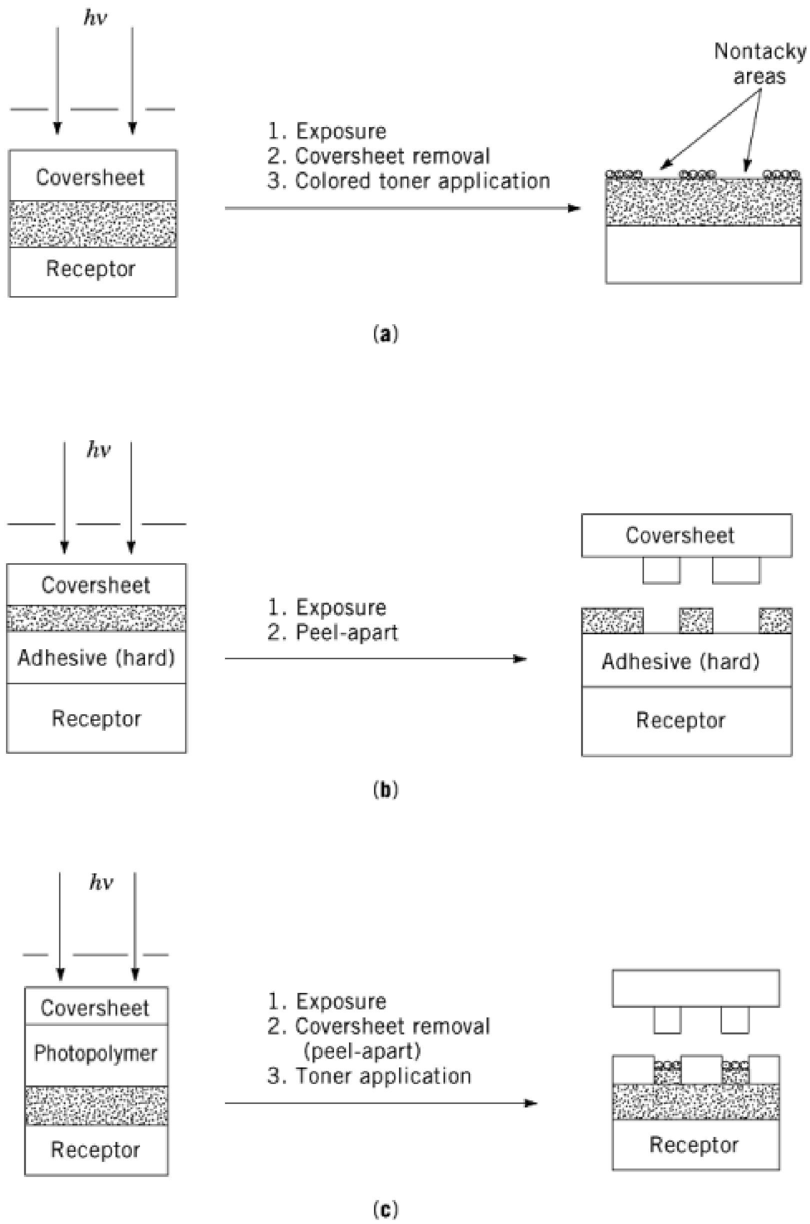


Fig. 8. (**a**) Positive proofing image formation; (**b**) positive working dry peel-apart process; and (**c**) peel-apart process.

where L_2 = biimidazole dimer, S = sensitizer, RH = chain – transfer agent, L_2^* = excited biimidazole dimer, $L^\bullet$ = biimidazole radical, S^* = excited sensitizer, $R^\bullet$ = chain – transfer agent radical, M = monomer, $M^\bullet$ = monomer radical, and P = polymer.

$$S \xrightarrow{h\nu} S^*$$

$$L_2 + S^* \longrightarrow S + L_2^*$$

$$L^\bullet + RH \longrightarrow R^\bullet + LH$$

$$L_2^* \longrightarrow 2L^\bullet$$

$$L^\cdot + RH \longrightarrow L^- + RH^{\ddagger}$$

$$RH^{\ddagger} \longrightarrow R^\cdot + H^+$$

$$R^\bullet + M \longrightarrow RH + M^\bullet$$

$$M^\bullet \longrightarrow \text{polymer}$$

The dry, peel-developable process has been extended to positive working, precolored surprint proofing systems, eg, Eurosprint (Du Pont) (43). The system contains two basic layers: a pigmented photopolymer or pigmented diazo layer, and a hard thermoplastic adhesive composed of mostly poly(vinyl acetate). The proof-making process is to laminate, expose (through a positive), and peel-develop successively the films corresponding to the appropriate colors desired for the proof. The unexposed pigmented layer remains behind on the adhesive and the exposed pigmented material remains on the coversheet when exposed with a positive separation.

The dry-processed, peel-apart system (Fig. 8**b**) used for negative surprint applications (39, 44) is analogous to the peel-apart system described for the overlay proofing application (see Fig. 7) except that the photopolymer layer does not contain added colorant. The same steps are required to produce the image. The peel-apart system relies on the adhesion balance that results after each exposure and coversheet removal of the sequentially laminated layer. Each peel step is followed by the application of the appropriate process-colored toners on a tacky adhesive to produce the image from the negative separations. The mechanism of the peel-apart process has been described in a viscoelastic model (45–51) and is shown in Figure 8**c**.

Negative-working, peel-apart films incorporating pigments in the photopolymer layer can also be used for proofing applications (52). The exposure process causes a reversal of the image in the sense that the unexposed pigmented material is removed with the coversheet upon peeling. The exposure causes a photo release of the exposed material from the coversheet and the nonexposed material is removed during the peel step as shown in Figure 9**a**.

The process used to make the proof involves the same lamination, exposure, and peel-apart steps shown before. Different photoactive systems having variants on the peel-developable system, ie, dual exposures to achieve a right-reading image on receptor or transfer processes, are reported in the patent literature (53, 54).

The wet-processed negative surprint systems (55, 56) introduced by 3M, Fuji, and others are generally composed of various types of diazo chemistry in a thin pigmented film. The negative systems rely on the solubility of the diazo salt resin in the unexposed state to effect image development. After sequential laminations,

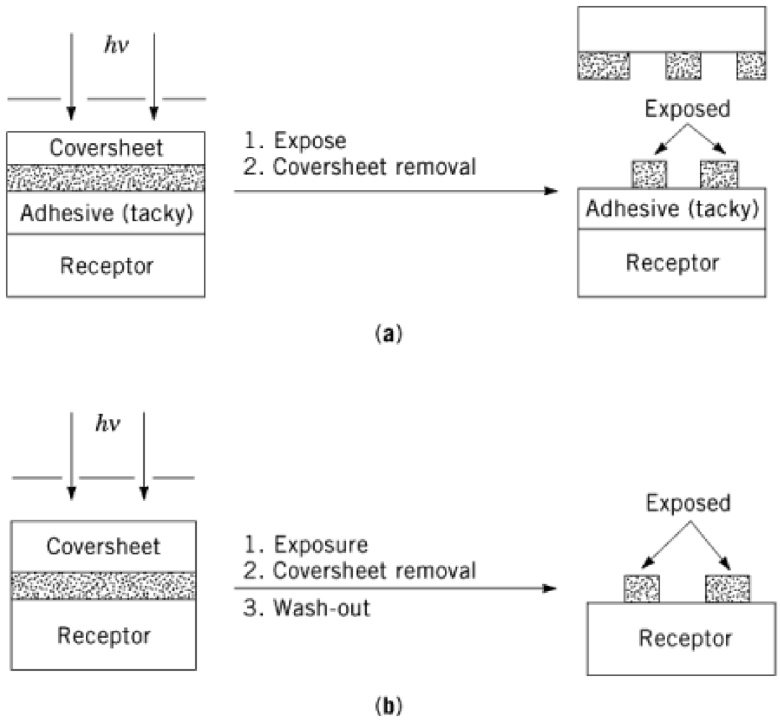
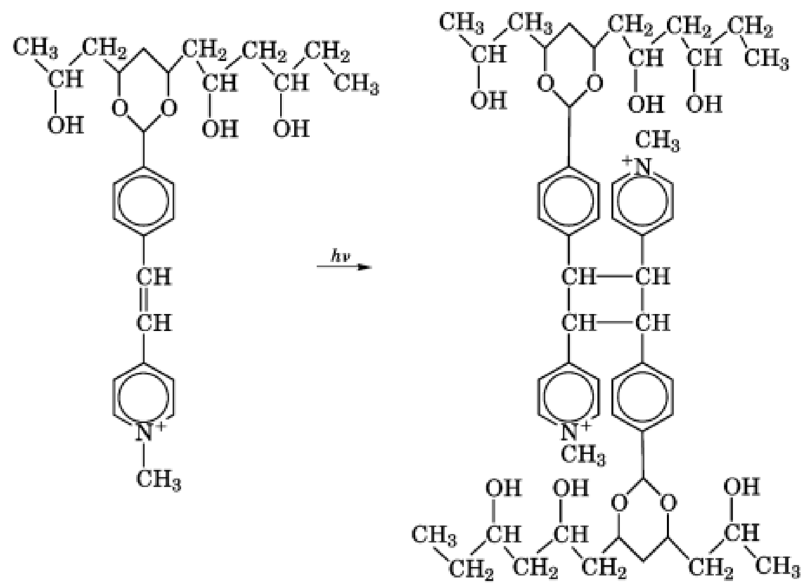


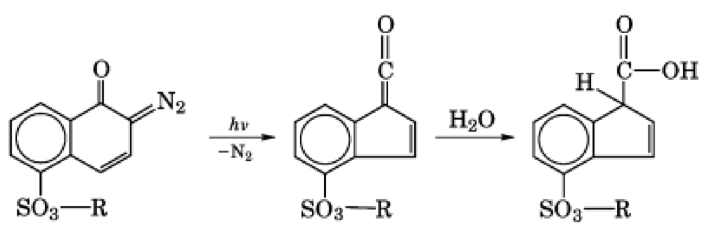
Fig. 9. (**a**) Reversal image formation and (**b**) wet-processed negative surprint.

exposures, and aqueous base wash-off steps with the individual colored films, the proof consists of exposed diazo and film-forming polymers. The wash-out systems used to process the products are generally aqueous, alkaline developers (Fig. 9**b**).

Newer systems have appeared on the market, in which tap water is used as the developer, thus making disposal of spent developer easy for the customer. The WaterProof surprint proofing system from Du Pont is characteristic of these environmentally friendly developer systems. Some tap water developer-based systems utilize the photocross-linking of poly(vinyl alcohol) (PVA) acetylized with a pyridinium salt (SbQ–PVA) (57, 58). Pigments are inserted into the SbQ–PVA polymer to provide the necessary colors for a surprint proofing system. SbQ–PVA photocross-links to the point of providing excellent distinction between the exposed and the unexposed material, thereby providing the basis for superior resolution.



The positive pigmented film systems are generally composed of various types of phenol–formaldehyde, cresol–formaldehyde, or other polymer derivatives containing the diazoquinone structure at various points along the polymer backbone (59). In the unexposed state, the polymer system containing the diazoquinone is insoluble. However, upon exposure to uv light, a photosolubilization reaction ensues when the diazoquinone moiety is converted to a carboxyl group. The reaction proceeds with the loss of nitrogen to form a ketene, which then readily reacts with ambient water to yield the solubilizing carboxylic acid group. The general reaction scheme can be depicted as follows, where R represents a polymer chain such as a phenol–formaldehyde derivative.



The right-reading positive image resides on the receptor film after lamination, exposure through a positive, and wash-out of the unexposed areas with a solvent or aqueous developer. The four-color proof is built up by the sequential lamination, exposure, and development steps.

6.6. Digital Proofing

In a modern electronic prepress environment, much of the page makeup is done using computer systems. Images separated on a scanner may be stored electronically; images created using an electronic drawing system may exist only as a digital file. It is necessary to proof these elements, as well as those that exist as film separations. One approach is to output the files on an imagesetter, ie, make films of the color separation, and proof by using an analogue system. This, however, may add extra expense and time to the process, and, as printers move closer to the goal of computer-to-plate or computer-to-press, film may never be needed. Digital proofing technologies then become necessary.

An ideal digital proofer would take digital files and output a hard copy that looks exactly like the printed page, including accurate color to judge the adequacy of the color-separation process. Several digital proofing technologies are being used. Brief descriptions follow. In all cases these technologies are also used as printing technologies.

6.6.1. Thermal Printing

Dye sublimation and thermal wax-transfer printers are commonly used as moderate quality digital proofers. Dye sublimation printers are the more acceptable, although these do not produce the halftone dots that a printer sees on the plate. The images produced have a photographic quality and the color accuracy is acceptable using modern color-matching technology. The typical dye-sublimation printer is capable of printing one or two standard size (8.5 × 11 in. (21.6 × 27.9 cm)) pages on a single sheet of paper. These printers are frequently used in design studios, where design comps are printed for internal use or customer approval, and where color accuracy is less important. Although the price of the printer is moderate, material costs tend to be high.

A high quality version of a dye-sublimation printer has been developed specifically for color proofing. This device uses a laser writing head, rather than the typical thermal printhead, to produce higher resolution images. The device is capable of true halftones, providing an accurate rendition of a printed page. It is, however, expensive both in equipment and materials cost.

6.6.2. Electrophotographic Printing

Two different categories of printer are used for electrophotographic printing. Common office color copiers or printers are often used for a low to moderate quality proof, where color accuracy is not required. These printers typically do not have high enough resolution to produce true halftone dots, so dithering schemes, ie, dot patterns used to simulate continuous tone, are used. The machines use dry powder toners. Monochrome office-type printers may also be used for proofing text-only documents or making layout proofs of color documents.

A higher quality category of electrophotographic printer has been developed strictly for proofing. This device has a much higher resolution, using liquid toners to produce true halftones. Thus the proofer can produce images that are close representations of a printed color piece. This proofer must be color-accurate for customer approval. It is also an expensive device, because of the accuracy required to achieve quality halftones.

