PART TWO:

PRINTING PROCESS PROFILE

I. PRINTING PROCESSES OVERVIEW[1]

This section presents a preliminary identification of the use clusters in the printing industry. These use clusters define sets of competing chemicals, processes, and technologies used in the industry and identify the environmental and health considerations associated with the members of each set. The use cluster approach allows risk evaluations to be performed on all members of the cluster and facilitates the development of risk reduction strategies by identifying viable substitute chemicals, processes, and technologies.

The printing industry is a very diversified and sophisticated industry owing to the multiplicity of printing processes utilized. These processes include lithography, gravure, flexography, letterpress, and screen printing, as well as a number of more recently developed plateless printing processes. According to Michael Bruno's Status of Printing, lithography, gravure, and flexography are the dominant processes, accounting for more than 83 percent of total U.S. printing industry output. Lithography alone accounts for nearly 50 percent of all domestic output. The importance of letterpress, until the 1940s the dominant printing process, is declining very rapidly and is being replaced by lithography and flexography. The various plateless printing processes are gradually becoming a major force in the industry because of their relative ease of use and the growing application of computer controlled printing operations. In 1991, the plateless processes accounted for only about three percent of total U.S. printing industry output. However, these processes are forecast to have a 21 percent market share by 2025 (Bruno 1990, 1991). Industry trends are summarized in Figure 8.

Some of the printing processes have several major subprocesses based primarily on the types of substrate or products printed. Lithography is divided into three subprocesses: sheetfed offset, heatset web offset, and non-heatset web offset. Gravure includes publication gravure, packaging gravure, and product gravure. Flexography consists of publication flexography and packaging flexography. The various plateless printing processes, all comparatively new technologies, include: electronic printing, ink

[1] Except where otherwise noted, the description of prepress, press, and postpress operations is a synthesis of information from the following sources: Adams 1988; Field 1980; Kirk-Othmer 1982; McGraw-Hill 1987; SRI 1990. Please see the Bibliography for full citations.

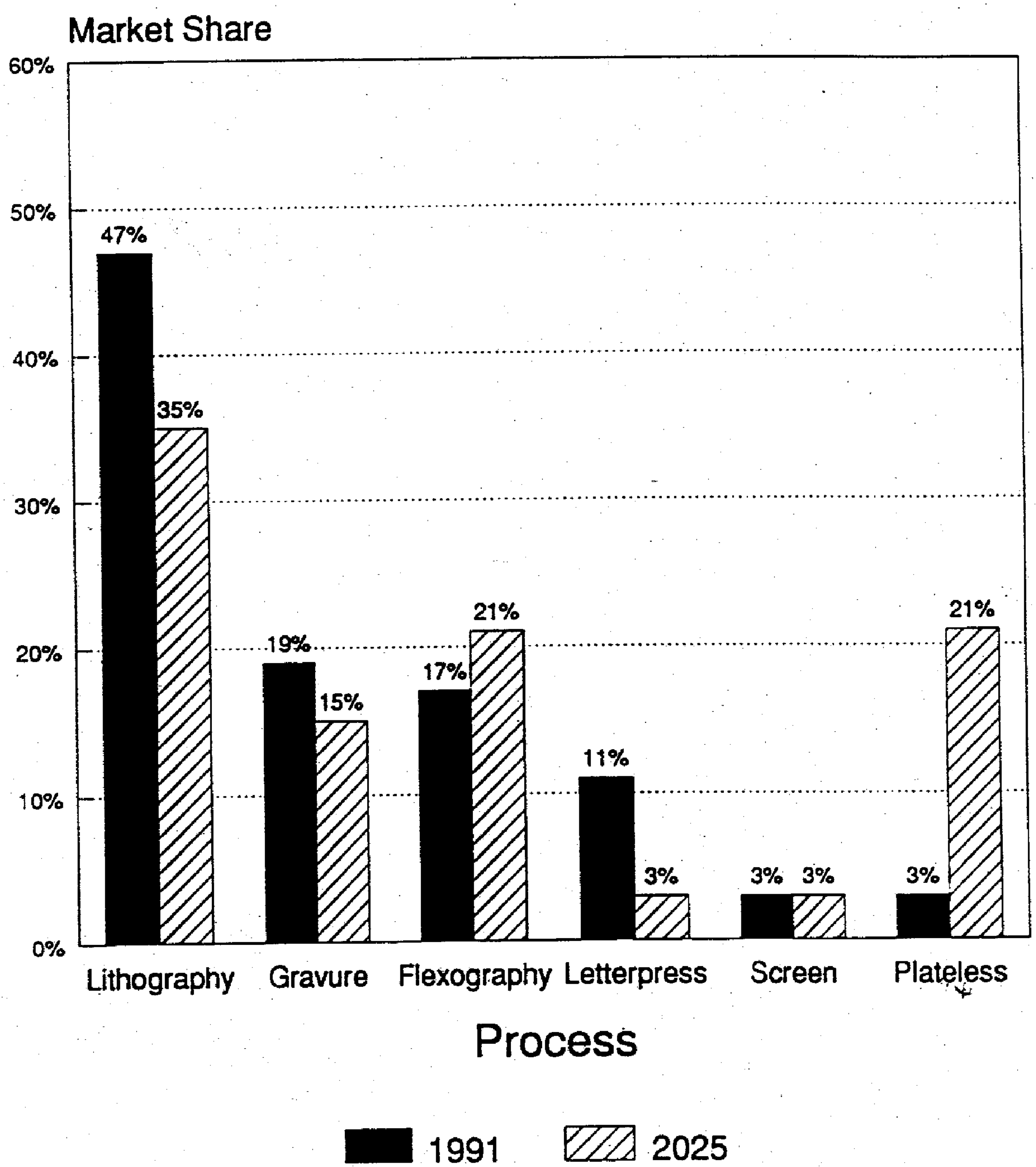

Figure 8. Trends in Printing Technology
(Source: Bruno 1990, 1991)

jet printing, magnetography, ion deposition printing, direct charge deposition printing, and the Mead Cycolor Photocapsule process (Bruno 1991).

Each of the printing processes can be divided into three major steps: prepress, press, and postpress. Prepress operations encompass that series of steps during which the idea for a printed image is converted into an image carrier such as a printing plate, cylinder or screen. Prepress operations include composition and typesetting, graphic arts photography, image assembly, and image carrier preparation. Press refers to actual printing operations. Postpress primarily involves the assembly of printed materials and consists of binding and finishing operations. Figure 9 presents a flow chart of the typical steps in the printing process.

Within each process, a variety of chemicals are used. Prepress operations typically involve photoprocessing chemicals and solutions. Inks and cleaning solvents are the major types of chemicals used during press operations. Postpress operations can use large amounts of adhesives, especially where the production of books and directories is involved. Of all the chemicals used in a typical printing plant, inks and organic cleaning solvents are the categories ordered and used in the largest quantities. Many of the chemicals used in the printing industry are potential hazards to human health and the environment. Occupational exposure to many of these chemicals are currently regulated by the U.S. Occupational Safety and Health Administration (GATF 1992b).

Extremely limited information was found on the volume of chemicals, especially specific chemicals, used in the printing industry. As noted above, inks and cleaners are the chemical products used in the largest quantities by the printing industry. No data on the quantity of cleaners used in the industry was found, however, information on volumes of ink and ink raw materials was available.

In 1991, the U.S. market for printing ink was 1.9 billion pounds. The market is expected to grow at an average annual rate of 2.2 percent through 1996 when the domestic market for printing is expected to total almost 2.2 billion pounds. Additional information on the 1991 and estimated 1996 U.S. market for ink by printing process is presented in Table 10.

Table 11 shows the estimated amount of solvents, resins, pigments, and additives consumed in the domestic production of printing inks.

With the exception of image carrier preparation, prepress operations are similar for the five major printing processes. Therefore, prepress operations, including a general overview of image carrier preparation, are discussed below in Section II. No discussion of prepress activities is included for the plateless

Figure 9. Flow Chart of a Typical Printing Process (Source: Field 1980).

Table 10. U.S. Market for Printing Inks (millions of pounds)

Printing Process	1991	1996	Average Annual Growth Rate 1991 - 1996 (Percent)
Lithographic	836	946	2.5
Gravure	477	528	2.0
Flexographic	363	441	4.0
Letterpress	154	101	-8.0
Other	110	141	5.0
Total	1,940	2,156*	2.2

* Column does not add due to rounding

Source: SRI 1993

Table 11. Estimated Domestic Consumption of Raw Materials for Printing Inks, 1991

Raw Material	Millions of Pounds	Percent of Total
Hydrocarbon and Oxygenated Solvents	660[1]	35
Resins Rosin Esters & Adducts	132	7
Metallized Rosin	106	6
Hydrocarbon Resins	99	5
Alkyds	33	2
Acrylics	55	3
Nitrocellulose	2	0.1
Polyamides	15	1
Miscellaneous[2]	44	2
Resin Subtotal	486	26*
Oils	363	19
Pigments	330	17
Additives	66	3
Total	1,905	100

* Subtotal does not add due to rounding

[1] Printers use an additional 495 to 660 million pounds of solvents at press side to dilute inks supplied by the manufacturer in concentrated form.

[2] Includes polyurethanes, cyclized rubber, shellac, casein, melamines, and others

Source: SRI 1993.

processes because in these processes almost all preparatory steps are accomplished using computers. Section III presents a description of image carrier preparation and printing for each of the five major printing processes. This section also includes brief discussions of a number of plateless printing processes. Because the use of chemicals is most extensive during image carrier preparation and printing operations, the chemicals used throughout the entire printing process (i.e., pre- through postpress) are discussed in this section. Postpress operations, fairly similar for all printing processes, are described in Section IV. Section V discusses technological trends in the printing industry.

II. **PREPRESS OPERATIONS**

A. Introduction

Prepress consists of those operations required to convert the original idea for a printed image into a printing plate or other image carrier. Prepress steps include composition and typesetting, graphic arts photography, image assembly, and image carrier preparation. With the exception of image carrier preparation, the prepress process is similar for the five major printing processes. Plateless process do most of the prepress steps using a computer.

B. Typesetting and Composition

During composition, text, photographs and artwork are assembled to produce a "rough layout" of the desired printed image. The rough layout is a detailed guide used in the preparation of the paste-up or camera ready copy from which an image carrier can be produced.

Traditionally, rough layouts and pasteups were composed by hand using: drafting boards; light tables; various paste-up tools such as technical pens, rulers, and cutting tools; and adhesives. The text used in the paste-up was typeset and printed mechanically.

However, composition has changed dramatically with the advent of computers. Both type and artwork can be generated and edited using computers. Computer systems can be equipped with both optical character recognition and photographic image scanners and digitizers so that pretyped material and photographic images can easily be incorporated into the document being composed. With the systems now becoming available, the computer can directly drive the typesetting and image carrier preparation processes once the page or entire document is laid out and ready for printing.

Typesetting operations assemble the type characters into pages. There are a number of methods of typesetting including manual assembly of pieces of metal type, mechanical assembly of lines of type, and phototypesetting. Until the 1950s, the majority of typesetting was performed using the Linotype machine which produces a "slug" or line of type from molten metal. Similar machines produced single characters of type. Today phototypesetting devices have almost completely replaced manual and mechanical methods of typesetting.

Phototypesetting devices, first demonstrated in the late nineteenth century, were introduced commercially in the early 1950s. They rapidly overtook the Linotype and similar machines in importance. In phototypesetting, individual type characters or symbols are exposed onto photographic film or paper. In early mechanical phototypesetting units, entire fonts of characters were stored as negatives on film. In the later generations of computer-driven phototypesetters, the image is generated electronically, and, in the latest generation of units, a laser is used to project the image onto the photographic film or paper. Phototypesetting produces high contrast, high resolution images ideal for printing purposes. Other computer driven output devices, which include strike-on, line, ink-jet, and laser printers, do not currently produce images of sufficient quality for use in large-scale commercial printing purposes though they are used extensively in in-plant printing applications.

C. Copy Assembly and Process Photography

Copy assembly consists of bringing all original work (text, pictures, and illustrations) together and preparing photographic images. The photographic images are in the form of either positive or negative films and are used for photomechanical image carrier preparation. Copy must be set up correctly to ensure the finished image carrier will produce a high quality print. Assembled copy that is ready for the photographic process is called a flat. When copy of various sizes and shapes is assembled for transfer to film the process is called image assembly or stripping.

The printing industry depends heavily on the use of highly specialized photographic equipment, methods, and materials to produce high quality printed material. Process photography refers to the photographic techniques used in graphic arts. Prior to the invention of electronic page making systems, virtually all printing processes employed photomechanical methods of making image carriers.

Two important types of photography used in the preparation of image carriers are line and halftone photography. Neither of these processes can be used to print a true continuous-tone photograph (i.e., a photograph with intermediate or graduated tones) though halftone can achieve the illusion of continuous tones. Letterpress, lithography, screen printing and some gravure methods involve both these types of photography.

Line photography is used to produce high contrast images on film. Image areas on the film are solid black; little or no illusion of intermediate tones can be achieved with this method.

As noted above, by using halftone photography the illusion of intermediate tones can be achieved for letterpress, lithography, lateral dot gravure, and screen printing. In halftone photography, continuous-tone images are broken down into high-contrast dots of equal density but varying sizes and shapes. (Depending upon the type and quality of printing being done, the density of dots varies from 24 to 120 per centimeter). If, for example, very small dots are used in one area of an image, that area appears to be lighter than those areas of the image where larger dots are used. This occurs because more of the lighter color substrate remains visible in the areas where the very small dots are used.

D. Image Carrier Preparation

Some form of image carrier is used in each of the five printing processes that now dominate the industry. The image carrier, often a plate, is used to transfer ink in the form of the image to the substrate. The image carrier must pick up ink only in the areas where ink is to be applied to the final image on the substrate. It must also reject ink in the areas of the image where it is not wanted. Figures 10 and 11 describe the basic principles of the image carriers used for the major printing processes.

Relief plates used in letterpress and flexographic printing have raised areas that pick ink up from the inking source. Non-printing areas are recessed below the level of the inking rollers and therefore are not coated with ink.

The reverse of a relief plate, the printing areas of a gravure image carrier are recessed below the level of the non-printing areas. The depressions, referred to as cells, pick up small amounts of ink as they pass through an ink fountain. The ink is then passed to the substrate from the cells. The surface of the plate is constantly scraped clean with a doctor blade so that no ink is retained except in the cells. Most gravure presses use a cylindrical image carrier, although some sheet-fed gravure presses and intaglio plate printing presses use a flat plate.

Planographic plates, used in offset lithography, have both the image and non-image areas on the same plane. The image and non-image areas of the plate are each defined by differing physicochemical properties. The image areas are treated to be hydrophobic (water-repellant) and oleophilic (oil receptive). Ink will adhere to these areas. The non-image areas, on the other hand, are treated to be hydrophilic (water loving), and will not accept ink.

The image carrier in screen printing consists of a porous screen. A stencil or mask of an impermeable material is overlaid on the screen to create the non-image area. The image is printed by forcing ink through the stencil openings and onto the substrate. The stencil openings determine the form and dimensions of the imprint produced.

PLATE TECHNOLOGIES

- RELIEF PRINTING
  - The image area is raised above the non-image area
  - Examples include letterpress and flexography
- PLANOGRAPHIC PRINTING
  - The image and non-image areas are on the same plain
  - The image and non-image areas are defined by differing physicochemical properties
  - Lithography is a planographic process
- INTAGLIO PRINTING
  - The image area is recessed and consists of etched or engraved cells of differing sizes and/or depths
  - Gravure is an intaglio process
- SCREEN PRINTING
  - The image area consists of a porous screen defined by a stencil of a non-porous material.
- PLATELESS PROCESSES
  - Electronic
  - Magnetographic
  - Ion-Deposition
  - Mead Cycolor Photocapsule
  - Electrostatic
  - Thermal
  - Ink-Jet

Figure 10. Image Carrier Technologies

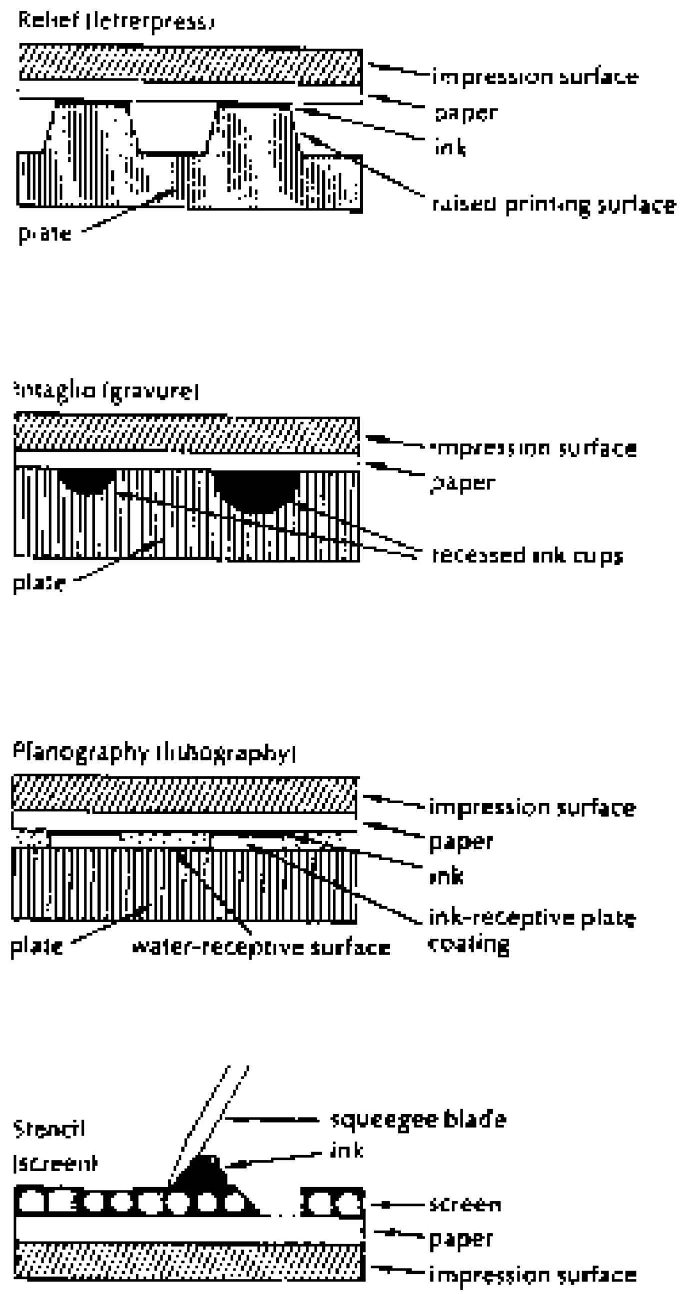

Figure 11. Image Carriers (Source: Field 1980. Reproduced by permission of Ayer Company Publishers, Inc.)

The primary method of image carrier preparation is the photomechanical process where a printing image is produced from a photographic image. Typically, with this process, a light sensitive coating is applied to a plate or other type of image carrier. The plate is then exposed to a negative or positive of a photographic image. The exposed plate then undergoes further processing steps. The individual photomechanical image carrier preparation processes are described in greater detail below. There are other methods of image carrier preparation: manual, mechanical, electrochemical, electronic, and electrostatic. Some of these processes, such as the manual and the mechanical processes, are of little or no commercial importance. Other processes, such as the electromechanical preparation of gravure cylinders, are discussed below where relevant.

1. Photomechanical Image Carrier Preparation

Photomechanical image carrier preparation begins with a plate, cylinder or screen that has been treated with a light-sensitive coating. (The types of light-sensitive coatings used are discussed in the following section.) The coated plate is exposed to light that has first passed through a transparent image carrier such as a film positive or negative. The exposed plate is then processed to produce a plate with defined printing and non-printing areas. Typically, the exposed areas on the plate are resistant to the developing solutions used to process the plate, though in some cases the opposite is true. In either case, during processing the soluble areas of the coating are washed away while the insoluble areas remain on the plate.

At this point image carriers produced from film negatives are essentially finished. The insoluble areas of coating remaining on the plate become the ink carrier during printing. Letterpress plates and lithographic surface plates are produced this way.

With image carriers made from film positives, the insoluble coating serves as a protective barrier during a further processing step called etching. The coating on this type of image carrier is often referred to as a "resist" because it resists the acid used to etch the plate surface. Image carriers produced by this method are used in lithography, gravure, and screen printing.

2. Light-sensitive Coatings

The three most important light-sensitive coatings used on image carriers are photopolymers, diazos, and bichromated colloids. Each of these coatings are discussed in more detail below. Silver-halide and electrostatic coatings are used infrequently for special purpose plates used in duplicating equipment.

a. Photopolymeric Coatings

Today, most image carriers are made using any of a number of different types of photopolymeric coatings. These coatings are characterized by the type of reaction they undergo upon exposure to light: photopolymerization, photocrosslinking, photoarrangement, and photodegradation. A well known example of a photopolymer coating is Kodak Photo Resist (KPR), a photocrosslinking polymer, which is used in image carrier preparation for all major printing processes as well as in the preparation of printed circuit boards.