6.6.3. Ink-Jet Printing

Continuous-flow ink-jet printers have made strong inroads as digital proofers in the 1990s. These printers, which do not have the resolution required for halftones, are capable of achieving multiple ink-density levels by striking the same spot on paper with multiple drops of ink. This results in a continuous-tone appearance. Color can be adjusted to achieve accurate matches to press, making ink-jet printing a satisfactory and moderately priced choice for proofing.

6.7. Monitors

Cathode ray tube (CRT) monitors are a key element of electronic prepress systems, providing an electronic canvas for the operator. They may also be used to judge general adequacy of color in a process called soft proofing.

For many years manufacturers of CRT monitors have sought to provide accurate soft proofing on their equipment. The process is difficult in that all CRTs work in a light-emissive RGB color space, whereas the printer uses subtractive color (CMYK). Black is therefore the most difficult color to reproduce, because a CRT cannot be any darker than it appears when current flow is off. The displayed color is also operator-dependent unless a calibration scheme is used to measure the output of the CRT. Soft proofing using a calibrated monitor is accurate for position and color when used by a trained operator. In general, for the customer who is primarily interested in seeing color as it is to appear on the printed page, CRT soft proofing is inadequate.

7. Image Duplication and Output

The principal processes for making many printed copies from a prepress image include lithography, gravure, flexography, letterpress, and screen processes, as well as the newer technologies of thermal printing, electrophotography, and ink-jet printing (see Imaging technology).

7.1. Lithography

Of the principal printing processes, lithography is by far the most widely used. But in spite of usage and the numerous studies (60) to which lithography has been subject over many years, the mechanism of the process is not well understood. This lack of knowledge reflects the complexity of the various interactions of ink, plate, and water that come into play whenever a lithographic plate runs on press.

Lithography is a planographic process. Image, or printing areas, and nonimage, or nonprinting areas, reside in the same plane and are differentiated by the extent to which these areas accept printing ink. Nonprinting areas are hydrophilic, accepting water and repelling ink; printing areas are oleophilic, repelling water and accepting ink. During printing, water is applied to the surface of the plate as an aqueous solution of surface-active agents, generally referred to as a fountain solution, and the ink is applied to the plate surface through a roller train.

Offset plates usually comprise a support, which may be fabricated from paper or plastic but most frequently from metal, and one or more layers of a radiation-sensitive composition. Aluminum has gained general acceptance as support material for several reasons. It is light in weight and has a well-adhered surface oxide layer that is resistant to corrosion under normal press-room conditions. Unlike paper or plastic, aluminum is not stretched significantly when mounted on the press cylinder, hence it is easily capable of maintaining good image registration, an important requirement when color work is being printed. The role of the aluminum in a conventional offset plate is not just simply one of acting as support for the radiation-sensitive coating and subsequently the printing image; it also participates directly in the printing process by providing the nonprinting regions of the final plate.

The first step in creating a printing image is usually to contact the surface of the radiation-sensitive coating of the printing plate with a photographic film positive or negative, and to expose it to a light source emitting between 380 and 420 nm, the spectral region to which most commercial offset plates are sensitized. So as to obtain acceptable image definition, the plate surface and overlying film must be in intimate contact during the exposure stage. This is best achieved by the use of a vacuum printing frame. For particularly rapid drawdown, ie, evacuation of air, a matte layer is applied to the surface of the radiation-sensitive coating. The next step is to treat the imagewise exposed plate with a specially designed aqueous or organic solvent-based developer solution in order to remove selectively the now comparatively more soluble portions of the coating, thus revealing the support surface in the underlying areas.

This surface must be such that the radiation-sensitive coating can be quickly and completely removed during the development process. Any residual material can cause ink to be picked up in the nonimage areas and transferred to the paper during the printing operation. The support surface in the revealed areas must be strongly hydrophilic, possessing a high affinity for water, and repelling oil-based printing inks. In the case of a positive working plate, it is the unexposed areas of coating that provide the final printing image; in the case of a negative working plate, the exposed areas. The image in either case must be strongly bonded to the support in order for it to resist the powerful abrasion forces which come into play during printing.

7.1.1. Substrate

To provide a surface that exhibits these properties, a multistage process is used. The surface of the aluminum sheet is first roughened or grained, either mechanically, using oscillating and rotating wire brushes, or by electrolysis in solutions of acid, typically hydrochloric and nitric acids, or possibly in mixtures of mineral and organic acids (61). The electrochemical process is the more expensive of the two, using a significant amount of electrical power and generating waste solutions, containing aluminum ions, that accumulate as the process continues. The surface structure obtained, however, is more uniform and consistent and is generally preferred. Mechanically grained plates are frequently used when high print quality is not a requirement, for example in the printing of newspapers. A grained surface is important for two reasons. This surface improves adhesion of the coating and of the printing image, and it also allows, through a considerably increased surface area, more water to be held in the nonprinting regions of the plate surface.

In addition to being grained, aluminum substrate used for presensitized printing plates is almost invariably anodized. The oxide film, weighing from 1–8 g/m^2 and produced by anodizing in a bath of acid, usually phosphoric or sulfuric, serves two purposes. It acts in concert with the rough surface structure to increase coating adhesion and, because it possesses the hardness, scratch resistance, and general ease of hydrophilization required for an effective lithographic surface, plays an essential role in providing the printer with a consistently acceptable level of press performance.

The anodized surface is often subjected to additional treatment before the radiation-sensitive coating is applied. The use of aqueous sodium silicate is well known and is claimed to improve the adhesion of diazo-based compositions in particular (62), to reduce aluminum metal-catalyzed degradation of the coating, and to assist in release after exposure and on development. Poly(vinyl phosphonic acid) (63) and copolymers (64) are also used. Silicate is normally employed for negative-working coatings but rarely for positive ones. The latter are reported (65) to benefit from the use of potassium fluorozirconate.

Some printing environments are aggressive and demand ultratough images and abrasion-resistant backgrounds. Conventional plates having polymer images tend to fail under these conditions. As a result there is a small market for plates in which both image and nonimage areas are metal and which comprise hydrophilic electroplated chromium on an ink-receptive copper (bimetal) or copperized steel (trimetal) base. The chromium layer has a higher pore density than anodized aluminum, providing an increased affinity for water, hence a reduced potential for dirty backgrounds. The plate is imaged using photographic masking followed by etching.

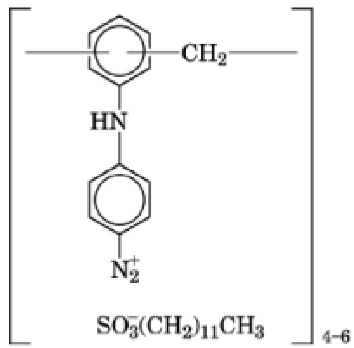
7.1.2. Radiation-Sensitive Coatings

There are two basic types of presensitized offset plates, negative and positive working. Plates are classified according to how their coatings respond to exposure to actinic radiation. Coatings that become less soluble in specific solvents, either through polymerization, cross-linking, or loss of certain functional groups, are employed in negative plate systems. In contrast, a coating that degrades on exposure to radiation, and hence becomes more soluble, is used in positive systems.

The differences in performance, which determine the printer's choice for one type of plate over the other, are no longer clear cut. Advances in electronic prepress have made it possible for the two systems to be more or less interchangeable for many types of work. The choice of negative or positive determines, possibly more than any other factor, the degree by which a halftone dot increases in size in going from film image to printed copy. When exposing a plate through a piece of film, light passes through the clear areas of film, then through the radiation-sensitive coating on the plate surface. Any remaining unabsorbed light it reflected from the support surface. As a result, the area of coating exposed is greater than the image size of film, leading to a developed dot size on a negative plate being 10% or so greater than that of the corresponding dot on the film; on a positive plate, the size is 10% or so smaller. This cause of dot gain can be corrected at the film-making stage, and is becoming less of a serious problem as scanners come into widespread use.

Positive plates are more expensive to make than negative, and also tend to be less resistant to the chemicals used on press. In order to increase their useful life, positive plates are often baked for a few minutes at temperatures of 220°C or more in order to harden, or insolubilize, the image material. Their use offers advantages, however. Apart from the reduced dot gain, which leads to better printed image quality, fewer problems are experienced at the film image assembly stage. The presence of dust on film and contact frame glass is not as serious a problem as it is in using negative systems.

7.1.2.1. Negative Plate Coatings. The bulk of negative plates have a diazo-based coating. This often comprises an *N*-aryl- or alkyl aminobenzenediazonium salt condensed with formaldehyde (66) or a methylol derivative (67) to form a low molecular weight polymer such as the following:



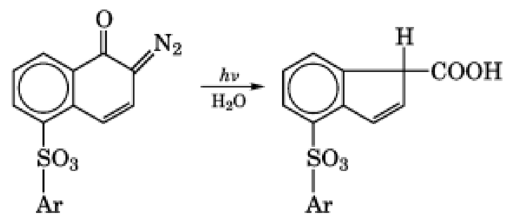
The hydrochloric and sulfuric acid-derived salts, although widely used, tend to give products having poor shelf life. Significantly improved coating quality and stability is possible, however, if the diazo resin is substantially water insoluble and coated from organic solvents. This can be achieved by the use of counterions derived from halogenated Lewis acids such as hexafluorophosphoric or tetrafluoroboric acids. Alternatively, sulfonic acids substituted with long-chain alkyl groups can be employed (68). High molecular weight polymers are often added to the coating formulation to boost the strength of the final image. Photolysis of the diazo compound with loss of the highly polar diazonium group provides sufficient solubility differential in aqueous surfactant solution for easy and rapid development.

Photopolymerizable compositions based on monomeric acrylic or other ethylenically unsaturated acid derivatives are becoming increasingly popular. When multifunctional derivatives are employed, three-dimensional networks having high strength and abrasion resistance are possible on exposure to light. A typical composition may contain an ethoxylated trimethylolpropane triacrylate monomer, a perester phenacylidene initiator (69), and an acrylic acid–alkyl methacrylate copolymer as binder.

Unlike diazo-based compositions, such materials have widespread use in other fields, eg, can coatings, paint (qv), varnishes, and inks. Their attractiveness stems mainly from the potential for amplification, hence high photographic speed, and from the relative ease of tailoring photoresponse to a particular region of the uv–vis spectrum. Free-radical polymerization suffers from oxygen inhibition effects, however, and lithographic or litho plate formulations using this technology are not free of the problem. Possible solutions include the use of oxygen scavengers (70) or of photoinitiating systems more resistant to oxygen quenching (71). The most effective approach is to apply an oxygen-impermeable overlayer to the radiation-sensitive coating (72).

7.1.2.2. Positive Plate Coatings. 1,2-Naphthoquinone diazide sulfonic acid esters are used extensively in the formulation of both photoresists and litho plate coatings (see Lithography (SUPPLEMENT)). As in the case of negative plates, a polymer binder is normally used to provide additional strength. In positive plate coatings this is almost invariably a phenol or cresol novolak resin. Di- and trihydroxy benzophenone esters and sulfonaphthoquinone diazides are frequently found in commercial formulations, as are esters of cresol–formaldehyde and pyrogallol acetone condensation polymers (73).

The process by which a solubility differential between exposed and unexposed areas occurs is well known (74). Photodegradation products of the naphthoquinone diazide sensitizer, eg, a 1,2-naphthoquinonediazide-5-sulfonic acid ester **(11)**, where Ar is an aryl group, to an indene carboxylic acid confers much increased solubility in aqueous alkaline developer solutions.



(11)

An interesting development allows a relatively conventionally formulated positive plate to be used in the negative mode (37). Heating a plate, which has been exposed through a film negative, to about 135°C for two minutes causes the indene carboxylic acid photodegradation products to decarboxylate and become alkali-insoluble. Cooling the plate and blanketwise exposing to light permit the originally unexposed material to be washed away on development.

7.1.3. Waterless Lithography Printing

Waterless printing processes have been actively researched since the late 1950s. The first commercial waterless plate was introduced in the 1960s. Waterless printing, or driography, is a method of printing that provides high quality reproduction without recourse to a dampening system, or fountain solution, on press. Without the problem of water-induced ink emulsification, prints exhibit sharper dots and good tonal gradation with little variation in density throughout the run.

The plate, available in both positive and negative versions, comprises a support, usually of aluminum, coated with a primer, a radiation-sensitive layer, and a top silicone layer. The silicone layer is ink-repellent and the underlying radiation-sensitive layer is ink-attractive. When the exposed plate is developed, the silicone layer is selectively removed according to the image pattern, revealing the underlying surface. This surface, being oleophilic, now constitutes the printing image. Whether the system is negative or positive working, ie, whether the silicone film is released from or bonded to the underlying surface following exposure and development, is determined by the nature of the radiation-sensitive composition. Positive systems result by using photopolymerizable or cross-linkable material that hardens on exposure to light, bonding to the silicone at the interface and causing it to be retained on treatment with a wash-off solution (75). Negative systems employ quinonediazides (76), which undergo photodegradation and release the overlying silicone.

In comparison to the organic photopolymer where the surface has been selectively revealed during wash-off treatment and which now forms the printing image, the silicone exhibits a low surface free energy and shows relatively little affinity for the specially formulated printing ink. This is borne out in practice so long as the ink viscosity on press is carefully controlled. Inks for waterless printing are designed to demonstrate optimum performance within a 5°C temperature range and therefore require ink-cooling systems in presses. A disadvantage of waterless plates in the 1990s is the relatively poor scratch and abrasion resistance of the nonimage surface compared to anodized aluminum.

7.1.4. Computer-to-Plate

The desire for direct digital output to litho plate goes back to the early 1970s when the first attempts were made to eliminate the film intermediate. At that time the drive came from a growing opportunity for facsimile transmission for newspapers and similar systems (77). Since then the digital revolution has changed the viability of direct digital to litho plate from a curiosity to a financial necessity for the lithographic industry as alternative direct-to-press (78) and direct-to-paper (79) approaches come closer to commercial reality. The litho plate technology avenues open to the system designer are high speed photopolymer, electrophotography, silver halide, and thermal imaging. These have not changed because laser imaging technology has been unable to accommodate the low sensitivity in the uv of diazo coatings. Early attempts provided plates of 1–10 mJ/cm^2 at 360 nm using a water-cooled argon ion laser. For a laser tube life of 100–500 hours, at $10,000 per tube, and plates having poor (1–100 days) shelf life and inferior plate resolution, the expected convergence between laser technology and photopolymer speed did not happen. Printers have continued to use conventional presensitized negative and positive plates. Plate chemistry has to match the capabilities of the commercial graphic arts lasers, ie, the air-cooled gas lasers, argon ion and helium neon, and gallium arsenide diode lasers.