Depending on the type of image carrier being produced, the hardened photopolymer coating may remain on the image carrier as either the image or non-image area following processing. Photopolymer coatings are characterized by wearability, temperature and humidity stability, and long storage life. Some also exhibit good solvent resistance. For example, if baked prior to use, lithographic plates produced using photopolymer coatings can be used for press runs in excess of one million impressions.

b. Diazo Coatings

Diazo coatings, introduced in the printing industry around 1950, are used primarily for coating both presensitized and wipe-on lithographic surface plates. For presensitized plates, the diazo coating is applied by a machine called a whirler which spreads the coating on the rotating plate. With wipe-on plates the coating is applied by the platemaker with a sponge or a roller applicator instead of by the usual whirler method. Diazo coatings are very thin and susceptible to abrasion and wear during the printing run and generally are used for short press runs of 75,000 impressions or less. However, pre-lacquered plates, plates supplied by the manufacturer with a lacquer impregnated in the plate coating, offer superior abrasion resistance and can be used for press runs in excess of 100,000 impressions. Most diazo plates have negative-process coatings, though positive process coatings are also used. Diazo coatings are used to presensitize deep-etch and bi-metal plates. Additionally, diazo is used to sensitize some colloid coatings.

The diazo resin most often used for plates is the condensation product of 4-diazodiphenylamine salt with formaldehyde. Diazo oxides such as pyridol[1,2-*a*]benzimidazol-8-yl-3(4*H*)-diazo-4(3*H*)-oxo-1-naphthalenesulfonate are also used (Kirk-Othmer).

Diazos are not usually affected by temperature and relative humidity and have a relatively long storage life. They can be processed by automatic plate processing machines which speed up production and result in much higher quality plates than manual methods. Automatic processing equipment can perform plate coating and exposure all in one continuous process. These machines are used extensively in newspaper printing.

c. Bichromated Colloid Coatings

Bichromated colloid coatings were widely used until the early 1950s; limited use continues today. They consist of a light sensitive bichromate and a collodion. The bichromate of choice is ammonium bichromate, with potassium bichromate used in special processes such as collotype. A collodion is an organic material that is capable of forming a strong continuous coating when applied to the image carrier. Collodions used for photoengraving are shellac, glue, albumin, and polyvinyl alcohol. Albumin, casein, alpha protein, polyvinyl alcohol, and gum arabic are used for lithography. Gelatin is used mostly for gravure, screen printing, and collotype. The colloid is formed when the finely divided bichromate and the collodion are mixed. Applied to the image carrier and exposed to light, the colloid forms an continuous, insoluble coating.

III. IMAGE CARRIER PREPARATION AND PRESS OPERATIONS

A. Lithography

1. Lithographic Platemaking

Lithography uses a planographic plate, a type of plate on which the image areas are neither raised nor indented (depressed) in relation to the non-image areas. Instead the image and non-image areas, both on essentially the same plane of the printing plate, are defined by differing physicochemical properties.

Lithography is based on the principal that oil and water do not mix. Lithographic plates undergo chemical treatment that render the image area of the plate oleophilic (oil-loving) and, therefore, ink-receptive and the non-image area hydrophilic (water-loving). During printing, ink is applied to the oleophilic image area of the plate. Water applied to the hydrophilic area of the plate prevents ink from migrating into the non-image area. During printing operations water is applied to the plate by a dampening system. The water is applied in the form of a fountain solution which consists primarily of water with small quantities of chemical additives intended to lower the surface tension of the water and control pH. Traditionally, isopropyl alcohol was used to control surface tension but in recent years it has been largely replaced by glycol ethers, especially 2-butoxy ethanol. This substitution was motivated by a variety of factors, including concerns about isopropyl alcohol's possible health effects, market pressures to reduce VOC emmissions, and regulations requiring reductions in VOC emmissions (Buonicore; DeJidas).

Surface, deep etch, and bi-metal plates, the are three main types of plates used in lithographic printing today, are categorized according to how the printing and non-printing areas are formed. The type of plate used by the printer depends largely on the length of the press run. Surface plates, the least durable of the three types of plates, are used for short runs; deep-etch for runs requiring up to 400,000 impressions; and bi-metal plates for runs requiring up to several million impressions.

a. Surface Plates

Surface plates are made with an aluminum base metal treated with a naturally oil-receptive, light-sensitive coating. During processing, the coating is exposed to light through a photographic negative or positive, thus rendering the image on the plate. The coating is then removed from the non-image areas making them water-receptive. These plates are used mainly for short runs due to their poor wear properties. However, applying a layer of lacquer to the image area substantially increases the number of copies that can be printed.

b. Deep-etch Plates

Deep-etch plates also have a water receptive coating on a base-metal of aluminum. Images are created on the plates by creating an oxide coating on the plate in the image areas, then applying an image bearing coating that adheres to the oxide and not to the base metal. The image becomes slightly countersunk during the processing. These plates are characterized by their long runs, usually in excess of 100,000 impressions. For runs of greater than 400,000 these plates can be copperized or anodized.

c. Bi-Metal Plates

Bi-metal plates take advantage of the affinity of some metals for ink and of others for water. For example, copper and brass are ink receptive while metals such as chromium, aluminum, and stainless steel have an affinity to water. Bi-metal plates are made of two electroplated metal layers. Once processed, the ink receptive metal layer is the image area and the layer with an affinity for water is the non-image area. Copper-surfaced and chromium-surfaced plates are the two main types of bi-metal plates produced today. The chromium-surfaced plate is popularly called a tri-metal plate because it consists of an aluminum base, followed by a layer of copper or brass, and finally a surface layer of chromium.

The plates are supplied either presensitized or ready for in-plant coating. The coating is generally exposed with a negative when using copper-surfaced plates and is always exposed with a positive when using chromium-surfaced plates. The exposed areas of the coating forms a hardened stencil that protects the surface layer of metal. An etching solution is then applied to remove the unprotected areas of the surface layer of metal and expose the underlying layer. On processed copper-surfaced plates, the copper layer forms the image area and the exposed underlying layer of aluminum or stainless steel forms the non-image area. On chromium- surfaced plates, the chromium forms the non-image area and the exposed underlying layer of copper or brass forms the image area. Bi-metal plates are very durable and are capable of press runs ranging into the millions of impressions.

2. Lithographic Presses and Printing

Lithography is well suited for printing both text and illustrations in short to medium length runs of up to 1,000,000 impressions. Feed stock can be either sheet or web.

There are three basic lithographic press designs: unit-design, common impression cylinder design, and blanket-to-blanket design. The unit-design press is a self-contained printing station consisting of a plate cylinder, a blanket cylinder, and an impression cylinder. Two or more stations may be joined to perform multi-color printing. Figure 12 shows a typical layout for a unit-design press. A common impression cylinder press consists of two or more sets of plate and blanket cylinders sharing a common impression cylinder. This allows two or more colors to be printed at a single station. A blanket-to-blanket press consists of two sets of plate and blanket cylinders without an impression cylinder. The paper is printed on both sides simultaneously as it passes between the two blanket cylinders (Field).

As noted in the introduction, lithography can be divided into three subprocesses: sheetfed offset, heatset web offset, and non-heatset web offset. The three subprocesses and the types of chemicals used in each are discussed below.

a. Sheetfed Offset

The sheetfed offset process is used mainly for relatively short runs in the production of commercial and packaging products. The inks used go through an oxidative polymerization drying process generating very little fugitive volatile organic compound (VOC) emissions. The majority of emissions that do occur are from the VOCs in the circulating fountain solutions and solvents used in cleaning presses, blankets, ink fountains, and rollers. Major categories of chemicals used in the sheetfed offset process include film developers and fixers, inks, blanket and roller washes, and fountain solution concentrate. Isopropyl alcohol is widely used in fountain solutions though alcohol substitutes are also available (GATF 1992b). A process flow diagram as well as information on the chemicals used in this process are presented in Figure 13.

b. Heatset Web Offset

The heatset web offset process is used primarily for long jobs at high speed (up to 40,000 impressions per hour) for the production of magazines, other periodicals, and catalogs. "Web" refers to the continuous sheets of paper, supplied in roll form, that are used in this type of printing. The web is cut into individual pages or sheets only after printing. Inks used

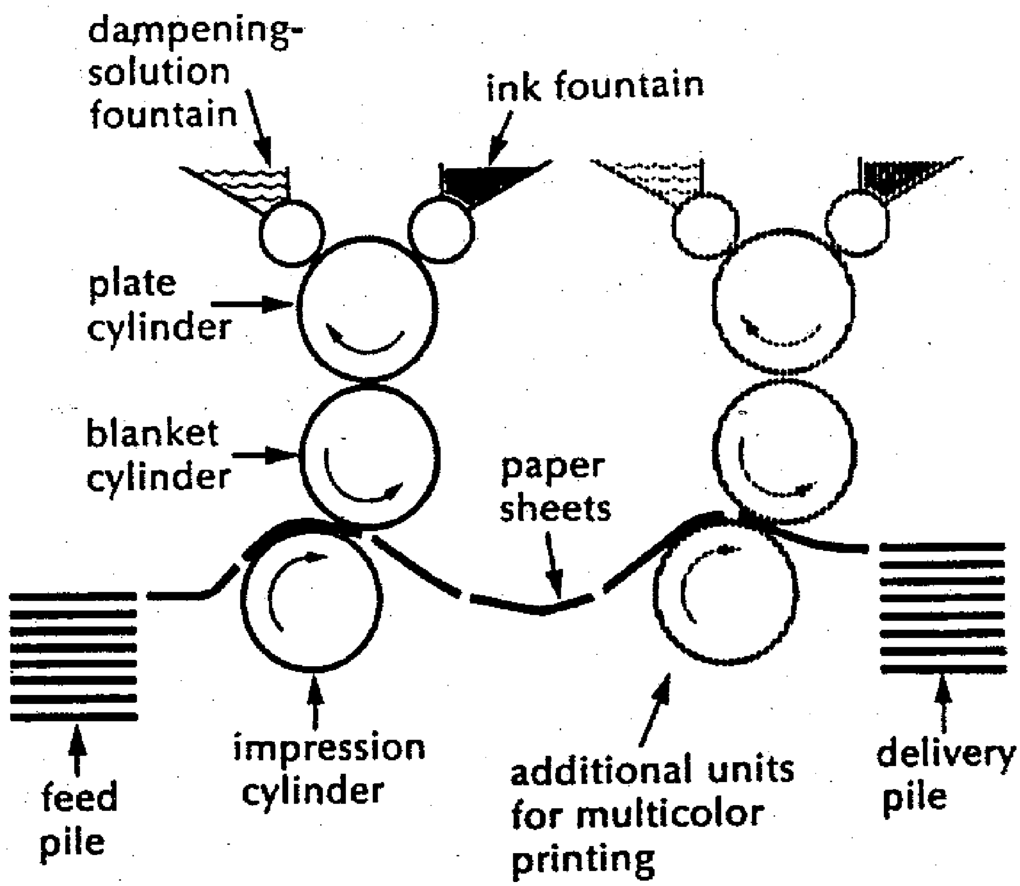

Figure 12. Simplified Lithographic Press Layout
(Source: Field 1980. Reproduced by permission
of Ayer Company Publishers, Inc.)

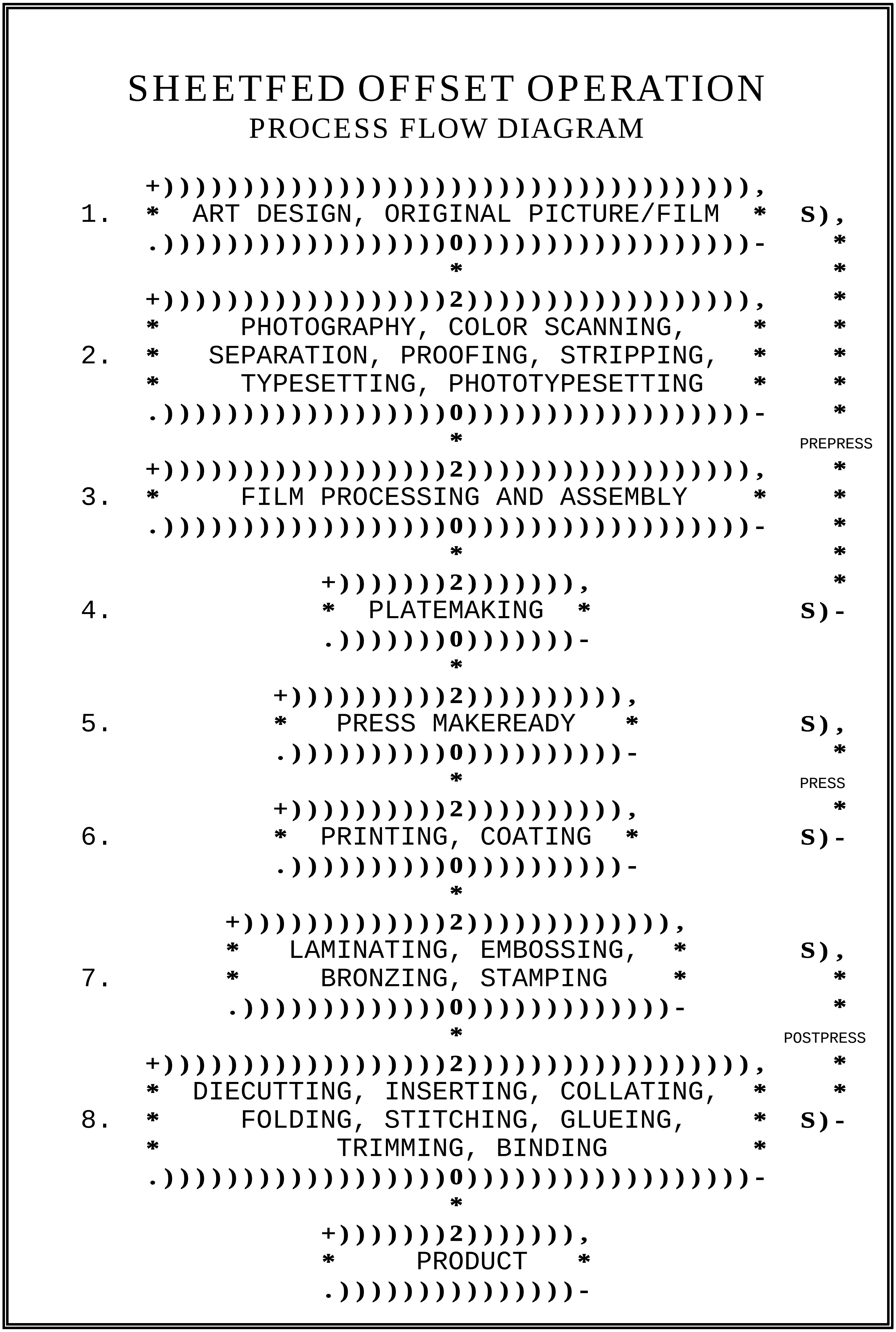

Figure 13. Sheetfed Offset (Source: GATF 1992b).

SHEETFED OFFSET (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive, cleaning solvent
2. Color scanner cleaner, deletion fluid
3. Film developer and fixer, film cleaner, film system cleaner, image cleaner/preserver, antistatic spray, adhesive
4. Plate developer and finisher, plate toner, plate system cleaner

5/6. Fountain solution concentrate, fountain solution defoamer, fountain solution additive, isopropyl alcohol, alcohol substitute, gum arabic, phosphoric acid

Sheetfed offset ink, ink preserver, tack reducer

Blanket wash, roller wash, type wash, glaze remover, UV-ink cleaner, sheetfed ink remover, plate preserver, roller lubricator, copperizing solution, rubber rejuvenator, blanket hardener, image remover, metering roller cleaning solvent

Varnish, UV-varnish, silicone coating

Anti-setoff powder

7. Adhesive, ink, bronze powder, metal foil
8. Adhesive

\- Specialty operations:

Lamination (glue, varnish, plastics)
Stamping (metal foil)
Thermography (polyamide resin)
Cellophane window (glue)
Numbering (ink)
Bronzing (copper/nickel powder)

Figure 13. Sheetfed Offset (continued).

SHEETFED OFFSET (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemical Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1-trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Plate developer	Benzyl alcohol, diethanolamine, polyvinyl alcohol, ethylene glycol, acetic acid
Plate finisher/ replenisher	Dextrin, mineral spirit, sodium hydroxide, N-methylpyrrolidone, sodium sulfite, potassium hydroxide
Image preserver	Stoddard solvent, phosphoric acid
Color proofing	n-Propanol
Press	
Ink, varnish	Petroleum distillates, vegetable oil, resin, rosin, dryers, pigments containing barium and copper
Coating	Polydimethyl siloxane
UV-ink	Acrylates, pentaerythritol tritetracrylates
Fountain solution	Isopropanol, 2-butoxy ethanol and other glycol ethers, gum arabic, ethylene glycol, phosphoric acid

Figure 13. Sheetfed Offset (continued).

SHEETFED OFFSET (cont'd)
MAJOR CHEMICALS USED (cont'd)

Operation/Process	Major Chemicals Used (Volumes of Individual Chemical Used Vary Greatly)
Press (cont'd)	
Wash solvent/plate cleaner	Aliphatic and aromatic hydrocarbons, mineral spirits, acetone, methylene chloride, xylene, toluene, glycol ethers, vegetable oils, fatty acids, surfactants
Copperizing solution	Ethylene glycol, isopropanol, methylene chloride
Glaze remover	Toluene, methanol, acetone
Postpress	
Glue	Paraffin wax
Bronzing powder	Copper, zinc, aluminum, stearic acid

Figure 13. Sheetfed Offset (continued).

in this process are dried by evaporating the ink oil, usually with a recirculating hot air system although direct flame impingement and infrared drying systems continue in limited use (Buonicore). Ink oil evaporated and emitted through dryer stacks is a potentially significant source of VOC emissions. Major chemicals used are quite similar to those used in sheetfed offset (GATF 1992b). A process flow diagram as well as information on the chemicals used in this process are presented in Figure 14.

c. Non-heatset Web Offset

The non-heatset web offset process is a high speed process used largely in the production of newspapers, journals, directories, and forms. The inks used usually do not require drying, therefore, the VOC emissions generated during the use of this printing process are quite small. Dampening and inking systems (including dampening chemistry and ink formulations) differ significantly from heatset web offset. The other major chemicals used in this process, however, are quite similar to those used in heatset web offset (GATF 1992b). A process flow diagram as well as information on the chemicals used in this process are presented in Figure 15.

3. Volume of Output and Percentage of Total Market

In 1991 lithographic printing accounted for 47 percent of the total value of U.S. printing industry output (excluding instant and in-plant printing). However, by 2025, lithography's share of the total U.S. market is expected to decline to 35 percent, due largely to competition from flexography and the various developing plateless printing technologies (Bruno 1990, 1991).

4. Number and Relative Size of Printing Companies

Of a total of 59,636 plants with printing presses, 54,472, or 91.3 percent, have offset lithographic presses. Of the plants with lithographic presses, about 92 percent have sheetfed presses and 11 percent have web-fed presses (some plants have both types of presses) (A.F. Lewis 1991).

As discussed in Section II of this report, the overwhelming majority of companies in the printing industry are small businesses. This is especially true in lithographic printing where about 85 percent of plants with lithographic presses employ fewer than 20 people and roughly half employ less than five. The relatively small number of plants with web-fed lithographic presses, however, tend to be considerably larger. Almost 60 percent of these plants have more than 20 employees (A.F. Lewis 1991).

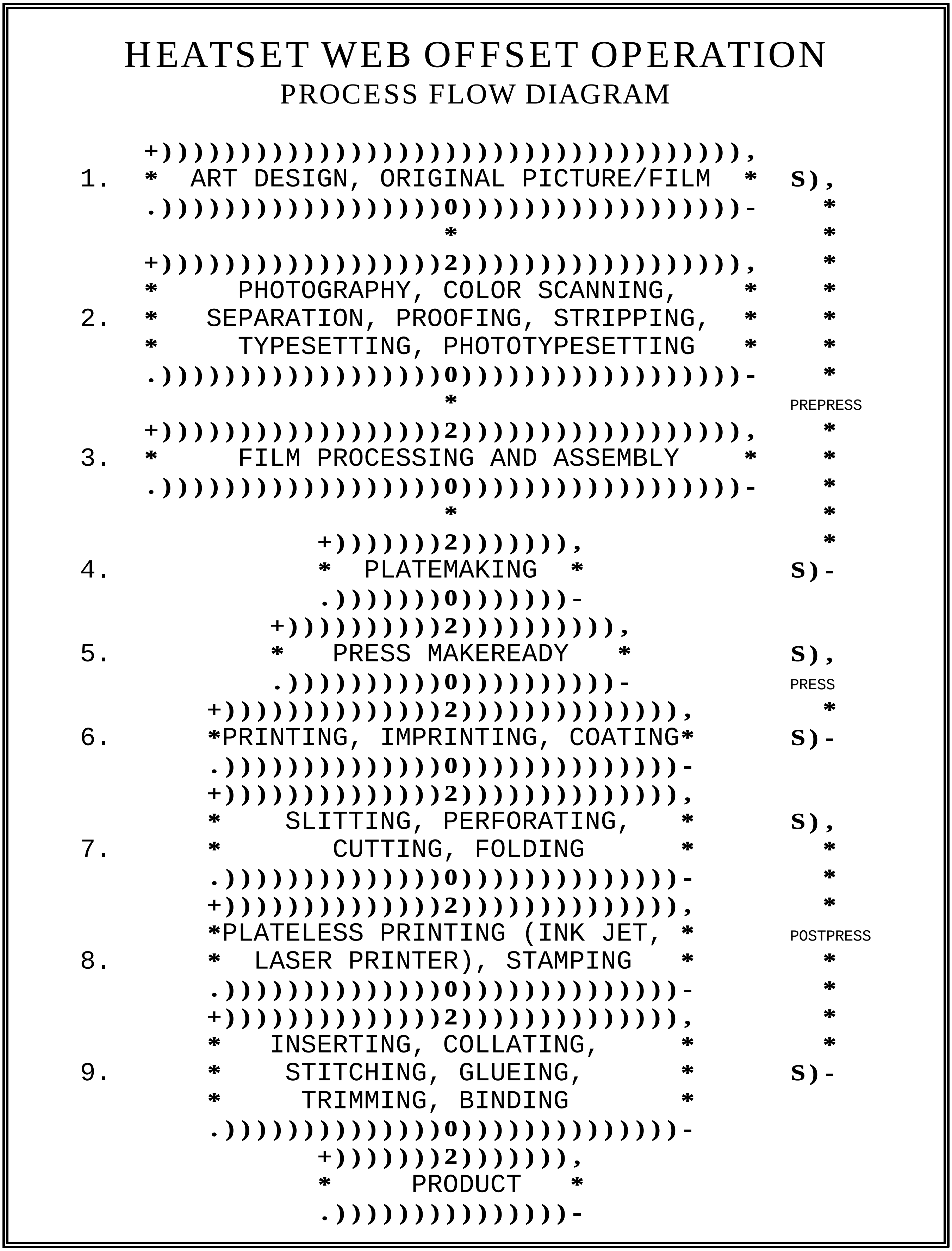

Figure 14. Heatset Web Offset (Source: GATF 1992b).