The energy in mJ required to expose the various plate chemistries is given below. To convert J to cal, divide by 4.184.

Plate chemistry	Energy required, mJ/cm^2
diazo	
positive	100–600
negative	100–600
photopolymer	0.1–500
organic photoconductor	0.001–0.05
silver halide	0.0001–0.05

At 1000 dots per centimeter, the standard imagesetter output resolution for color litho printing, the data rate to the laser is 28 MHz, a rate only just possible in the mid-1990s. Printers, however, require access to plates within five minutes to keep expensive presses rolling. As can be seen from the list above, only the organic photoconductor (OPC) and the silver halide plates can deliver this photographic speed. The diazo chemistry is entirely too slow.

7.1.4.1. Photopolymer. The best fit of commercial lasers and plate technology for speed is that of organic photoconductor and silver halide. Photopolymer technology is close to being viable, using improved laser power, more efficient optics, or high speed photopolymers (see Photoconductive polymers). Optimization of photopolymer speed, spectral sensitization to the visible wavelengths, and the emergence of new lasers, such as the diode-pumped frequency-doubled Nd^{3+} yttrium aluminum garnet (YAG) laser, promise convergence of laser technology and photopolymer speed. Figure 10 shows the photopolymer plate structure and process of use.

Typical photopolymer plates comprise a photosensitive layer containing an acrylate monomer; a photoinitiation system, eg, a perester; and a sensitizing dye, eg, a coumarin (qv). The photosensitive coating is usually covered by a 2-μm overcoat, generally a water-soluble polymer such as poly(vinyl alcohol), which substantially prevents polymer-chain termination by oxygen. In order to ensure shelf stability at high photographic speeds, laser exposure is used, which provides a free radical that is relatively stable at room temperatures. Only when the plate is heated to over 100°C does the polymerization proceed to completion. Apart from this heating step the processing chemistry is familiar to all plate-making: alkaline development followed by application of a hydrophilic polymer layer common to each of the processes described herein.

7.1.4.2. Electrophotography. Electrophotographic plate-making systems using organic photoconductor materials have been used successfully in cameras, eliminating film, by newspapers since the early 1980s and have been tried in the computer-to-plate application (80). The coating composition is typically an OPC, such as an oxadiazole, a sensitizing dye such as a rhodamine, and an alkali-soluble support resin.

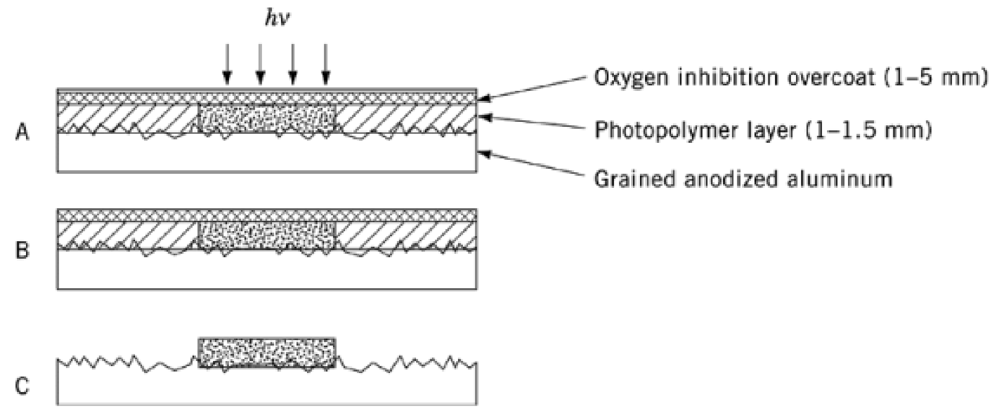


Fig. 10. Photopolymer plate structure and process of use: A, upon exposure to laser light, $h\nu$; B, upon heating to 120°C; and C, after development, rinsing, and gum treatment.

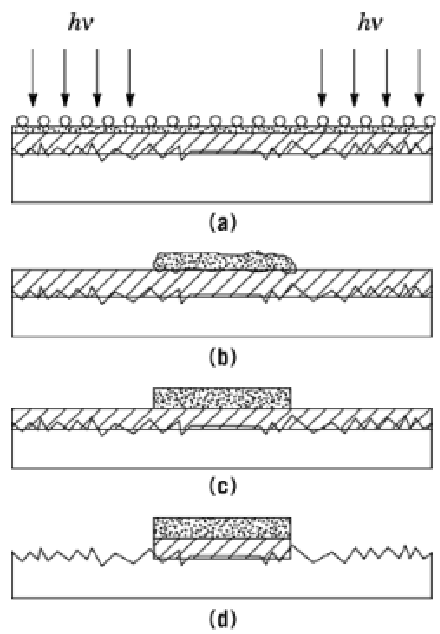


Fig. 11. Electrophotographic plate structure and process of use: (**a**) laser exposure of the negatively charged photoconductor, ○, sitting on the plate surface; (**b**) application of oppositely charged toner particles from a magnetic brush or an aprotic liquid carrier; (**c**) fusing of the toner particles on the coating; (**d**) decoating the unprotected alkali-soluble coating and washing and gumming the plate.

The structure of an electrophotographic plate is shown in Figure 11. Latent image instability and problems in the control of the complex imaging system of charging, toning, fusing, and developing together make the application of OPC to quality four-color work difficult. These problems limit OPC application to simple camera systems (see Electrophotography).

7.1.4.3. Silver Halide on Diazo Plates. Silver halide has high photographic speed and a highly developed sensitizing and stabilizing technology. The principal problem is stabilizing the silver halide materials on an

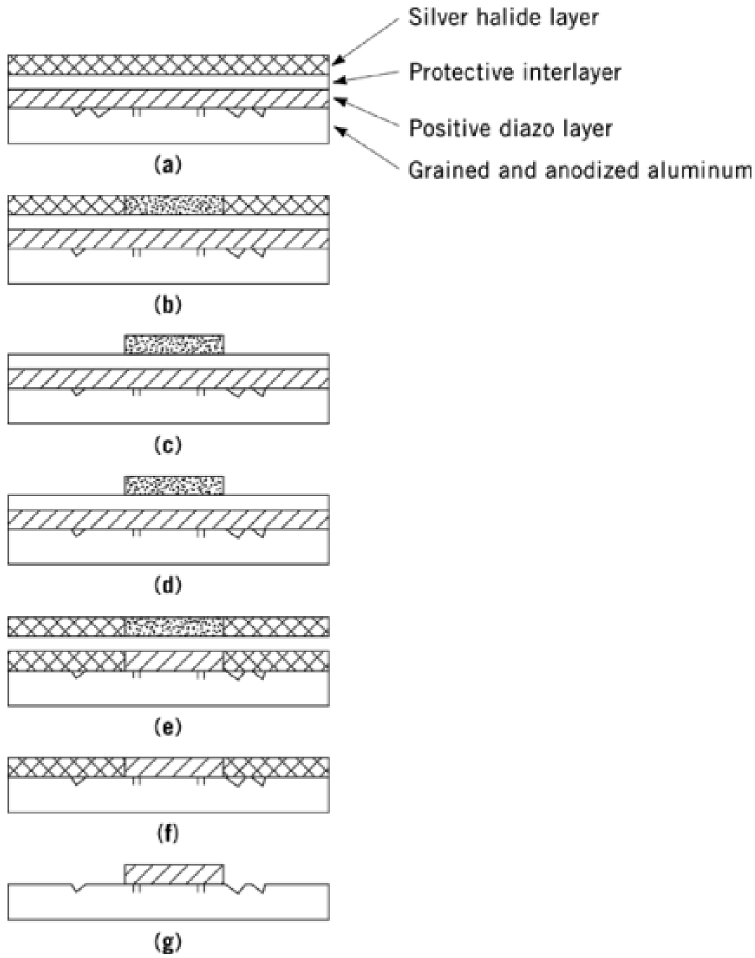


Fig. 12. Silver halide on diazo plate: (**a**) structure upon imagewise laser exposure; (**b**) development of silver image; (**c**) fixation of unexposed areas; (**d**) after rinsing; (**e**) upon blanket uv exposure; (**f**) after washing off; and (**g**) after developing, rinsing, and finishing.

aluminum substrate and providing a durable printing image. One system (81) takes a standard positive working diazo plate overcoated with an appropriately sensitized silver halide emulsion. The structure and process of use are shown in Figure 12. This system has one significant advantage over other silver halide-coated aluminum plates (82). The silver halide emulsion is separated from the aluminum by the layer of diazo, thus preventing interaction between the highly sensitized emulsion layer and the aluminum metal, a notorious source of fog for photographic film. Although the processing cycle is complicated, a conventional, well-understood plate results for use on the press.

7.1.4.4. Single-Sheet Diffusion Transfer. Another solution to the interaction between silver halide and aluminum is that of single-sheet diffusion transfer (83, 84). By carefully specifying the graining and anodizing conditions, a stable and substantially continuous anodic layer of aluminum oxide, which minimizes the fogging and associated interactions, can be obtained. This litho plate on aluminum is produced using the well-known diffusion transfer process (85). Du Pont Silverlith is a computer-to-plate product based on this technology. The aluminum plate is coated first with a receptor layer, then with a conventional silver halide emulsion. On

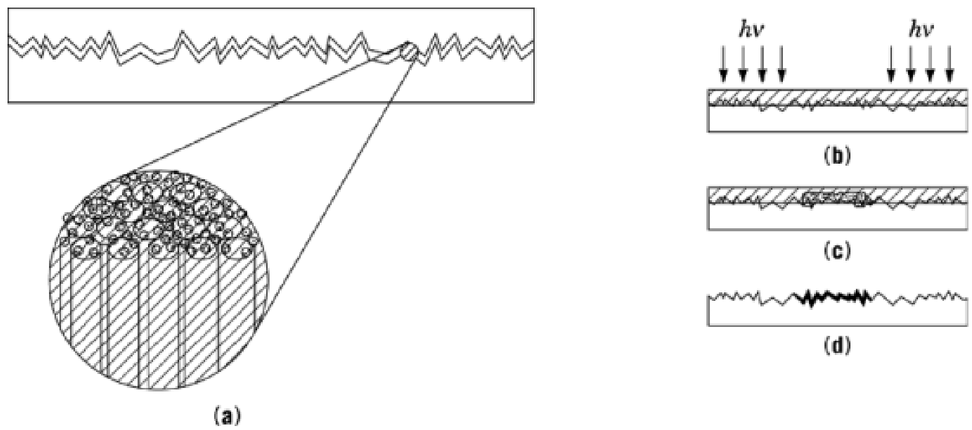


Fig. 13. Single-sheet diffusion transfer plate: (**a**) structure; (**b**) upon exposure to light; (**c**) development; and (**d**) washing off and finish. In (**a**) the plate is first coated with a receiver layer of small (<5 nm) catalytic sites. The photographic layer is a spectrally sensitized silver halide emulsion. In (**c**) the exposed areas develop as silver metal. Unexposed areas diffuse down to the receiver layer and form the printing image. In (**d**) the emulsion is washed off, revealing the silver printing image on the anodic layer (⁓).

development the developer monobath first chemically develops the exposed silver halide areas, then solubilizes the exposed silver grains as complexes, which are reduced at the nucleating receptor layer by hydroquinone. Because these sequential processes are taking place simultaneously, controlling the kinetics of such a process is crucial. It is therefore of prime importance that the chemical development process is much faster than the solubilization.

The silver image (83) is made ink-receptive by reaction, ie, chemisorption, with an oleophilic molecule such as phenyl mercaptotetrazole, which has an active sulfur group (thiol-thiolate) and a phenyl group to impart oleophilicity. The system has the advantage of a simple processing scheme at the expense of an unconventional printing image. The structure and process of use are shown in Figure 13.

7.1.4.5. Thermal Imaging. Advances in near-infrared (nir) laser diode technology have led to the promise of economical thermal imaging at 800–1100 nm (see Light generation, light-emitting diodes). State-of-the-art plate materials, as of 1995, had a sensitivity of 200 mJ/cm^2 at 850 nm, 1000 times less sensitive than the fastest available visible sensitive photopolymer plates. A number of different thermal imaging mechanisms are being evaluated, including ablation (79), thermal coalescence, and photopolymerization. Each of these approaches is interesting but, as of this writing, laser technology is expected to dictate which technology is to be employed.

7.1.5. Direct-to-Press

A novel approach, pioneered by Heidelberg Druckmaschinen AG and Presstek, is to expose printing plates directly on the printing press, using a laser-based system. In this case, a special waterless printing plate is mounted on all four units of a special printing press. Each unit also has a laser head that scans the width of the plate cylinder as the latter slowly rotates. The laser ablates a surface layer, exposing the ink-receptive surface of the plate. Because the plates are exposed directly on the press, color-to-color registration is not a problem. Printing can begin as soon as the plates are written. This type of technology serves a market between the short-run color electrophotographic printers and a long-run conventional plate and press system.

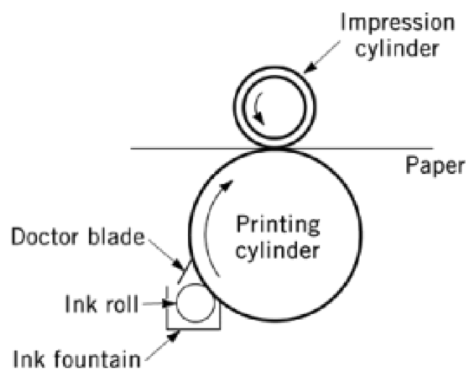


Fig. 14. Gravure printing system.

7.2. Gravure

The gravure printing process, sometimes called intaglio or rotogravure, utilizes a recessed image plate cylinder to transfer the image to the substrate. The plate cylinder can be either chemically or mechanically etched or engraved to generate the image cells. The volume of these cells determines the darkness or lightness of the image. If an area is darker, the cells are larger; if the area is lighter, the cells are smaller.