HEATSET WEB OFFSET (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive, cleaning solvent
2. Color scanner cleaner, deletion fluid
3. Film developer and fixer, film cleaner, film system cleaner, image cleaner/preserver, antistatic spray, adhesive
4. Plate developer and finisher, plate toner, plate system cleaner

5/6. Fountain solution concentrate, fountain solution defoamer, fountain solution additive, isopropyl alcohol, isopropyl alcohol substitute, gum arabic, phosphoric acid

Heatset web offset ink, ink preserver, tack reducer, UV-ink

Blanket wash, roller wash, glaze remover, ink remover, plate preserver, roller lubricator, copperizing solution, rubber rejuvenator, blanket hardener, image remover, metering roller cleaning solvent

Varnish, silicone coating

7. None
8. Adhesive, ink, metal foil
9. Adhesive

- Specialty operations:

  Stamping (metal foil)
  Laminating (varnish)
  Numbering (ink)

Figure 14. Heatset Web Offset (continued).

HEATSET WEB OFFSET OPERATION (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1 trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Plate developer	Benzyl alcohol, diethanolamine, polyvinyl alcohol, ethylene glycol, acetic acid
Plate finisher/ replenisher	Dextrin, mineral spirit, sodium hydroxide, N-methylpyrrolidone, sodium sulfite
Image preserver	Stoddard solvent, phosphoric acid
Color proofing	n-Propanol
Press	
Ink, varnish	Petroleum distillates, vegetable oils, resin, rosin, dryer, pigments containing barium and copper
Fountain solution	Isopropanol, 2-butoxy ethanol and other glycol ethers, gum arabic, phosphoric acid, ethylene glycol
Wash solvent/plate cleaner	Aliphatic and aromatic hydrocarbons, mineral spirits, acetone, methylene chloride, xylene, toluene, isopropanol, glycol ethers, vegetable oils, fatty acids, surfactants
Glaze remover	Toluene, methanol, acetone
Postpress	
Glue	Paraffin wax, isopropanol, trichloroethylene, toluene, ammonia, amines

Figure 14. Heatset Web Offset (continued).

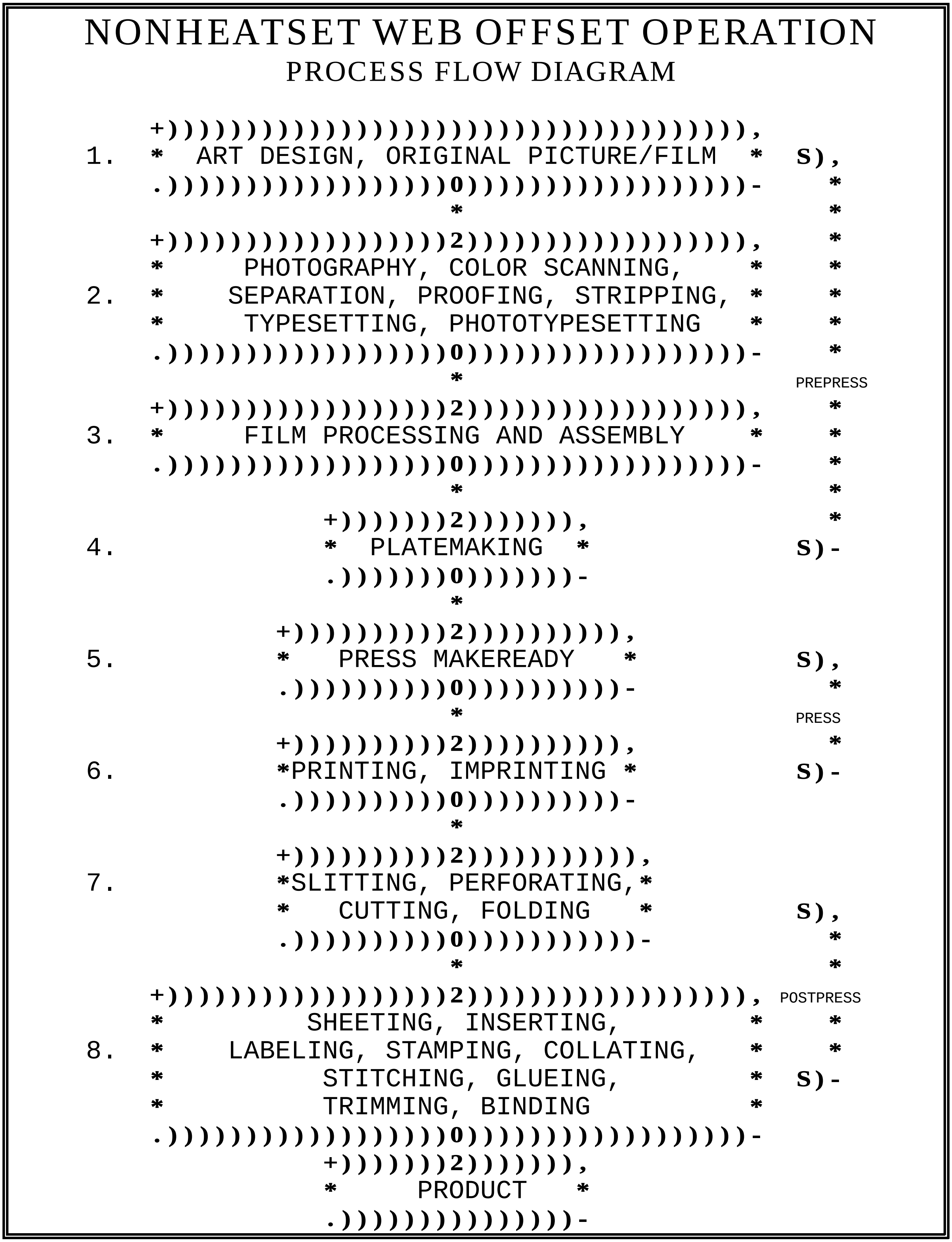

Figure 15. Non-heatset Web Offset (Source: GATF 1992b).

NONHEATSET WEB OFFSET (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive, cleaning solvent, glass cleaner
2. Color scanner cleaner, deletion fluid
3. Film developer and fixer, film cleaner, film system cleaner, image cleaner/preserver, antistatic spray, adhesive
4. Plate developer and finisher, plate toner, plate system cleaner

5\6. Fountain solution concentrate, fountain solution defoamer, fountain solution additive, isopropyl alcohol, isopropyl alcohol substitute, gum arabic

Nonheatset web offset ink, ink preserver, tack reducer, UV-ink

Blanket wash, roller wash, glaze remover, UV-ink cleaner, sheetfed ink remover, plate preserver, roller lubricator, copperizing solution, rubber rejuvenator, blanket hardener, image remover

7. None
8. Adhesive, ink, metal foil

\- Specialty operations:

Stamping (metal foil)
Thermography (polyamide resin)
Numbering (ink)

Figure 15. Non-heatset Web Offset (continued).

NONHEATSET WEB OFFSET (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1-trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol alcohol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Plate developer	Benzyl alcohol, diethanolamine, polyvinyl alcohol, ethylene glycol, acetic acid
Plate finisher/ replenisher	Dextrin, mineral spirit, sodium hydroxide, N-methylpyrrolidone, sodium sulfite
Image preserver	Stoddard solvent, phosphoric acid
Press	
Ink	Soybean oil and other vegetable oils, hydrotreated & solvent extracted naphthenic distillates and paraffin oils, alkyds and other resins, rosin, dryers, clays, carbon black, pigments containing barium and copper
Fountain solution	Isopropanol, 2-butoxy ethanol, gum arabic, dextrin, phosphate salts, silicates, surfactants, polyols, ethylene glycol, dipropylene glycol, synthetic cellulose, isopropanol
Wash solvent/plate cleaner	Aliphatic and aromatic hydrocarbons, ethanol, mineral spirits, acetone, glycol ethers, vegetable oils, fatty acids
Glaze remover	Toluene, methanol, acetone
Postpress	
Glue	Paraffin wax, isopropanol, trichloroethylene, toluene

Figure 15. Non-heatset Web Offset (continued).

B. Gravure

1. Gravure Cylinder Making

Currently, the dominant gravure printing process, referred to as rotogravure, employs web presses equipped with cylindrical, copper-clad plates. In gravure printing, the image is transferred from a sunken surface. The image area of a gravure cylinder consists of a pattern of depressions or cells etched into the cylinder. Following etching, the cylinder is completed by the application of an electroplate of chromium which improves its durability.

A number of other types of gravure presses are currently in use. Rotary sheet-fed gravure presses are used when high quality pictorial impressions are required. They find limited use, primarily in Europe. Intaglio plate printing presses are used in certain specialty applications such as printing currency and in fine arts printing. Offset gravure presses are used for printing substrates with irregular surfaces or on films and plastics.

The cylinders used in rotogravure printing can be from three inches in diameter by two inch wide to three feet in diameter by 20 feet wide. Publication presses are from six to eight feet wide while presses used for printing packaging rarely exceed five feet. in width. Product gravure presses show great variation in size, ranging from presses with cylinders two inches wide, designed to print wood grain edge trim, to cylinders 20 feet wide, designed to print paper towels.

Five different processes, conventional, direct-transfer, variable-area/variable-depth, laser, and electromechanical, have been used to prepare gravure cylinders. The first four use a chemical process to etch cells on the cylinder while the fifth process uses an electronically controlled mechanical process to engrave cells on the cylinder. Electromechanical engraving has almost entirely replaced chemical etching in the preparation of gravure cylinders. Currently, the electromechanical process is used to prepare 100 percent of publication gravure cylinders and 95 percent of packaging and product gravure cylinders. The remaining five percent of product and packaging gravure cylinders, intended for various special applications, are prepared either by the direct transfer or the laser process (Tyszka 1993). The cost of preparing gravure cylinders using any process is high when compared to other types of image carriers. The primary advantage of gravure cylinders is that they have a long service life and will yield a very large number of impressions without degradation. Each of the five processes are discussed in greater detail below.

a. Conventional Gravure

The conventional process of preparing gravure cylinders uses either bichromate-sensitized carbon tissue or special photographic transfer film as the light-sensitive coating and etchant resist. Carbon tissue consists of a pigmented gelatin coating on a paper substrate. It is sensitized with a bichromate solution immediately before it is used. The cylinder preparation process is the same whether the carbon tissue or photographic film are used.

During the cylinder preparation process, the resist is exposed twice using a high intensity ultraviolet light, one time to each of two different glass positives. The first exposure is through a continuous-tone positive. The second exposure is through a gravure screen consisting of transparent lines (150 to 175 per inch) and opaque dots (Buonicore).

During the first exposure, the bichromated gelatin is hardened in proportion to the optical density of the positive image. During the second exposure, maximum hardening of the gelatin occurs in areas under the transparent lines in the screen while the pattern of opaque dots prevents hardening in other areas. The sheet of carbon tissue and hardened gelatin carrying the image is transferred to a copper-clad cylinder. Traditionally, the image is then etched into the cylinder with acid. The more heavily exposed areas of the gelatin are more resistant to the effects of the acid. In these areas no etching will occur or only shallow cells will be etched into the copper cylinder. Deeper cells will be etched on the copper cylinder in areas where the gelatin received less exposure. The process results in a regular pattern of un-etched high spots (lands) and cells of varying depths. In the U.S., the conventional process for gravure cylinder preparation has been replaced by the electromechanical process.

b. Direct-Transfer Gravure

In the direct-transfer process, photographic polymer plates replace the glass photo plates used in the conventional gravure cylinder preparation process. A special wrap-around positive consisting of a combination of half-tone and screened solids is used to transfer the image to the cylinder (Buonicore). The half-tone image is contact printed onto a copper cylinder that has been treated with a photopolymer emulsion. The cylinder is then etched using a process similar to that described for the conventional gravure cylinder preparation process. Cylinders prepared by the direct-transfer process are currently used primarily for printing specialty packaging.

c. Variable-area/Variable-depth Gravure

Cylinders prepared by this process were once used for most multi-color printing in the United States. The method combines elements of the two previously described processes for gravure cylinder preparation. A half-tone and a continuous-tone image are both contact printed on to a sheet of sensitized carbon tissue and gelatin. The carbon paper/gelatin sheet is transferred to the copper cylinder. The cylinder is etched producing a pattern of discontinuous ink cells of varying size and depth which correspond to the areas of light and shadow on the continuous and half-tone composite image. Cylinders prepared by this process are typically used in very long press runs because of their good wear characteristics. In the U.S., the variable-area/variable depth process for gravure cylinder preparation has been replaced by the electromechanical process.

d. Laser Imaging

A proprietary system developed in Japan uses laser technology to image a cylinder treated with a photopolymer resist. However, once the resist has been exposed, traditional chemical etching techniques are used to prepare the cylinder. This process finds limited use in the preparation of cylinders for packaging and product gravure printing (GAA 1991).

e. Electromechanical Engraving

The electromechanical cylinder engraving process, introduced in the late 1960s, has largely replaced the chemical etching process for the preparation of gravure cylinders. Electromechanical engraving is performed using a computer-controlled lathe-type cutting machine. The lathe uses a diamond tool to engrave a pattern of variable size and depth cells on the copper cylinder. Engraving speeds range from 2,000 to 5,000 cells per second with a speed of 3,200 cells per second being typical. At 3,200 cells per second, a typical 30 inch by 40 inch cylinder would require two hours and 20 minutes to engrave.

An electronic signal that is varied to represent values from zero to 100 percent controls the cutting of corresponding size cells on the cylinder. Typically, the electronic signal originates from a drum scanner (or one of the more recent and faster scanning technologies such as the high-speed drum scanner or the flat-bed scanner). The image to be engraved is mounted on the drum of the scanner and as the drum spins, the image is scanned by a combination microscope and electronic eye mounted on the scan carriage.

With early electromechanical engravers, what was seen by the electronic eye of the scanner was immediately engraved on the gravure printing cylinder. Today, however, entire images are scanned into computer memory to be used whenever needed. The computer storage of scans has a number of advantages: cylinder quality can be improved because stored images can be previewed for errors; images can be electronically manipulated; images can be engraved as often as desired without loss of quality; and entire cylinders can be engraved in one nonstop pass of the engraving head (GAA 1991).

Recently direct digital engraving has become widespread. With this process the image can be created and manipulated using an image handling computer. Therefore, the steps of creating, copying, and rescanning film, and the loss of quality inherent in these steps, can be avoided (GAA 1991).

2. Gravure Cylinder Plating

Today virtually all finished gravure cylinders have a copper surface coated with a thin layer of chromium. The copper carries the engraved image while the chrome provides a protective layer against the friction of the doctor blade and the printing substrate (GAA 1991).

Both the copper and chrome layers are applied using an electroplating process. Copper plating is used for plating base copper onto repaired cylinders and for replating the image carrier layer onto the base copper layer of previously used cylinders. The electrolyte used in the acid plating process consists of copper sulfate, sulfuric acid, deionized water, and small quantities of organic additives. Use of a cyanide based electrolyte for copper plating is restricted to the original manufacture of cylinders (GAA 1991).

Chrome plating is applied in a very thin layer so as to change the shape of the cells engraved in the copper as little as possible. For most applications the chrome is plated in layers of about six microns (0.00023 inches), though thicker layers are applied to protect cylinders from the abrasive inks used in some product gravure printing (GAA 1991). The primary electrolyte used in chrome plating consists of chromic acid, sulfuric acid, deionized water, and small amounts of organic additives (GAA 1991).

3. Gravure Presses and Printing

The gravure process has its origins in the early seventeenth century when the intaglio printing process was developed to replace woodcuts in illustrating the best books of the time. In early intaglio printing, illustrations were etched on metal, inked, and pressed on paper.

Gravure, still also known as intaglio printing, makes use of the ability of ink to adhere to a slight scratch or depression on a polished metal plate. Today almost all gravure printing is done using engraved copper cylinders protected from wear by the application of a thin electroplate of chromium. During printing, the surface of the engraved cylinder is flooded with ink with the excess removed by a mechanical wiper known as a doctor blade. Paper or another substrate is brought into contact with the cylinder with sufficient pressure that it picks up the ink left in the depressions. Characteristic of this method of printing is a sharp, fine image.

Web-fed gravure presses account for almost all publication, packaging, and product gravure printing. These presses are generally custom manufactured machines designed for a specific range of products. The typical press is highly automated and consists of multiple print units. The printing mechanism in a rotogravure press consists of a gravure cylinder and a smaller, rubber clad impression cylinder. A typical modern rotogravure press is shown in schematic form in Figure 16. Rotogravure presses do not use elaborate trains of inking rollers like those in certain types of presses. Instead, low-viscosity inks are flooded onto the printing cylinder from an ink fountain. Excess ink is wiped from the cylinder by a doctor blade. During printing the paper passes between the impression roller and the gravure cylinder. The rubber covered impression roller applies pressure to the paper and the ink in the cells on the cylinder is transferred to the paper.

Other types of gravure presses in commercial use today are sheet-fed, intaglio plate, and offset gravure. These types of presses are used primarily for special printing applications.

Sheet-fed gravure is used when very high quality impressions are required. Uses include the production of pictorial impressions for art books and posters and short runs of high quality packaging material such as cosmetics cartons. Sheet-fed gravure presses are also used for overall coating of products printed by sheet-fed offset to provide high brilliancy to the printed sheet and for the application of metallic inks that cannot be applied by the offset method. Additionally, sheet-fed gravure presses are used to produce proof copies prior to large rotogravure runs (GAA 1991).

The sheet-fed gravure press differs from the web-fed press primarily in that paper is delivered to the press as pre-cut sheets instead of a continuous web. The printing mechanism in a typical sheet-fed gravure press consists of a gravure cylinder and an impression cylinder of the same size. The plate itself is a flexible metal sheet wrapped around a carrier cylinder equipped

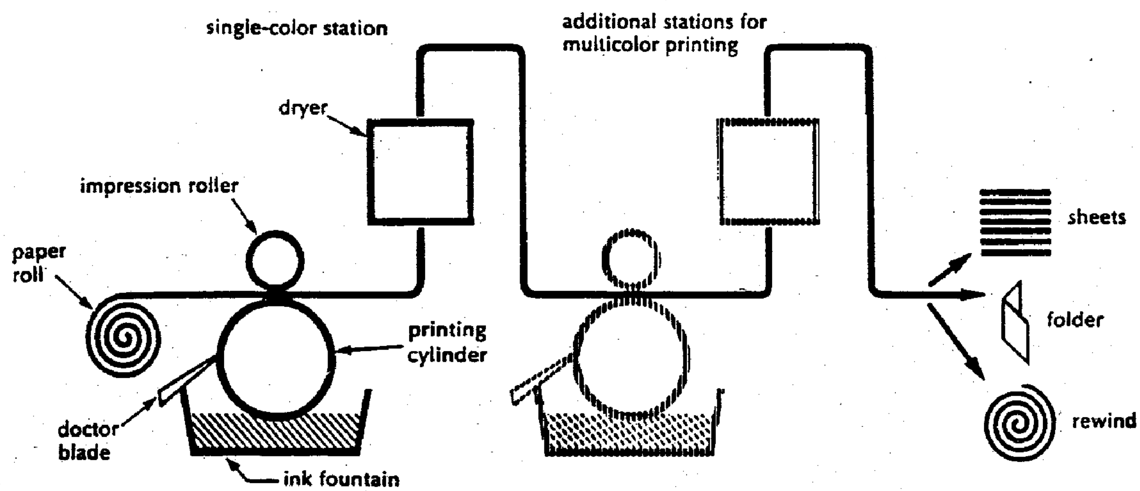

Figure 16. Rotogravure Press (Source: Field 1980. Reproduced by permission of Ayer Company Publishers, Inc.)

with a gripper to hold the plate in place during printing. The gap in the cylinder is fitted with a protective cover once the plate has been mounted. This cover prevents ink from collecting in the gap and consequently producing an unwanted image on the substrate. Ink is flooded onto the plate from a fountain roller. In multicolor printing, air may be directed at the plate to slightly dry the ink and thus assure proper trapping of the ink in the cells. A limited number of sheet-fed gravure presses use a flat plate instead of a cylinder as the image carrier (GAA 1991).