Traditionally, a gravure cylinder was prepared chemically by using an etch process. Since the early 1970s, electromechanical engraving, in which a diamond stylus cuts the cells into cylinders, has been the preferred approach. Of particular significance over the years has been Hell's Helioklischograph electromechanical engraving system. Later alternative approaches have included laser and electron-beam engraving.

In gravure, all elements within the image are screened. This is in contrast to flexographic and lithographic plates, which can contain true solids as well as halftones.

The gravure printing process is based around an inking system that is extremely simple, giving the process a high degree of consistency, particularly with regard to color printing. This consistency is difficult to match using other printing techniques. The system, shown in Figure 14, utilizes a liquid ink that has traditionally been solvent-based, although environmental pressures have resulted also in the development of aqueous-based inks.

The gravure cylinder sits in the ink fountain and is squeegeed off with a doctor blade as it rotates. The impression cylinder is covered with a resilient rubber composition, which presses the paper into contact with the ink in the tiny cells of the printing surface. The image is thus transferred directly from the gravure cylinder to the substrate. Frequently an electrostatic assist is used to help the ink transfer from the gravure cylinder to the substrate. Gravure inks are comprised of pigment, resin binder, and, most frequently, a volatile solvent. The ink is quite fluid and dries entirely by evaporation. In multicolor printing, where two or more gravure units operate in tandem, each color dries before the next is printed. This is seen as a particular advantage for gravure over, for example, offset, where the placing of wet ink on wet ink can lead to inferior print quality. The wet ink on dry and the simple ink train, together with a long run-length capability, have led to the belief that gravure has traditionally set the standard for high quality printing.

The gravure market can be considered to comprise three approximately equal segments: publications, packaging, and specialty printing. In publications, gravure retains a significant proportion of the long-run magazine market; however, web offset is rapidly eating into this market as litho plates become capable of printing one million and more impressions. In packaging printing, where paperboard and repeat-run cartons are encountered, gravure is the ideal process. The cylinder lasts virtually forever and color consistency is high. The final third of the gravure market is specialty printing of such items as wallpaper, gift wrap, and floor coverings. Shifts between these gravure market segments are anticipated but the total share, about 10% for the U.S. commercial printing market, is expected to remain unchanged throughout the 1990s.

The fundamental strengths of gravure are that the process provides consistent color throughout long print runs, and, because of its ability to apply heavy ink coverage, can be used to print high quality work or to print on a lower grade of paper than offset and still maintain acceptable print quality. Additionally, gravure generates overall less waste than offset.

In contrast, the primary process disadvantages of gravure are long lead time, high cost of manufacture for gravure cylinders, generally long press make-ready times, and environmental hazards associated with the use of solvent-based inks. These need to be eliminated if the technique is to remain competitive. Developments in the gravure process have therefore been directed at addressing these shortcomings. Work has continued on the assessment of laser engraving to speed up the engraving process. Lasers are capable of cutting between 25,000 and 30,000 cells a second, significantly faster than electromechanical systems. As of this writing, the Max Daetwyler Corporation is developing a direct digital laser engraving system. Linotype-Hell is also working on developments to transfer digital data to the engraver faster. Of particular interest is Gypsy, Linotype-Hell's digital cylinder preparation system that outputs a full cylinder of pages digitally for instant engraving on the Helioklischograph. No film intermediate is required.

Additionally, attempts are being made to streamline the gravure process by improving make-ready times. Press manufacturers Cerutti and Albert-Frankenthal are working on cassette systems where jobs are prepared outside the press and subsequently loaded with virtually zero stop time. Computer control of press functions such as compensators, angle bars, and folders also help reduce press make-ready time.

The environmental concerns associated with the use of toluene, a toxic and flammable aromatic hydrocarbon, as a gravure ink solvent must be addressed. Whereas ink manufacturers are working on the development of water-based inks, the slow drying times and poor printing qualities of the prototype products have impeded commercialization. Furthermore, the high cost of these materials is seen as a barrier to their introduction.

7.3. Flexography

Flexography is a variation of letterpress printing used mainly for packaging applications. It is characterized by the use of an elastomeric printing plate, fast drying inks, and an anilox roll ink-metering system. A principal advantage of flexography is its ability to print on a wide range of substrates, including plastic films, foils, coated and uncoated paper, paperboard, and corrugated board. Other advantages include low cost and short cycle time, ability to change cylinder diameters to reduce stock waste, precise ink transfer with minimum on-press adjustments, ability to print one layer and laminate another layer over it, and ability to print continuous patterns such as wallpaper and gift wrap.

Limitations of flexography include higher highlight dot gain and lower solid density as compared to gravure and offset. The increased dot gain results from a combination of printing plate deformation and ink spread on press. Another limitation is the inability to print uniform solids and halftones using the same plate without substantial make-ready. The increased pressure required for uniform solids increases dot gain in highlights.

7.3.1. Flexographic Printing Press

A typical print station is shown in Figure 15. The three basic types of flexographic presses are shown in Figure 16. Dryers generally separate individual print stations. In the stack press (Fig. 16**a**), individual print stations are in sequence one on top of the other. This press is used primarily for paper and laminated films. Advantages include accessibility to print stations and the ability to reverse the web, thus allowing printing both sides in one pass. The central impression press (Fig. 16**b**) has its print stations distributed around a large central impression cylinder, which is precisely geared to each print station and thus improves registration. This press

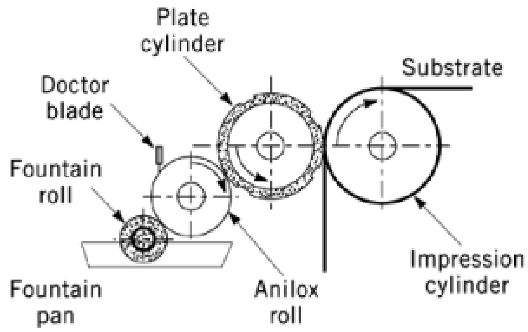


Fig. 15. Flexographic printing station, where the fountain pan supplies ink to the rubber fountain roll, which in turn supplies ink to the anilox roll. The doctor blade removes excess ink from the surface of the anilox roll so that it transfers a uniform layer of ink to the printing plate. The printing plate then transfers this layer of ink to the substrate, which is supported by the impression roll.

is used mainly to print high quality wide-web films. The in-line press (Fig. 16**c**) is used mainly for printing corrugated and folding cartons, as well as for narrow-web tags and labels.

7.3.1.1. Anilox Rolls. The heart of the flexographic printing system is the anilox roll, a steel cylinder optionally coated with ceramic and engraved with a pattern of pits or cells. The function of the anilox roll is to meter a uniform film of ink from the ink fountain to the printing plate without the need for continuous adjustment. There are many types of anilox rolls, distinguished by the mode of engraving, the materials of construction, the pattern of the cells, and the cell geometry. Two main families are mechanically engraved chrome rolls and laser-engraved ceramic rolls.

Mechanically engraved chrome rolls are steel cylinders engraved by a precision tool. Following engraving the rolls are plated with copper, which acts as a bonding layer, and chrome, which hardens the surface. Mechanically engraved chrome rolls have been the mainstay of the industry for many years. However, upon the introduction of the reverse-angle doctor blade, which has better control of the metering of the ink, and the subsequent wear problems, the industry has been steadily shifting to laser-engraved ceramic rolls.

Ceramic rolls are steel cylinders that have been coated with a ceramic, usually chromium oxide, layer and then engraved with the beam from a CO_2 laser. By controlling the energy and timing of the laser pulse, the depth and diameter of the anilox cell can be tightly controlled. Anilox roll variables include the screen count and screen angle as well as cell volume. Unlike mechanically engraved rollers, the volume of laser-engraved rolls is independent of screen count, allowing a variety of rollers having a wider range of volumes and screen counts. The ceramic coating reduces doctor blade wear by an order of magnitude, thus prolonging the life of the roll.

7.3.2. Flexographic Printing Plates

There are three primary types of flexographic printing plates: molded rubber, solid-sheet photopolymer, and liquid photopolymer.

7.3.2.1. Molded Rubber Plates. Initially, flexographic printing plates were made of hand-cut or molded rubber. The basic steps of rubber plate-making include (*1*) preparing an engraving by exposing a photoresist-coated magnesium plate to uv light through a photographic negative, washing away the unexposed resist with chlorinated solvent, and acid-etching the unprotected magnesium; (*2*) molding a phenolic matrix board using the magnesium engraving; and (*3*) molding the rubber plate using a matrix mold.

Molded rubber plates transfer ink well and, when large numbers of identical designs are needed, are inexpensive to make. However, environmental concerns over the use of acid etching solutions to prepare the

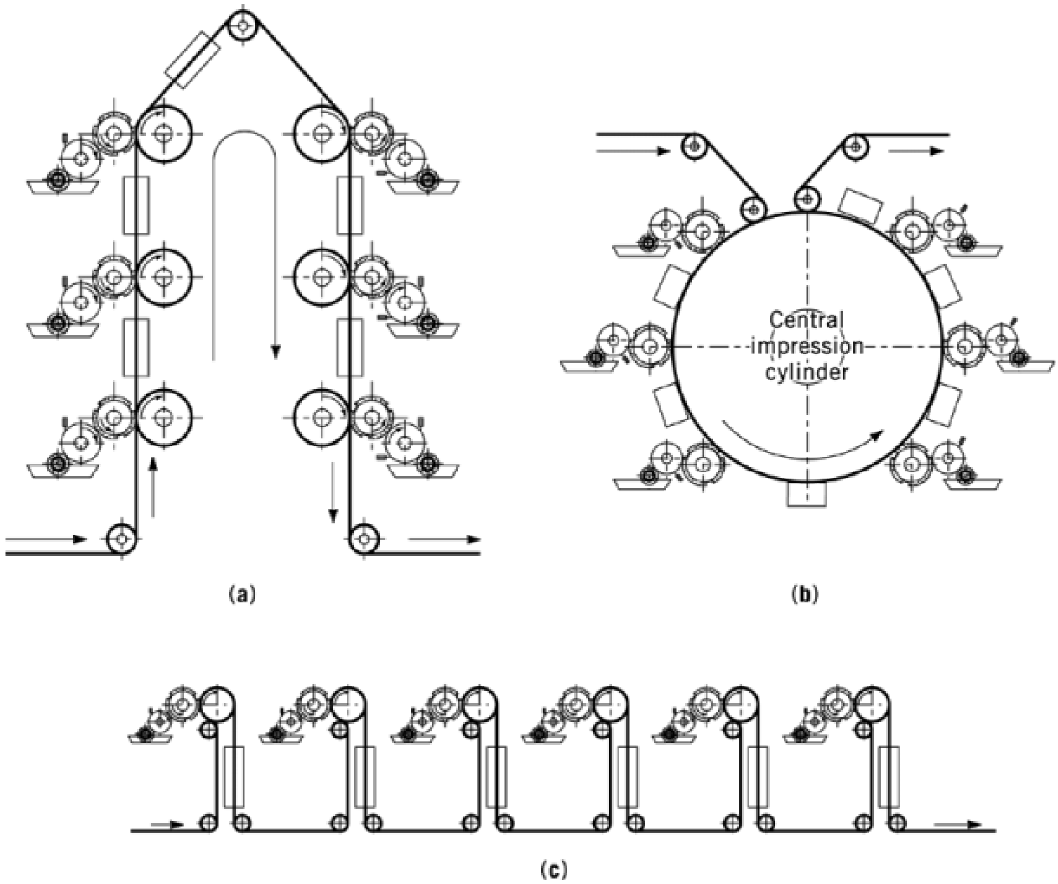


Fig. 16. Schematics of flexographic presses, where the arrow designates the direction of the web flow and ▭ represents an interstation dryer. (**a**) Stack press; (**b**) central impression press; and (**c**) in-line press.

magnesium engraving, poor thickness uniformity, and poor dimensional stability of the molded plates are the disadvantages. Photopolymer molding plates, both solid and liquid, have replaced most magnesium engravings.

7.3.2.2. Solid-Sheet Photopolymer Plates. Solid photopolymer plates consist of an elastomeric, photosensitive layer bonded to a polyester support. The plate formulation usually contains an elastomer that provides the required properties of flexibility and resilience (see Elastomers). Acrylic or methacrylic monomers, which, in the presence of sufficient energy, polymerize to reduce the solubility of the material, are employed along with a photoinitiator, which absorbs uv radiation and initiates polymerization. Various additives such as thermal stabilizers, plasticizers (qv), and dyes are also present. These photopolymer plates are made by back exposure to uv to consume stabilizers and define relief height, uv exposure through a photographic negative to form the image, removal of unexposed areas with a solvent to form the relief image, drying to remove solvent, overall exposure to eliminate surface tack, and post-exposure to further cross-link and toughen the plate. Advantages of solid-sheet photopolymer plates over rubber include improved dimensional stability derived from the polyester support, longer print run length, improved print quality including more predictable rendition of four-color process images, and better thickness uniformity.

Newer technology involves aqueous-processible photopolymer plates. Many plate-makers and printers are eager to switch to water processing in order to eliminate volatile organic solvents. The chemistry and process of use are similar to that of the solvent-processible plate except that in the aqueous plate, the elastomer has pendent carboxyl, hydroxyl, or other water-soluble groups to allow aqueous processing.

7.3.2.3. Liquid Photopolymer Plates. Another form of photopolymer plate is the liquid system, which is used successfully in corrugated and newspaper markets. The plate-making process is similar to the solid-sheet photopolymer plate except that before exposure to uv, the liquid photopolymer, which consists of liquid rubber oligomers and cross-linkers, is sandwiched between thick glass plates to provide defined and uniform thickness during exposure. The main advantage over solid plates is the use of lower cost materials. Disadvantages include inferior thickness uniformity and limited-run life.

7.3.2.4. Laser-Engraved Rubber. Relief images can also be made by laser engraving a rubber-coated cylinder. The rubber layer is selectively ablated by a CO_2 laser beam, leaving a relief printing image. This method eliminates the need for a photographic negative, and is ideal for printing continuous tone. Laser imaging cannot reproduce the fine screen rulings obtainable with solid plates and is limited to ca 34 lines/cm (85 lines/in.).