Intaglio plate printing is used to produce stamps, currency, bank notes, securities, and stationary items such as invitations and business cards. It is also used for fine arts printing. Most intaglio plate presses use gravure printing cylinders. However, a flat gravure plate is used for fine arts printing. Intaglio plate printing presses differ from other gravure presses primarily in the inking system which is designed to handle thick paste-like ink (GAA 1991).

The offset gravure press is a standard gravure unit to which a rubber-covered transfer roller has been added. The image to be printed is transferred from the gravure printing cylinder to the roller. The transfer roller then prints the image on the substrate. The transfer of the image from the cylinder to the roller is similar to the transfer method used in offset lithography. Offset gravure presses are used to print substrates with irregular surfaces such as wood veneer or decorated metal (GAA 1991).

Another type of offset gravure press, the flexo gravure press, is currently used for printing clear film overwraps for paper towels and tissues as well as high quality plastic shopping bags. A flexo gravure press is a flexographic press on which the anilox roller has been replaced by a gravure printing cylinder (GAA 1991).

In order to fill the tiny cells on the printing cylinder or plate, very low viscosity inks must be used in gravure printing. The inks are maintained in a low viscosity state by the use of solvents. The solvents must be evaporated quickly so that the ink will dry before the paper reaches the next printing station on the press. This is necessary because wet inks cannot be overprinted without smearing and smudging. Therefore, high volume air dryers are placed after each printing station. The solvent-laden air from the dryers is passed through either a solvent recovery system or solvent vapor incinerator. A typical recovery system uses beds of activated carbon to absorb the solvent. Saturated beds are regenerated by steam. The solvent laden steam is then condensed and the water and solvent separate by gravity. Greater than 95 percent of the ink solvents are recovered using this process (Buonicore). The solvents can either be reused or destroyed by incineration.

Water-based inks are now being used in the industry, especially for packaging and product gravure. However, their introduction has required changes in ink formulation, cylinder engraving, press operation and dryer design. While the use of water-based ink reduces or eliminates the VOC emissions and safety hazards associated with solvents, their higher surface tension and slower drying rate continue to be obstacles to their expanded use (Buonicore).

In some printing processes, both sides of the web can be printed simultaneously. However, in gravure, printing of one side of the web must be completed before the other side can be printed. In practice, the web is printed on one side, rewound, flipped over, then printed on the other side. Some rotogravure presses are designed with a turning station that rotates the web 180 degrees. The web is then run through a parallel paper path with different cylinders that prints the opposite side of the paper. These presses are called double-ended presses.

Currently, an important advantage of gravure printing is that it allows high-quality images on inexpensive paper. Formerly, a major problem with gravure printing was the need to use very smooth and, therefore, expensive paper. In gravure printing, ink transfers by direct contact, so depressions and other irregularities in the paper can cause skips in the printing. In the late 1950s a very smooth coated paper (i.e., trailing-blade coated paper) was introduced that essentially solved the problem of skips in publication gravure printing.

The introduction of an expensive coated paper did not, however, help printers using newsprint and rough board stocks. The development of an electrostatic assist method eventually solved the problem of skips for these types of printers. In the electrostatic assist process, a negative charge is applied to the printing cylinder and hence to the ink and a positive charge to the impression roller and hence the paper. The ink is electrostatically lifted from the printing cylinder to the paper during printing.

A distinction is also made between gravure web-fed presses used for different substrates, and chemical usage is largely dependent on substrate. Based on substrate, the three types of gravure printing are: publication, packaging, and product gravure. These presses and related chemical usage are discussed in more detail below.

a. Publication Gravure

Publication gravure is used primarily for very long press runs required to print mass-circulation periodicals, directories, inserts, and catalogs. Publication gravure maintains a competitive edge in the printing of mass-circulation magazines because the process offers high speed, high quality four color illustrations on less expensive paper, variable cut-off lengths, and flexible folding equipment. These presses can have as many as ten printing stations - four for color and one for monochrome text and illustration in each direction so that both sides of the web can be printed in one non-stop operation. They can handle web widths of up to 125 inches and are equipped to print most large format publications in circulation today. Publication gravure presses can also be fitted with cylinders of differing diameters to accommodate varying page sizes.

The major types of chemicals used in publication gravure include adhesives, metal plating solutions, inks, and cleaning solvents. In terms of chemicals, publication gravure differs from packaging and product gravure primarily in its heavy reliance on toluene-based ink (GATF 1992b). The publication gravure industry has had little success with water-based inks (Buonicore). The industry has found that in publication gravure where the substrate is always paper stock, water-based inks have not been capable of printing commercially acceptable quality productions runs of 2,000 to 3,000 feet per minute. A process flow diagram as well as information on the chemicals used in this process are presented in Figure 17.

b. Packaging Gravure

Packaging rotogravure presses are used for printing folding cartons as well as a variety of other flexible packaging materials. In addition to printing, packaging gravure presses are equipped to fold, cut, and crease paper boxes in a continuous process. Packages are usually printed on only one side, so the number of print stations is usually about half that required for publication gravure presses. However, in addition to printing stations for the four basic colors, packaging gravure presses may employ printing stations for the application of metallic inks and varnishes as well as laminating stations designed to apply foils to the paper substrate prior to printing.

Packaging gravure presses are designed with the accurate cutting and creasing needs of the packaging material in mind. However, image quality is generally less important in packaging printing than in most other types of printing and, subsequently, receives less emphasis.

The chemicals used in packaging gravure are similar to those used in publication gravure. However, the inks used in packaging gravure are largely alcohol- and not toluene-based (GATF 1992b). Water-based inks are being successfully used for lower quality, non-process printing on paper and paperboard packaging and for

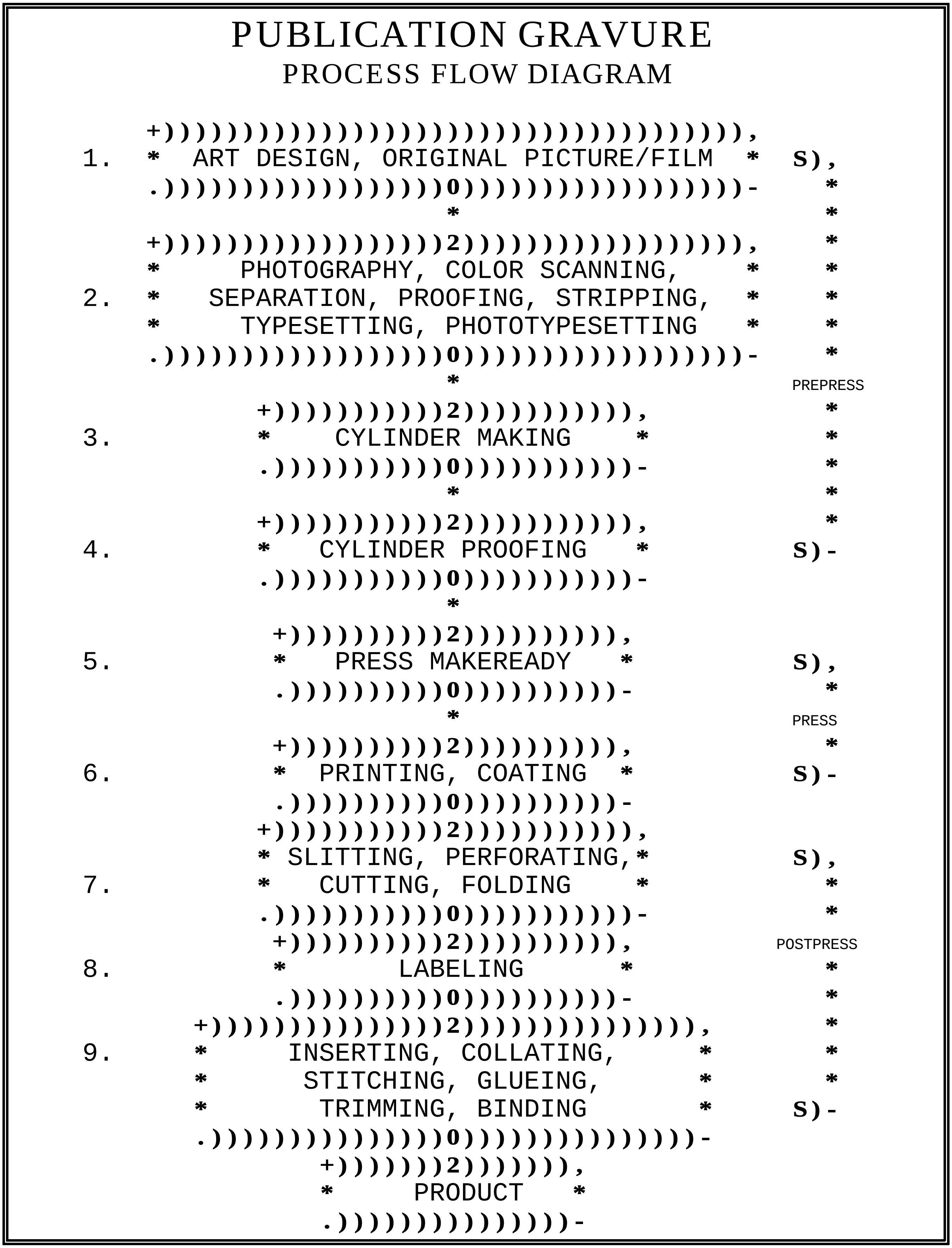

Figure 17. Publication Gravure (Source: GATF 1992b).

PUBLICATION GRAVURE (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive, glass cleaner

2. Photographic processing solution, cleaning solvent

3. Chromium plating solution, polishing compound, etching solution, copper plating solution, nickel plating solution, sulfuric acid solution, degreasing salt, dechroming solution

4. Cylinder cleaner, gravure ink, cylinder cleaning solvent, roller cleaner, toluene, alkane hydrocarbons

5/6. Gravure ink, imprinting inks, ink remover, splicing cement, ink jet inks

7. None

8. Adhesive, cleaning solvent, adhesive remover

9. Adhesive, adhesive remover

Figure 17. Publication Gravure (continued) (Source: GATF 1992b).