7.3.3. Flexographic Printing Inks

Conventional flexography uses low viscosity fast-drying inks. These are typically solutions having 25–35% solids content, which consists mainly of nearly equal parts of a pigment or pigments dispersed in polymer resins (see Pigment dispersions). These resins form the ink film and attach the pigment to the substrate. About 5% of the ink may consist of additives such as slip agents, surfactants, plasticizers, and antifoams. The solvent portion is usually a blend of alcohols and acetate esters. Drying rate can be varied by changing the ratio of acetate to alcohol in the solvent.

For aqueous inks, the resins are water- or alkali-soluble or dispersible and the solvent is mostly water containing sufficient alcohol (as much as 25%) to help solubilize the resin. To keep the alkali-soluble resin in solution, pH must be maintained at the correct level. Advances include the development of uv inks. These are high viscosity inks that require no drying but are photocurable by uv radiation. In these formulations, the solvent is replaced by monomers and photoinitiators that can be cross-linked by exposure to uv radiation. The advantage of this system is the complete elimination of volatile organic compounds (VOC) as components of the system and better halftone print quality. Aqueous and uv inks are becoming more popular as environmental pressure to reduce VOC increases.

7.4. Letterpress

Letterpress is the oldest and, until the mid-1960s, the dominant and most versatile printing process. As of the 1990s, it is used mainly in high quality design work, fine books, and quality stationery. Unlike lithography, which prints best on coated papers, letterpress can print on any paper, provided that the paper is of even thickness, flat, and reasonably rigid.

Letterpress is printed directly by the relief method from cast metal or plates on which the image or printing areas are raised above the nonprinting areas. Ink rollers apply ink to the surface of the raised areas, which transfer it directly to paper. Flat-bed cylinder presses are available but most letterpress is printed on rotary presses.

7.4.1. Make-Ready

Because pressure is needed for ink wetting and transfer and because the image elements in letterpress vary in size, the same amount of printing pressure or squeeze exerts more pressure on highlight dots than on shadow dots. This necessitates considerable make-ready to even the impression so that the highlights print correctly and do not puncture the paper. Precision plates and premake-ready systems have helped reduce make-ready time, but it is still appreciable for quality printing and is a reason letterpress has been largely replaced by other processes.

7.5. Screen Printing and Stencil Processes

7.5.1. Image Carriers for Stencil Processes

There are two stencil processes in general use: screen printing and stencil duplicating. Screen printing used for art reproduction is called seriography.

Screen-printing image carriers can be produced manually or by photomechanical means. The screens can consist of silk cloth having mesh counts of 40–80 openings per lineal centimeter. Nylon screens are used for textile printing and metal screens of phosphor bronze and stainless steel are used for fine-detail printing in meshes as fine as 120 openings per lineal centimeter. The screen material is attached to a rigid frame and stretched tightly so that it is level and smooth. The stencil is applied to the bottom side of the screen, ie, the side in contact with the surface to be printed. Ink having a consistency similar to thick paint is used in the screen. Ink is transferred by rubbing on the screen surface using a rubber squeegee. The screens can be used for ca 10^5 impressions.

Screen printing is also practiced by using rotary screens, made by plating a metal cylinder electrolytically onto a steel cylinder, removing the cylinder after plating, applying a photopolymer coating to the cylinder, exposing it through a positive and a screen, developing the image, and etching it. The result is a cylinder having solid metal in the nonimage areas and pores in the image area. On rotary screen presses, the ink is pumped into the cylinder, and the squeegee, which is inside the cylinder, controls the flow of ink through the image pores to the substrate.

Manual stencils are made by knife-cutting special film stencil materials. These consist of two plastic layers. The image to be printed is cut through one layer, and this part of the stencil is placed in contact with the underside of the screen. A solvent, which is insoluble in the ink but attaches the cut stencil to the screen, is applied and then the backing layer is removed. Manual stencils can also be produced by drawing directly on the screens using special materials.

Photomechanical stencils are of two types: direct coatings and transfer films. Direct coatings are either bichromated gelatin or bichromated poly(vinyl alcohol) (PVA). The coated screens are exposed through a positive, washed, and inspected. These screens are used for printing electronic components. They are not practical for commercial work because of the difficulty of reclaiming the screen after use.

There are four transfer-film methods for making screens: carbon tissue, unsensitized film, presensitized film, and photographic transfer film.

7.5.2. Screen Printing

The process of screen printing has been reviewed (86). In general, printing is done by feeding the paper into the press in sheets, ie, sheet-fed, or from rolls, ie, web-fed. Greeting cards, maps, and some textiles (qv) are printed on sheet-fed presses. Web-fed presses are also used in printing textiles. Many presses are multicolor, ie, they can print a number of colors in succession. Usually each color requires a separate complete unit, ie, inking, plate, and impression mechanism, on the press. Some presses can print both sides of the sheet in one pass through the press.

7.5.3. Manufacture by Screen Printing

A large use of screen printing is in the manufacture of electrical circuits having high volumetric efficiency (small size) compared to standard breadboard circuits. The manufacturing process involves the sequential printing of a circuit layer followed by a drying step. The circuit is usually fired at high temperature ($>600^\circ C$) to sinter the inorganic phases. For some applications the firing step is omitted or replaced by other types of processing, eg, etching. Screen printing uses a screen with a pattern formed by polymer, and an electrically functional ink. The printing is done on a substrate, usually made of ceramic, eg, alumina, but plastic and other materials are also used. These substrates vary in size, but are normally no larger than 15×10 cm and less than 1-mm thick.

7.6. Thermal Printing

Thermal printing is a generic name for methods that mark paper or other media with text and pictures by imagewise heating of special-purpose consumable media. Common technologies are direct thermal; thermal, ie, wax, transfer; and dye-sublimation, ie, diffusion, transfer. Properties and preferred applications are diverse, but apparatus and processes are similar (87–89).

Thermal printing usually involves passing materials over a full-width array of electronically controlled heaters (a thermal printhead). This marks thousands of spots simultaneously, so pages print relatively quickly. Image data to control the printhead usually come from computer systems. Black-and-white and full-color systems are both practical. Color is slower and more costly to purchase and use, primarily because this involves three or four successive printing operations, one for each color used.

7.6.1. Printhead Technology

The printhead is common to the various thermal printing technologies. Printhead design and control are important. The heads are expensive page-wide printed circuit-like linear arrays of resistors, which must be fabricated uniformly (90–93). Electronic controls must maintain functional uniformity in use. Self-heating, abrasion, and chemicals evolved during printing reduce both image quality and head life. High power lasers can replace printheads for certain precise thermal printing applications, especially in the area of digital printing. Laser-addressed printers are capable of writing halftones, making such printers useful as digital proofers (94, 95).

7.6.2. Direct Thermal Printing

Inexpensive telephone-facsimile printing commonly involves the early direct thermal marking method. Another use is wide-format computer-aided drafting output. Direct thermal involves imagewise heating of a single-component consumable. For example, a coated paper can change color or density as it passes over a printhead. Early processes melted wax overlayers to expose a colored base. However, most systems employ chemical means: a coating of two or more colorless but reactive components is fused to generate a high contrast mark, for instance by using leuco dye chemistry (96). The printing layer may contain a flouran leuco dye precursor, and an acid developer such as bisphenol A in a kaolin and poly(vinyl alcohol) binder (97, 98). Direct thermal prints are usually monochrome, but are available in various colors. Marking is usually binary (full density or nothing), but time and temperature adjustment can achieve intermediate values. Maximum density ($\sim$1.3 optical density) requires 1 to 2 J/cm^2 (0.24–0.48 cal/cm^2) dissipation to heat the coating above $\sim$100°C for 1–2 milliseconds. Systems usually write another line of marks about every 5 ms. Most coatings and printhead technology work best at 8 to 24 marks per millimeter spacing (200–600 dots/in.). Prints, which can be a meter or more wide and any length, are relatively unattractive. The media coating feels slippery and is hard to write on. Images also have low contrast. However, printing is fast, uses simple and inexpensive apparatus, and is cheap, running around $0.01 per page.

7.6.3. Thermal Transfer Printing

Wax transfer is another name for thermal transfer printing. Some typewriters and many reliable, high quality ticket and label makers use black-only thermal transfer. Computer-display capture, presentation transparencies, publication proofing, business chart and document printing, and sign-making are uses for color thermal transfer printing.

Thermal transfer involves imagewise heating of a donor ribbon facing a receptor page (99). The donor and receptor meet at the thermal printhead. Donor ribbons print an equivalent size page. These ribbons are typically page-wide rolls of color-coated plastic film, consisting of 3–12-μm thick biaxially oriented polyester or polycarbonate. The printhead side of the film is treated to reduce friction. The marking side has several micrometers of waxes (qv) and binders, pigments and dyes, dispersants, and softening agents coated over a release layer. A typical formulation may be 40% ester wax, 20% microcrystalline binder wax, 20% pigment and dye colorants, 10% oils and other softening agents, and 10% dispersants and other components. Coatings have carefully tailored melting and rehardening temperatures (100).

Color ribbons hold sequentially coated page-sized regions of marking material: magenta, cyan, yellow, and sometimes black. Donor ribbon and receptor pages move together between the thermal printhead and a pressure roller. About 1 J/cm^2 (0.25 cal/cm^2) raises the donor coating temperature above 50 to 80°C to induce melting and adhesion to the cool receptor. Proper peel angle and delay after imaging are important for good image quality.

Full-color printing requires pages be reprinted three or four times in registration. Receptors pass over the printhead several times at exactly the same speed and location, but contact a differently colored section of donor. A fourth pure black color can improve dark picture regions, sharpen text and line art, and mask color misregistration.

Thermal transfer marks are usually shiny, thick, soft and scratchable, and relatively high in optical density and color saturation. The color coating either transfers entirely or not at all. This binary marking process requires picture regions to be halftoned for simulation of intermediate densities and colors. Marked-spot size and shape are usually about the same size as the printhead heating elements. Donor properties and printhead technology limit addressability to about 12 marks per millimeter (300 dots/in.), limiting the quality of halftone reproduction.

Thermal transfer printers are relatively complex, both mechanically and electronically. In addition to precise mechanisms they require sophisticated electronics for networking and PostScript interpretation. Cost of equipment and consumables ($0.50–$1.00 per page) is relatively high.

Receptors range from standard size (A4) to tabloid size (A3) pages, ie, 8.5×11 in. (21.6×27.9 cm) to 11×17 in. (30×43 cm), but media-handling mechanisms often prevent marking close to page edges. Special papers are usually required for good print quality. Most color pages physically print in less than one minute, which is often faster than image data acquisition and interpretation.

7.6.4. Dye-Sublimation Thermal Printing

Dye-diffusion thermal transfer was developed primarily for reproduction of natural pictures. A combination of modest resolution and precise control of individual spot density gives good results for electronic photography and publication proofing. Printing engines are superficially similar to thermal transfer apparatus. Some operate either way. Media handling is about the same, and full color also employs overprinting a page three or four times. However, the actual marking processes are quite different.

Transfer occurs by sublimation, condensation, and diffusion (101). Printhead thermal dissipation causes donor dye to travel to the surface of the donor ribbon and convert directly to a gas. Colorant puffs immediately strike the nearby receptor and soak in, assisted by residual printhead heat.

The donor coatings are thin ($\sim$1 μm) solid solutions of dye ($\sim$6%) in a thermally stable binder that remains attached during printing. This coating may include tiny beads to establish precise donor–receptor spacing, reduce heat loss, and prevent sticking. The coatings are typically solid solutions of volatile dyes in a thermally stable binder such as ethyl cellulose. Receptors must be smooth, and are polyester–silicone coated to aid dye diffusion and stabilization. Finished prints are glossy.

Dye sublimation requires more heat dissipation and a longer ($>$10 ms) heating period to make a dark mark than does thermal transfer. Careful manipulation of heating time and temperature can proportion mark size and dye content to cover a wide density range (0 to ca 2 optical density).

Dye-sublimation printheads usually have 8 to 12 elements per millimeter (200–300 dots/in.). However, colorant dye evolution, transfer, and diffusion cause relatively big, round, and fuzzy marks that usually significantly overlap their neighbors. Thus adjacent dye-sublimation marks mix quite smoothly. Because the amount of dye transferred can be controlled by thermal input from the printhead, the process is actually

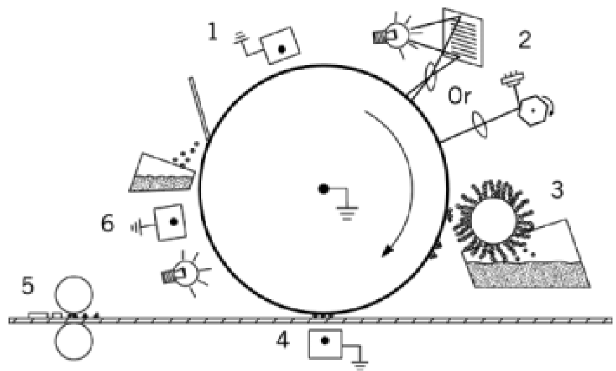


Fig. 17. Schematic photocopier or digital printer. The numbers correspond to the six process steps described in text. The arrow indicates the direction of the drum movement.

analogue. Halftoning is not normally required. The resulting pictures can be attractive and resemble photographs. Unfortunately the large fuzzy marks do a poor job of reproducing sharp-edged features such as text.

Print sizes range from tiny (2×3 in. (5×7.6 cm)) to fairly large (A3) (11×17 in. (30×43 cm)). Printing time varies accordingly, but is seldom faster than a few minutes per page. Equipment cost depends on image size, quality, and speed. Cost is usually higher than a similar thermal transfer printer. Consumable costs are high, averaging from $2 to $8 per page.

7.7. Electrophotography

The importance of electrophotography (qv) cannot be overstated. This well-named, complex technology describes both the product, ie, an optical copy or photograph of an original, and the key to its process, ie, electrostatics.

The electrophotographic system (102, 103) involves two key physicochemical elements: a photoreceptor and a toner. The minimum requirements of the process are (*1*) to charge a photoconductive photoreceptor uniformly; (*2*) to illuminate selectively the photoreceptor to form a latent electrostatic image; and (*3*) to develop the image by applying charged toner. These steps are illustrated in Figure 17.

Some photoreceptors are used with a positive surface charge; others are used with a negative charge. By electrically biasing the toner development module with respect to the photoreceptor and using toner of the proper charge, toner can be attracted to either charged or discharged portions of the latent image. In an office copier it is common to illuminate an original document and relay reflected light to the photoreceptor in order to discharge areas that do not receive toner, eg, the paper background, while attracting toner to the remaining charged areas, eg, text on the original. In electronic printers, however, it is common to illuminate and thus discharge areas that are intended to hold toner, eg, text, while repelling toner from the still charged background. Various models that optimize system performance, as well as competitive and patent positions, have resulted in literally thousands of variants in systems and materials choices.

Surrounding the three minimum-requirement steps of the electrophotographic system are many additional steps that depend on system design, but by far the most common implementation of electrophotography adds (*4*) electrostatic transfer of the toned image to paper, and (*5*) thermal fusing of toner to surface paper fibers and to neighboring toner particles. This fusing often involves contacting the toned image with heated, coated rubber rolls that must not remove significant amounts of toner or disturb the fragile image while heating the image to $>100^\circ$C.

Once toned, the latent image on the photoreceptor can be used only once; hence, after the transfer step (*6*) the residual toner is cleaned from the photoreceptor and residual charge is optically erased, after which the process repeats from step (*1*). This process can be repeated from as slowly as four times per minute in equipment designed for personal use, to more than 200 times per minute in high speed copying or printing equipment. The photoreceptor must survive this series of process steps until it wears out, after 2,000–1,000,000 copies, depending on the design of the equipment. In low volume equipment the photoreceptor, toner supply, and toning, charging, erasing, and cleaning systems are contained in a replaceable toner cartridge that can be discarded or recycled. In high volume applications each subsystem is individually replaced at the end of its service life.

The photoreceptor must hold an electrostatic charge from the time it is charged by a corona device until the image is toned, ie, from 0.25–10 s. The photoreceptor must also be photoconductive so that charge is dissipated where light strikes it. Inorganic photoreceptors can be based on amorphous Se and Se–Te alloys, CdS or CdS–polyester laminates, amorphous Si:H, or ZnO. A huge range of organic photoconductors (OPCs) have been developed to reduce manufacturing costs and eliminate heavy-metal waste, particularly in toner cartridge-based systems. These OPCs involve a thin lower layer designed to absorb light and generate electron–hole pairs, and a thicker dielectric layer above the first, which is designed to resist mechanical wear while transporting photogenerated holes toward the negative surface charge.

Toner particles are always composite materials (qv), sufficiently large to contain the colorant, magnetic material, and polymers, yet small enough to have an average particle size of 3–20 μm. Toner must be electrostatically chargeable, most often by tribocharging, and have a polarity such that the toner is attracted to the appropriate areas of the photoconductor. The toner must fuse to form a durable surface upon mild heating, yet be low cost and easily ground or milled to the appropriate particle size. A wide range of thermoplastics is used, including poly(methyl methacrylate), polystyrene, polyesters, and polyamides. Black toner contains carbon black, and may also contain iron oxide to make it magnetic. Toners can be conductive or insulating, and may have other important properties for a final application, such as magnetic readability and pigment to impart spot or process color. In dual-component development systems, common in high volume systems, the toner particles are used in conjunction with large magnetic carrier beads which, together with a magnetic roller system, brush toner onto the latent image. In monocomponent systems, common in low copy volume systems, the toner particles are themselves made magnetic by inclusion of magnetic materials (qv).

Liquid toners are suspensions of toner particles in a fluid carrier. The carrier is typically a hydrocarbon. Dielectric, chemical, and mechanical properties of the liquid must be compatible with the photoreceptor, the suspended toner particles, and the materials of the development equipment. Liquid toners are capable of producing higher resolution than dry toners because of the smaller (3–5 μm) particle size achievable. Development of the latent image occurs as it passes through a bath of toner and the charged particles are attracted to the oppositely charged surface.

Monochrome image quality has become nearly impeccable in the 1990s, and the difference between lithographic and electrophotographic printing of text is more economic than aesthetic. Halftone images, however, are clearly below newspaper quality in all but the most expensive high resolution digital printers. In inexpensive machines, however, there may still be limitations such as background toning, lack of edge sharpness of lines and curves, image quality limited by the copy lens, banding in solid areas, poor solid area development, mottle, low density, and limited selection of compatible printing substrates.

Electrophotography is especially valuable in those applications where access to one or a small number of copies is required instantly from desktop computers or in a small office, and where a per-copy cost of \$0.07–\$0.10 is acceptable. In walk-up copier/finishers where 1–50 collated and stapled, single- or two-sided documents are required, per-copy cost of \$0.03–\$0.05 is expected. At the highest end of electrophotographic volume where a single machine might produce one-half to a million copies per month, possibly as a copier/digital printer capable of electronic collation, individualization of copy sets, binding with covers, and management of data from a network, cost is \$0.015–\$0.035 per copy. In emerging short-run color printing where spot-color or full-color sheet-fed or web-fed electrophotographic presses push the limits of the technology, cost may be from $0.25 to as high as $1 per copy.

Two manufacturers have developed electrophotographic printers for the short-fun fast-response color printing market (104). The advantage to the user is that there is no need to print a large number of an item to reach an economical point for a printing press. Print jobs do not need to be inventoried or discarded when obsolete. Single or a few copies can be rapidly produced with no extra expense. Reprinting, and changing information in the job, is a simple task without the need to prepare film and printing plates because the entire job is handled electronically until the sheets are actually printed.

These machines show markedly different design philosophies. Indigo, Ltd., of Israel, has developed a liquid toner-based sheet-fed printer. It can print on both sides of the page in turn. With appropriate binding options, it is capable of providing fully finished color books. The Xeikon machine (Belgium) is a dry-toner web printer that prints on both sides of the paper in a single pass. It is also capable of in-line binding to produce finished books. These machines are aimed at the large and growing market for a few hundred copies of a color piece at fast turnaround.

Despite the many advantages of electrophotographic printing processes, a principal economic disadvantage remains: each print costs the same. There is no economy of scale as more prints are made, as is the case for conventional printing. This limits electrophotography to the short-run market.

7.8. Ink-Jet Printing

Ink jet is a digital printing process in which small drops of ink are propelled from a nozzle to a receiving surface without contact between the ink source and the surface. There are two type of ink jets: continuous and impulse. The former generate a continuous stream of ink drops from each nozzle. The size and frequency of drops in a continuous ink-jet printer are determined by pumping pressure, ink viscosity, and nozzle size. Drops not needed for printing are electrostatically charged and deflected into a sump. Impulse printers generate drops only in response to a computer signal.

There are two modes of printing using continuous ink jets. These differ in whether deflection is used to adjust the trajectory of a drop to a spot on the paper other than the one it would strike without deflection. Each drop in the binary, or undeflected drop, printer follows one of two possible trajectories. It either flies straight to the target spot on the paper or is deflected to a sump. The operation of a continuous ink-jet system is shown in Figure 18. Binary printers provide the greatest accuracy in drop placement and best image quality because deflection is used only on nonprinting drops. Deflected drop printers are used for low resolution printing applications. For example, a single stationary jet can print lines of readable product codes onto products or containers passing by in a factory.

There are two types of impulse printers (Fig. 19). A piezoelectric ink jet propels a drop by flexing one or more walls of the firing chamber to decrease rapidly the volume of the firing chamber. This causes a pressure pulse and forces out a drop of ink. The flexing wall is either a piezoelectric crystal or a diaphragm driven by a piezoelectric incorporated into the firing chamber (Fig. 19**a**). Thermal impulse ink jets also propel one drop at a time, but these use rapid bubble formation to force part of the ink in a firing chamber out the orifice (Fig. 19**b**).

Continuous Ink Jet is the oldest, most mature of the ink-jet technologies. Development as a computer printer technology began long before the age of digital computers. In 1867 Lord Kelvin conducted experiments on continuous jets and in 1878 Lord Rayleigh published his work on the basic physics of drop formation. Since that time much work has been directed toward understanding and controlling the process, first for printing output from analogue devices and later from digital computers. Milestone products include an oscillograph recorder in 1951; the first commercial computer printer, for industrial marking of packages, in 1958; and a large-format four-color printer in 1985. Although continuous ink-jet technology is relatively mature, continued innovations in drop charging technology have enabled high quality printing at print speeds up to 305 m/min.

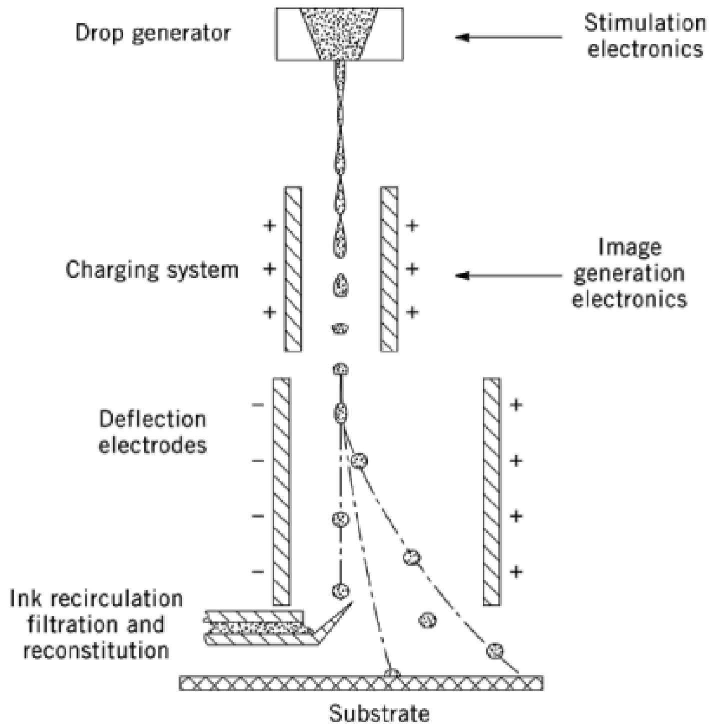


Fig. 18. Schematic of a continuous ink-jet system.

Further advances in equipment are expected to come from improvements in the design and engineering of new printers for specific market applications.

There was a logical progression of technology development from continuous to piezoelectric ink jet. Designers of continuous ink-jet systems ensure that the ink stream breaks into drops of constant size and frequency by applying vibrational energy with piezoelectric crystals at the natural frequency of drop formation. This overcomes the effects of any random forces from noise, vibrations, or air currents.

By changing the role of the piezoelectric crystal from regulating drop formation to propelling drops, the need for high pressure ink-pumping systems, drop charging and deflection systems, and waste ink plumbing systems were eliminated.

The earliest significant technical work on piezoelectric ink jet began in the 1930s and the first true commercial activity was begun in the late 1960s. This early development effort, aimed at office printing applications, had limited commercial success. The first successful piezoelectric ink-jet printer was introduced in 1977. It printed a relatively crude character set using an array of 12 jets in its printhead.

Canon and Hewlett-Packard independently began work on thermal impulse ink-jet technology for a brief period before introducing successful products in 1984. Since that time, both companies have introduced a steady stream of improved products, primarily for office use. Initially, thermal ink-jet products were thought of as improved versions of dot matrix printers. The newest products offer text quality comparable to high quality office printers, and incorporate color capability, even in the lowest cost offerings. Near-photographic color pictures can be created by using software available on standard personal computers. Several million of these devices are sold annually for office and home use.

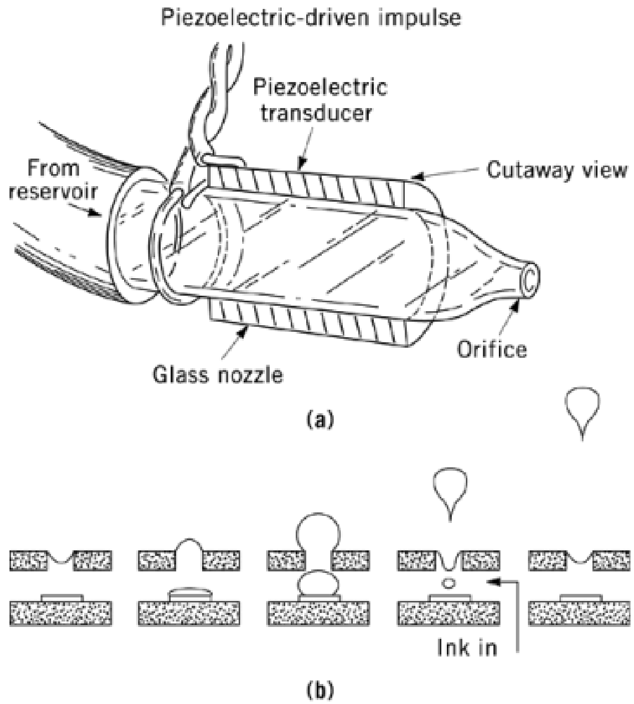


Fig. 19. Ink-jet system: (**a**) piezoelectric ink-jet firing chamber and (**b**) bubble formation in thermal ink-jet technology. (Courtesy of Trident Inc.)

7.8.1. Inks

The main components of the inks are typically water, colorants, and humectants. Additives are used to control drying time, waterfastness, lightfastness, and consistency of drop formation. Water is an excellent vehicle for ink jet because of its high surface tension and safety in all environments.

The principal physical properties influencing ink performance are surface tension and viscosity. High surface tension is desired for good droplet formation and capillary refill in drop-on-demand ink jet. Low viscosity is desired because less energy is required to pump and eject ink. Conductivity is also an important parameter. Continuous ink-jet inks must have some conductivity to allow for charging. Low conductivity is generally preferred for impulse, particularly thermal ink jet, because excess ions can cause corrosion of the printhead.

Inks for continuous ink-jet printers typically comprise dyes dissolved in water or solvent having salts added to make the ink conductive for electrostatic charging. Whenever waterproof printing is required, low boiling solvent inks are used. For printers that are used in office environments, water is used as the ink solvent. Using water-based inks, humectants may be added to inhibit drying of ink in the sump and surfactants are added to wet the printing surface.

Piezoelectric impulse ink-jet inks may be aqueous or solvent-based. They may also be solid at room temperature. Phase-change inks consist of colorant dissolved or dispersed in waxy polymer. When the printer is turned on, the temperature of the ink is raised and maintained above its melting temperature. The ink solidifies immediately after printing. The first phase-change ink-jet printer was introduced to the market in 1988, setting a new standard for print quality on various types of paper and other substrates. Several companies, eg, Tetranix, have developed products based on the phase-change ink-jet technology.

Piezoelectric impulse ink-jet printers are especially sensitive to bubbles in the ink. A bubble in the firing chamber absorbs some of the compressional force from the flexing of the chamber wall and reduces drop volume and drop velocity, thereby affecting print quality. Because of the limited range of motion of the crystal, bubbles are not readily ejected, and the loss of print quality owing to their presence is persistent.

Thermal impulse ink-jet systems impose extreme requirements on stability of ink ingredients to high temperatures. The temperature of the resistive heater in the firing chamber rises from its steady-state temperature to about 400°C within several microseconds. When the bubble of superheated steam forms at the heater surface and expands to propel some of the ink out of the nozzle, dissolved solids precipitate onto the resistor surface. If these are not immediately redissolved after firing and refilling, then repeated firing causes an accumulation of solids on the resistor that interferes with heat transfer and firing. Even trace quantities of materials that are only sparingly soluble in ink tend to accumulate on the heater and damage the jet over time.

There are several conflicting demands on the ink to achieve high quality prints, fast print speed, and high reliability. For print speed, fast drying time is desired, but the ink must not dry in the ink-jet nozzles in order to avoid plugging. High quality text is achieved by holding the colorant on the surface of the paper, but this slows drying time and leads to intermingling or bleed between adjacent colors. Also, improved waterfastness and durability of the printed images is needed for many applications.

The colorant in ink for ink jet has traditionally been water-soluble dyes. High solubility is needed to prevent the dyes from precipitating and clogging the nozzles. The dye itself, its counterions, and impurities in the dyes can cause crusting. Pigment dispersions are gaining importance as colorants in ink jet because of the generally greater lightfastness and image durability compared to dyes. Using pigmented inks, ink-jet performance is dependent on dispersion quality. The first commercial thermal ink-jet printers containing pigment dispersions were introduced in 1993 by Hewlett-Packard using Du Pont inks.

Humectants and low vapor pressure cosolvents are added to inhibit drying of ink in the nozzles. Surfactants or cosolvents that lower surface tension are added to promote absorption of ink vehicle by the paper and to prevent bleed. For improvements in durability, additional materials such as film-forming polymers have been added. Ink developments are providing ink-jet prints with improved lightfastness, waterfastness, and durability. As a result, such prints are beginning to rival the quality of electrophotographic prints.

7.8.2. Applications

7.8.2.1. Industrial Marking. Ink jets are routinely used to print product identification codes directly onto products or product packages as part of the manufacturing process. The continuous ink-jet system suppliers have made small-character industrial printing systems used for component marking and unit product identification a fertile market area. The continuous ink-jet system's capability of printing at high speeds without contact on a variety of packages has led to a large market opportunity in printing "best used by" messages, lot numbers, and identifying dates and manufacturers on a variety of products from beer cans to wire and cables.

7.8.2.2. Personalization of Commercial Printing. Ink jet is used for personalizing magazines and bulk-mail advertisements printed on traditional offset printing presses. Scitex Digital Printing sells continuous ink-jet printing stations that may be installed in-line with traditional web-fed offset printing presses. The system includes a data system, a database of variable information, and the ink-jet imager. The variable information consists of names, addresses, etc. The supplier information consists of product names, logos, maps to local outlets, etc.

The improved quality of binary continuous arrays is beginning to enable printing of both the fixed and variable information by the ink-jet imager. This trend is expected to accelerate with improvements in image quality, because of the cost advantage of single-process printing. Scitex Digital Printing has demonstrated a 61 m/min printing press that uses the same technology in a page-wide array. Equipment advances such as these are breathing new life into what had been a mature technology.

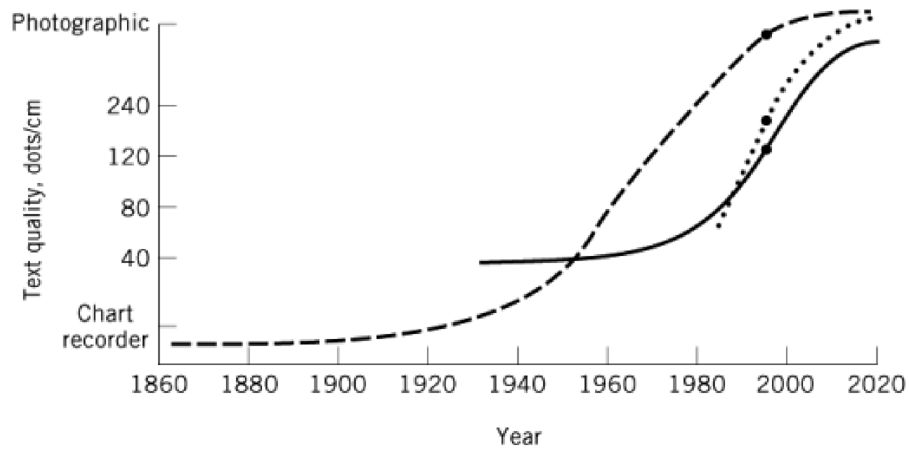


Fig. 20. Growth in image quality of ink-jet technology, where • corresponds to quality in 1995 for (–) continuous flow, (—) piezoelectric, and (…) thermal drop-on-demand.

7.8.2.3. Office. Various segments of the office market have the largest population of computers, and thus the greatest demand for computer printers. In 1994, however, more computers were purchased for home use than for the office. The fastest developing computer printer technology is thermal ink jet, whether measured by rates of performance increase, price decrease, or purchase.

7.8.2.4. Computer-Aided Design. Computer-aided design (CAD) program users are a significant growing market for large-format thermal ink-jet printers. These printers are rapidly replacing pen plotters as the preferred output device (see Computer-aided design and manufacturing (CAD/CAM)).

7.8.2.5. Graphic Arts. Continuous ink-jet printers were introduced to the graphic arts in the mid-1980s for proofing of digital image files prior to lithographic printing. Their quality and functionality have been improved and by the mid-1990s they were widely accepted, in spite of the differences in dot structure between ink-jet images and litho images. Because of the slow printing speed, their use has been limited to proofing.

7.8.2.6. Future Possibilities. Ink jet has the potential to become the predominant digital printing technology because of its cost advantage and simplicity. Growth in image quality of ink-jet technologies is shown in Figure 20. Printing by ink jet requires only one critical process step, ie, the jetting of ink, and can apply all four colors to the page at the same time. By contrast, electrophotography has six critical process steps for each color: clean, charge, expose, tone, transfer, and fuse.

Originally conceived as a universal printing technology suitable for any application, ink jet satisfies a wider range of user requirements than any other printing technology and has become one of the most important methods for office computer printing, industrial marking, graphic arts, and other applications. The direct, noncontact features of ink jet have been extremely important in opening up applications of ink-jet printing, especially in industrial settings, where the surfaces to be printed are often rough or uneven.

Much of the future performance of ink jet is dependent on advances in ink formulation (see Inks). Early ink-jet printers used special media for printing, but there is a demand for printing on a wide variety of paper stocks using a given ink. A strong driving force in the commercial success of ink jet has been the simplicity and low cost of the printer. Thus there is market resistance to achieving improvements through costly printer enhancements.

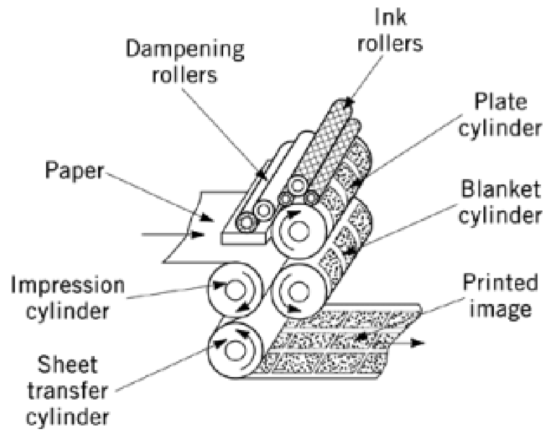


Fig. 21. Offset lithographic printing process. See text.

8. Image Distribution

8.1. Media and Inks for Printing

Some of the complex interactions in printing processes are exemplified in offset lithographic printing, where several components act together to produce an image on the printed sheet. The offset lithographic printing process is illustrated in Figure 21, where the following steps take place. (*1*) The fountain system delivers water, via the dampening roll, at a fixed temperature, pH, and conductivity, to the surface of the rotating plate; (*2*) the inking system delivers a controlled amount of ink to the plate; (*3*) the fountain solution interacts with the nonimage part of the plate surface; at the same time, the ink adheres to the image areas (the inked image area is composed of halftone dots and/or solids); (*4*) the plate cylinder rotates in contact with the rubber-covered offset (or blanket) cylinder; (*5*) the inked areas of the plate are transferred to the blanket; (*6*) the printing paper, which has its own set of properties, including texture, surface hardness, thickness, strength, and absorbency, passes between the blanket cylinder and the impression cylinder, and the inked image area is transferred to the paper; (*7*) the ink dots settle onto the surface of the printed sheet; some mechanical spreading of the dots occurs because of the pressure between the cylinders and from diffusion; part of the ink is absorbed into the paper; (*8*) solvents in the ink begin to evaporate as soon as the printed dot is exposed to air; assisted in some presses by heat and/or uv radiation, the ink dots begin to dry and the tack of the ink changes accordingly; and (*9*) the printing stock passes into the next color section of the press, where the process begins again. These interactions can be better controlled by understanding the various printing media (13).

8.1.1. Printing Ink Formulation

Inks typically contain three main components: pigments, ie, the colored, solid ingredients; vehicles, ie, the fluid ingredients; and additives, such as driers and extenders.

8.1.1.1. Pigment Color. Pigments, the solid coloring substance in ink, are the most noticeable on a printed sheet. Ink pigments typically fall into a few classes of compound: cyans (and greens) are usually copper phthalocyanines, whereas yellows, reds, and oranges are azo pigments or metal salts of azo dyes. Carbon black is usually used for black. Pigment choice is dependent on a number of properties in addition to color. Cost is extremely important in this competitive industry.

8.1.1.2. Vehicles. The solid pigments are dispersed into the ink vehicle, which consists of a combination of resin, oil, and solvent. The solvent is absorbed by the paper, leaving a partially dry ink film of resin and oil that binds the pigment to the paper. This film then hardens by oxidation. Oxidation of the vehicle is aided by varnish driers, ie, metallic salts. Cobalt driers are considered the most effective (see Driers and metallic soaps).

The oils can be either vegetable oils or hydrocarbon oils. The choice depends on the desired ink properties and cost. Soybean oil, although commonly used, is only one of a number of vegetable oils used successfully. Linseed, corn, canola, and tung oil are also common. A drive toward increased use of soy and other vegetable oil-based inks is motivated in large part by public and governmental concern for the environment. Petroleum-based inks can contribute to air pollutants (qv) because of the volatile organic components, principally hydrocarbons, that such inks release as they dry.

A primary source of environmental pollution from printing ink comes from the metal-based pigments used, as well as various resins, waxes, and drying agents that are also part of the inks. These materials are added to inks regardless of the source of the oil. As a result, petroleum inks are just as suitable for landfill disposal under U.S. EPA regulations as are vegetable oil inks.

8.1.1.3. Ink Transparency. Four-color lithographic printing depends on the subtractive properties of colored light. When viewing a printed piece, the source of illumination light must pass through several layers of ink before it is reflected back from the paper surface, and finally passes back through the ink layers. The inks act like selective color filters, only permitting certain colors to pass through.

Complex secondary and tertiary colors are formed when the light passes through multiple layers of these ink filters. In order for overprinted inks to act as subtractive color filters, the ink layers must be transparent enough to allow light through in the first place. Completely opaque inks would show only the color reflected from the surface of the top color. Transparency is largely a function of pigment particle size, and how well the pigment is dispersed in the vehicle. Poor dispersion, or large particle size, results in inks that scatter light, and which are thus not transparent. The apparent hue of an ink may also be affected by these properties.

8.1.1.4. Ink Tack and Flow. Tack is a measure of the cohesion of an ink film, which gives the ink resistance to splitting between two rapidly separating surfaces, such as the plate and the blanket. Ink flow must be balanced with tack. High tack affects the ease with which paper runs through the press. Excessive tack can cause dot loss (picking), and may even damage the surface of the plate. Ink flow refers to the ink property that causes it to level out the way true liquids do. On press, an ink should not exhibit markedly long or short flow properties. Long (low viscosity) inks, such as used with newsprint, have a tendency to fly or mist on press. Short inks tend to cake up on the rollers, plate, or blanket.

8.1.1.5. Density and Ink Film Thickness. Because ink film thickness directly impacts color, it is important to control film thickness on press. The amount of ink transferred to paper, along with a related factor, dot gain, which refers to how the halftone dots spread under the pressure of the printing process, is the tool by which a press operator monitors color on press.

8.1.2. Paper

A wide variety of substrates, such as paper (qv), polyester or other plastic films, or even metal, can be used as substrates for printing (13). By far, however, most printing is done onto paper. Printing paper is manufactured in an enormous variety of sizes, shapes, colors, and surface finishes. Many of these variables have a significant impact on the appearance of the printed sheet. Others may affect how the paper is handled by the press, how quickly ink dries after printing, and how fast the paper can be moved through the press. Different paper types are suited to the needs and requirements of different types of printing. Categories of paper include ground wood, in which the wood pulp is retained, and wood-free or free sheets, in which the wood pulp is removed and the remaining fibers are bleached. Examples of paper types are book papers, business papers, envelope papers, label papers, and news print (see Pulp).

8.1.2.1. Paper Production and Properties. During the paper production process, the wood pulp is mixed into an aqueous slurry, which is poured onto a continuously moving wire mesh and drained by gravity. Additional water is then squeezed out of the paper by a felt web pressed from above. This pressed side, referred to as the felt side, has smaller, finer fibers and is therefore smoother. It is also the preferred printing side.

The bottom or wire side of the paper exhibits a more pronounced grain and a greater openness, which affects ink appearance on paper, because the wire side loses short fibers, paper sizing, and filler through the wires. Although the wire side is usually not the preferred printing side, if both sides are to be printed, the characteristics of both sides need to be considered.

As the paper moves through the production process, the fibers tend to align themselves parallel to the course in which they are moving. This general orientation of the paper fibers is referred to as the grain or grain direction. Grain is mainly significant when the paper is to be folded. Folding cross-grain weakens the paper along the fold.

Paper absorbency is important for proper ink drying. A paper's surface should allow the ink vehicle to penetrate at the proper rate to achieve proper setting of the ink. If the surface is too absorbent, it causes low ink holdout and loss of gloss. If it is not absorbent enough, it causes ink to transfer to other sheets in a stack, or sheets to stick together.

Many papers are coated to add smoothness, gloss, and brightness. Coatings include binders (such as latex), starches, and clays. Fluorescent brightening agents may also be added. Coated papers are typically used for high quality printing because colors print better on those stocks. Some paper stocks are calendered as an alternative to coating. Calender rollers are sets of steel rollers having polished surfaces, located at the dry end of a paper machine. As paper runs through the rollers under high pressure, it becomes progressively smoother, more compact, and more glossy.

8.1.3. Recycled Paper

Recycling paper involves repulping and chemical de-inking (see Recycling, paper). Repulping the paper further shortens the wood fibers, lowering bonding strength. Because fiber strength is also reduced by bleaching, it is often not practical to bleach recycled papers to the same extent as virgin paper. As a result, recycled papers do not have the same purity, brightness, and strength of virgin papers. Recycled paper also accepts ink on press much differently from virgin paper.

Paper runability, literally its ability to run through the press, is affected by (*1*) its surface strength, ie, papers used in offset printing require greater surface strength than other papers because of the force applied by viscous inks; (*2*) shear and tensile strength, ie, papers need to be able to withstand the stresses of passing between multiple sets of rollers, often under high pressure; and (*3*) dimensional stability, ie, in offset lithography, a paper must be able to endure stretching in different directions as it passes between rollers and has ink and moisture transferred to it, and when heat is applied to dry ink. Any permanent stretch can lead to registration problems, which affect the ability of the press to print color consistently.

Paper printability, its ability to be ink-receptive, is determined by smoothness, absorbency, porosity, and ink holdout capability.

8.1.4. The Printing Process

True integration of all facets of the printing process is limited, in most cases, to sporadic measurements of the individual elements and processes that contribute to the final product. There is only a limited effort underway as of the mid-1990s to establish close links between electronic prepress and conventional processes such as proofing, plate-making, and printing.

8.1.4.1. Variables. The basic operations of printing use consumable products that affect print quality. Photographic film used in conjunction with a laser film recorder or imagesetter accepts the digital data as a halftone representation of a scanned image. This film is then used for analogue proofing applications and ultimately for making plates for color printing.

Exposure and development must be predictable and repeatable because multiple pieces of film may be used for a single plate exposure. The proper exposure source and the intensity of that source must be established. The imagesetter must be properly linearized to produce the desired precise halftone dots. This film must be handled under correct safelight conditions and machine-processed in chemical developers at the correct speed and temperature.

Proofing materials have many of the same sources of variability as film, plus the added problem of registering, ie, accurately overlaying, the different colored layers. The printing plate must be exposed precisely to hold all that is discernible in the films. The accuracy of the exposure is critical because the plate must retain all the information contained in the films for faithful reproduction on the press.

8.1.4.2. Instrumentation Used for Process Control. Although measurement tools have been used for some time in the printing industry, instruments such as densitometers have only begun to gain wider acceptance in the 1990s, especially in the production of final films from scanning. Rather than trained personnel, densitometers are widely used at the printing press to control color. As print buyers become more sophisticated, more accurate color control is needed to ensure that the job is produced according to specifications.

Usually specifications are dictated by readings of the solid density numbers (100% dot or solid area), uniform density across the sheet, and dot gain (apparent dot growth from film to printed sheet) values in the quartertone (25%), midtone (50%), and three-quartertone (75%) dot regions, that typify the high quality printing expected when using new four- to eight-color printing presses. The proof is often used as the quality standard which the printed piece must meet.

Instruments like colorimeters and spectrophotometers are used less often. These are used primarily for manufacturing control of printing inks. Frequently, however, inks other than yellow, magenta, and cyan are used for spot-color applications, and in those instances a spectrophotometer ensures the correct match of an ink blend to standard.

Process control (qv) of a lithographic printing press is a difficult chore even for an experienced operator. Largely, control of the press has been left to experienced operators who manipulate a mixture of water and ink to control an ink film emulsion that eventually transfers to the paper to create the printed piece. Among the variables that may need to be adjusted are the following: ink tack, which measures the cohesion of an ink film; ink–water balance, because too much water in ink can cause emulsification and destroy the necessary relationship needed to print sharply; pH and temperature of both the fountain solution, which comprises the water, alcohol, or alcohol substitutes, and the buffering agents, which prevent inking the nonimaged areas of the plate; hardness and squeeze of the various rollers that transport the ink/water and paper through the printing press; amount of ink delivered to each zone across the width of the press; condition of the blankets that pick up the ink from the plate and transfer it to paper, ie, if blankets are worn or misused, image deterioration may result, and if packed incorrectly, image quality may be affected by higher or lower dot gain.

Guidelines for uniform density and dot gain limits have been established. These criteria are the standards used to control the press. A densitometer is used to measure these standards and measurements are made on sheets removed as the press is running. The operator then uses these measurements to guide press adjustments, primarily ink flows, to correct the printed result to standard (8).

8.2. Finishing

Some printing, such as stationery or small posters, can be delivered as printed, but most printing must be converted from printed press sheets to a finished piece through various finishing and bindery processes. Finishing is a general term that includes a number of different and often specialized operations that transform printed press sheets into their final form (8, 13). Some of the most common finishing operations include cutting, folding, stitching, collating, binding, scoring, perforating, round cornering, drilling or punching, die-cutting, embossing, laminating, and padding.

Most finishing work cannot be done in-line with a press. However, in some instances, such as web-fed presses, some folding, collating, and binding can take place. This is confined to printing where large quantities are required, such as newspapers, catalogs, and magazines. When preparing press sheet layouts, print planners must consider the type of finishing equipment they use because the printer's imposition, ie, the arrangement of pages in a press layout to ensure the correct order after the printed sheet is folded, must suit the finishers' equipment.

8.3. Binding

The work required to convert press sheets into finished books, magazines, and catalogs is called binding. Binding includes processes such as saddle and side stitching, perfect binding, mechanical or coil binding, and book binding. All binding methods usually begin by folding a single press sheet printed on both sides down to a signature. Signatures vary from 4–64 pages on a single sheet to maximize press sheet usage, but are usually 16 or 32 pages.

The simplest and least expensive method of binding is the saddle stitch method, in which signatures are collated together and placed on a saddle beneath a mechanical stitching head. Staples are forced through the spine of the book. Most magazines are assembled using the saddle stitch method because of cost and the reader's need to open and lay the magazine flat. When too many signatures or pages are required, side stitching is used as an alternative to saddle stitching. Side stitching allows for bulk assembly. Wire staples are forced through the side of a group of pages about 0.25 in. from the edge. A cover is generally glued around the piece to finish it off. A disadvantage of side stitching is that the finished book cannot lay flat. *National Geographic* magazine is an example of side stitch binding.

Perfect binding or adhesive binding has become a popular alternative to stitched binding. However, this kind of binding is not as durable as stitched pages. The process starts with the collation of pages into a set. The set moves to a roughing station where the back or folded edge is ground off, leaving a rough surface for the adhesive to grip. Heated adhesive is applied and then a cover is attached. Perfect binding allows for books to lay flat and is commonly used for telephone and paperback books.

Mechanical or coil bindings are used for notebooks and calendars. The pages are collated and special drilling equipment is used to punch holes in the paper. Metal or plastic coils are inserted. This durable binding allows finished books to lay flat.

Edition binding or case binding is the most common method used for school textbooks and other hardbound books, including this *Encyclopedia*. This process uses collated signatures that are sewn on special machines which pass thread through the folds of each signature and are knotted at the back. Glue is applied to the spine and hard covers are attached. Finished books are then dried in special hydraulic presses.

Throughout the binding process, many finishing operations may be used to enhance the final appearance of the book. Round cornering of pages, covers, and inserts, along with trimming the final product, all add to the successful assembly of the final piece.

9. Environmental Aspects

Printing processes generate waste. Many environmental regulations apply, as do several alternative choices for action. With the common goal of protecting the environment, printers must balance and carefully analyze all waste minimization, treatment, and recycling programs to minimize costs in a competitive industry (see Recycling; Wastes, industrial).

The environmental restrictions under which printers must operate continue to increase. Federal, state, and local governments all have a say in controlling discharges to the air, land, and water. Improving environmental performance means moving up the waste management scale. On the lower end of the scale the strategies of waste disposal and waste minimization are found. On the higher end are the superior strategies of waste recycle and the ultimate strategy of no waste.

9.1. Recycling

Many printing wastes can easily be directed to well-established recycling outlets, ie, corrugated packaging material, scrap paper, and aluminum-based printing plates. There is also an existing market for recovery of silver and polyester from films used in the printing process.

Photoprocessing chemicals, solvents, and inks are much more difficult to recycle, but printers who partner with their suppliers and promote the use of environmental products have made progress in this area of recycling as well.

9.2. Waste Materials and Emissions

In 1990, there were significant changes in the Clean Air Act, which resulted in provisions for better control of volatile organic compounds (VOCs) that directly impact air quality. Printing presses and associated operations usually generate VOCs through the use of solvents, press washes, fountain solutions, and inks. Minor contributions also come from film and plate production. Various approaches to reducing VOCs include refrigeration of fountain solutions; add-on controls, ie, combustion of ink/solvent residue; press enclosures; and substitution of low VOC products.

9.3. Sewer Disposal

Photoprocessing and printing wastes tend to be aqueous solutions that are combined with other plant effluents and sent to the local sewer plant for treatment. The parameters of concern include silver, pH, and biological oxygen demand (BOD). BOD is a measure of how well a waste material degrades in the environment. Lower values are preferred. Silver-bearing waste streams are typically treated on-site, and the treated effluent is released to the drain. The printer usually receives a small cash credit for silver recovered.

As of 1995, the trend was to reduce the impact on sewer systems and the printer's environmental liability. This can be accomplished through aqueous systems where quality can be maintained, through recycling, or through waste minimization programs. Quite often, printers avoid local sewer systems in treating wastes, for fear of violating permit conditions. The newest technologies involve fully recyclable chemistries, thus eliminating sewer waste.

9.4. Solid and Hazardous Wastes

Among the most stringent environmental regulations impacting the printing industry are the hazardous waste control standards issued under the Resource Conservation and Recovery Act (RCRA). These rules focus on hazardous wastes such as chlorinated solvents, flammable waste inks, and wastes containing heavy metals. Printers must segregate these materials on-site and ship them via an approved hazardous waste hauler to a permitted facility. Many solid wastes generated from the printing process are not hazardous and often may be recycled locally, eg, corrugated paperboard, aluminum printing plates, and paper from scrap product.

9.5. Employee Safety and Health Issues

Printers, like other industrial employers, must be concerned with employee safety and occupational health regulations. Increased public awareness and a trend toward healthier life-styles have resulted in a push for reducing hazardous chemicals, especially carcinogens, in the workplace. Among other things, printers should have thorough training programs in the areas of employee safety and training.

10. Economic Aspects

The printing and publishing industry, though large and growing, is highly fragmented. The value of shipments from the industry worldwide exceeded $400 billion in 1993, $176 billion in the United States alone. The industry is growing at a real growth rate of 3–8%/yr, $\sim 2 - 4\%/\text{yr}$ in North America and Western Europe, and 6–8%/yr in developing countries of the world. The printing industry consumed approximately $82 billion in materials in 1993 to produce its products, of which approximately 90% was paper and ink. The outlook for the printing industry is reviewed annually (105).

On a worldwide basis the printing industry ranks as number four in manufacturing employment. Over 4.5 million people are employed at more than 350 thousand sites. In the United States, 1993 employment exceeded 1.5 million, an increase of over 180 thousand jobs in the period of 1982–1993. Similar growth in employment is being experienced worldwide. Table 1 shows industry trends in the United States, which are typical of those worldwide. These do not include revenues from packaging or office copying.

Table 1. 1987–1993 Printing and Publishing Industries Value of Shipment, $\$ \times 10^9$

Industry segment	1987	1990	1993	CAGR[a], %
newspapers	31.90	34.60	35.80	1.9
periodicals	17.30	20.40	22.70	4.6
books				
publishing	12.60	15.30	18.20	6.3
printing	3.30	4.10	4.90	6.8
miscellaneous publishing	7.80	8.90	10.80	5.8
commercial printing	44.80	52.90	61.60	5.5
printed packaging	54.00	58.00	60.00	1.7
business forms	7.40	7.80	7.10	−0.7
greeting cards	2.90	3.80	4.80	8.8
blank books	2.90	3.10	3.70	4.1
bookbinding	1.20	1.40	1.60	4.9
typesetting	1.80	1.90	2.00	1.8
plate-making services	2.40	2.80	3.10	4.4
Total	190.30	215.00	236.30	4.0

[a] CAGR = compound annual growth rate.

The printing industry is undergoing unprecedented change that is expected to continue into the twenty-first century as digital technology, economic restructuring, and global competition combine to change the operating environment. The printers' role in this changing industry is still evolving but is certainly expected to involve more than just producing ink on paper. It is estimated that before the year 2050, 50% of sales revenues will come from products not produced in 1994 (106). Traditional print, however, should continue to be the primary communication vehicle for information well into the twenty-first century. Significant restructuring and capital investments are being made to optimize production processes and to position for future growth. This may result in short-term excess capacity. Over the long-term, however, the printing industry, as it becomes a more integral part of the multimedia communications industry, should continue to grow and prosper.

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