PUBLICATION GRAVURE (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1-trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Cylinder making	Barium chloride, 1,1,1-trichloroethane, aliphatic petroleum distillates, ammonium oxalate, ammonium molybdate, barium formate, calcium benzoate, chromic acid, citric acid, copper sulfate, dicarboxylic acid, cupric tetrafluoborate, ethyl acetate, ethylenediamine, formaldehyde, copper, hydrogen peroxide, hydrochloric acid, muriatic acid, isopropanol, phosphoric acid, sodium hydroxide, sulfuric acid, zinc chloride
Press	
Ink, varnish	Hexane, mineral spirits, heptane, lactol spirits, petroleum naphtha, VM&P naphtha, toluene, xylene, alcohols
Wash solvent	Toluene, aliphatic and other aromatic hydrocarbons, ethanol, mineral spirits, acetone, isopropanol
Postpress	
Glue, adhesive	Paraffin wax, toluene, 1,1,1-trichloroethane, isopropanol

Figure 17. Publication Gravure (continued) (Source: Mathtech).

printing on non-absorbent packaging substrates such as plastics, aluminum, and laminates (Tyszka 1993). Use of water-based inks is expected to increase; however, problems still limit their use at press speeds above 1,000 feet per minute (Buonicore). A process flow diagram as well as information on the chemicals used in this process are presented in Figure 18.

c. Product Gravure

The continuous printing surface found on gravure press cylinders provides the "repeat" required to print the continuous patterns found on textiles and a variety of other products. In the textile industry, a gravure heat transfer process using subliming dyes is used to print images on paper. These images are then transferred from the paper to a fabric (usually polyester) through a combination of heat and pressure. The gravure process is also used to print continuous patterns on wallboard, wallpaper, floor coverings, and plastics.

The chemicals used in product gravure are similar to those used in both publication and packaging gravure. However, product gravure uses both water- and solvent-based inks (GATF 1992b). The industry has used water-based inks successfully on medium-weight papers and on nonabsorbent substrates such as plastics, aluminum, and laminates (Tyszka 1993). However, problems such as paper distortion and curl persist with lightweight papers (Buonicore). A process flow diagram as well as information on the chemicals used in this process are presented in Figure 19.

4. Volume of Output and Percentage of Total Market

In 1991 gravure printing accounted for 19 percent of the total value of U.S. printing industry output (excluding instant and in-plant printing). Between 1991 and 2025, gravure's market share is expected to decline to 16 percent of the total U.S. market. Gravure will continue to be the dominant process for the printing of long-run products such as mass-circulation magazines and catalogs, and certain types of packaging. However, the long-run products market is relatively mature and little growth is expected (Bruno 1990, 1991).

5. Number and Relative Size of Printing Companies

Based on a member survey, the Gravure Association of America reports that there were 1,090 plants with gravure presses in 1989 (GAA 1989). Gravure printing is generally used by medium to large size printers (Lewis 1992).

PACKAGING GRAVURE

PROCESS FLOW DIAGRAM

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    +))))))))))))))))))))))))))))))))))))))),
1.  *  ART DESIGN, ORIGINAL PICTURE/FILM  *  S),
    .))))))))))))))))))0))))))))))))))))))-    *
                       *                       *
    +))))))))))))))))))2))))))))))))))))))),   *
    *     PHOTOGRAPHY, COLOR SCANNING,     *   *
2.  *   SEPARATION, PROOFING, STRIPPING,   *   *
    *     TYPESETTING, PHOTOTYPESETTING    *   *
    .))))))))))))))))))0))))))))))))))))))-    *
                       *                 PREPRESS
           +))))))))))))2))))))))))),          *
3.         *    CYLINDER MAKING    *           *
           .)))))))))))0)))))))))))-           *
                       *                       *
           +))))))))))))2))))))))))),          *
4.         *   CYLINDER PROOFING   *          S)-
           .)))))))))))0)))))))))))-
                       *
            +)))))))))))2))))))))))),
5.          *   PRESS MAKEREADY   *           S),
            .))))))))))0))))))))))-            *
                       *                     PRESS
            +)))))))))))2))))))))))),          *
6.          *  PRINTING, COATING  *           S)-
            .))))))))))0))))))))))-
                       *
           +))))))))))))2)))))))))),
7.         *LAMINATING, DIECUTTING*            S),
           .)))))))))))0))))))))))-              *
                       *                         *
    +))))))))))))))))))2))))))))))))))))))),     R
8.  *          INSERTING, COLLATING,       * POSTPRESS
    *     FOLDING, STITCHING, GLUEING,     *     T
    *          TRIMMING, BINDING           *   S)-
    .))))))))))))))))))0))))))))))))))))))-
               +)))))))2))))))),
               *     PRODUCT   *
               .))))))))))))))))-
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Figure 18. Packaging Gravure (Source: GATF 1992b).

PACKAGING GRAVURE (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive, glass cleaner

2. Photographic processing solution, cleaning solvent

3. Chromium plating solution, polishing compound, etching solution, copper plating solution, nickel plating solution, sulfuric acid solution, degreasing salt, dechroming solution

4. Cylinder cleaner, gravure ink, cylinder cleaning solvent, roller cleaner

5/6. Gravure ink, imprinting inks, ink remover, splicing cement, isopropyl alcohol, ink jet inks

7. Adhesive, cleaning solvent, adhesive remover

8. Adhesive, adhesive remover

Figure 18. Packaging Gravure (continued) (Source: GATF 1992b).

PACKAGING GRAVURE (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1-trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Cylinder making	Barium chloride, 1,1,1-trichloroethane, aliphatic petroleum distillates, ammonium oxalate, ammonium molybdate, barium formate, calcium benzoate, chromic acid, citric acid, copper sulfate, dicarboxylic acid, cupric tetrafluoborate, ethyl acetate, ethylenediamine, formaldehyde, copper, hydrogen peroxide, hydrochloric acid, muriatic acid, isopropanol, phosphoric acid, sodium hydroxide, sulfuric acid, zinc chloride
Press	
Ink, varnish	Toluene, xylene, mineral spirits, acetone, methyl ethyl ketone, methyl isobutyl ketone, ethyl acetate, isopropyl acetate, n-propyl acetate, butyl acetate, n-butyl acetate, ethylene glycol monoethyl ether, methanol, ethanol, isopropanol, tri-decanol
Wash solvent	Aliphatic and aromatic hydrocarbons, ethanol, mineral spirits, acetone, toluene, isopropanol
Postpress	
Glue, adhesive	Paraffin wax, toluene, 1,1,1-trichloroethane, isopropanol

Figure 18. Packaging Gravure (continued) (Source: Mathtech).

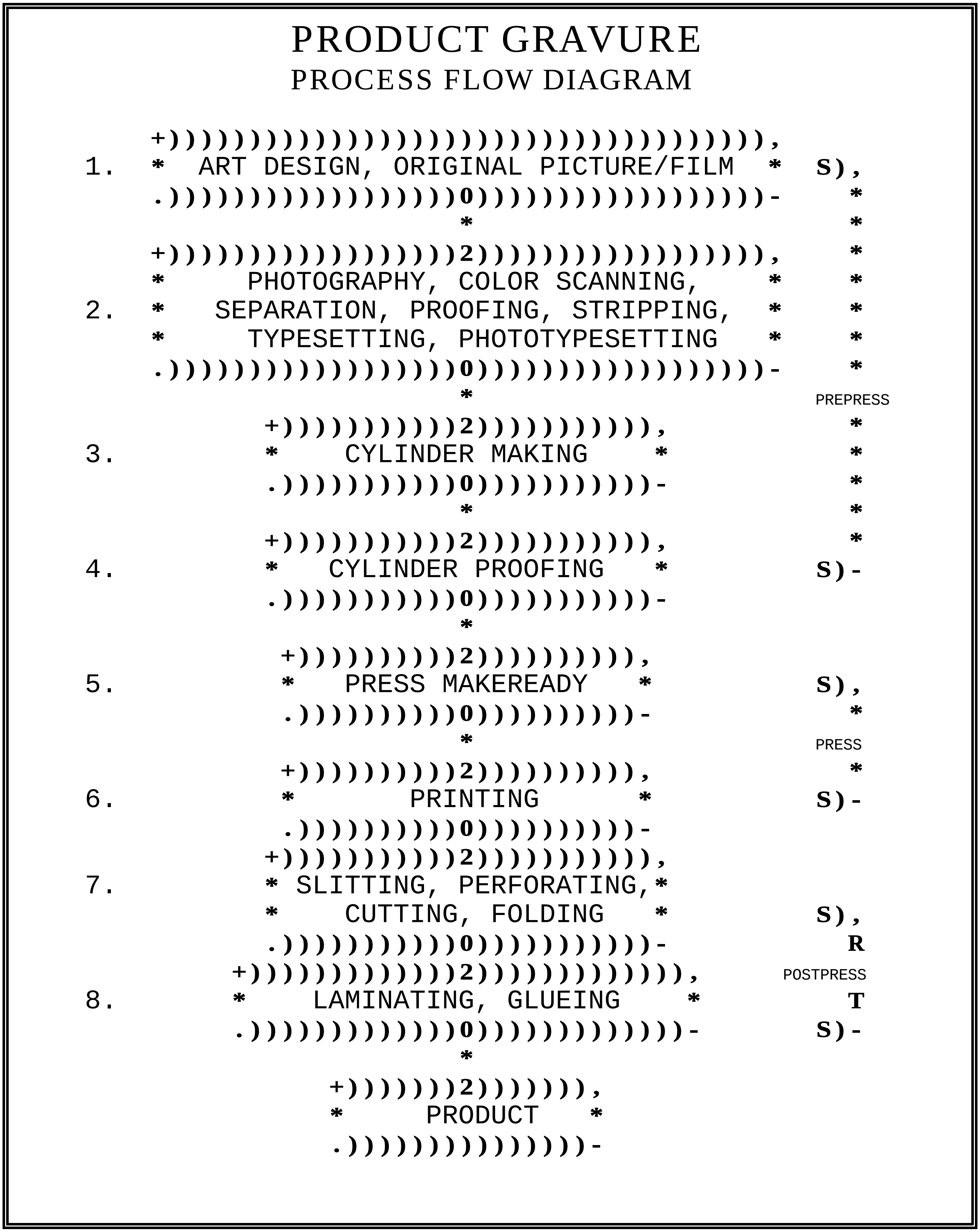


Figure 19. Product Gravure (Source: GATF 1992b).

PRODUCT GRAVURE (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive, glass cleaner

2. Photographic processing solution, cleaning solvent

3. Chromium plating solution, polishing compound, etching solution, copper plating solution, nickel plating solution, sulfuric acid solution, degreasing salt, dechroming solution

4. Plate cleaner, gravure ink, cylinder cleaning solvent, roller cleaner

5/6. Gravure ink, imprinting inks, ink remover, splicing cement, isopropyl alcohol, ink jet inks

7. None

8. Adhesive, cleaning solvent, adhesive remover

Figure 19. Product Gravure (continued) (Source: GATF 1992b).

PRODUCT GRAVURE (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1-trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Cylinder making	Barium chloride, 1,1,1-trichloroethane, aliphatic petroleum distillates, ammonium oxalate, ammonium molybdate, barium formate, calcium benzoate, chromic acid, citric acid, copper sulfate, dicarboxylic acid, cupric tetrafluoborate, ethyl acetate, ethylenediamine, formaldehyde, copper, hydrogen peroxide, hydrochloric acid, muriatic acid, isopropanol, phosphoric acid, sodium hydroxide, sulfuric acid, zinc chloride
Press	
Ink, varnish	Toluene, xylene, mineral spirits, acetone, methyl ethyl ketone, methyl isobutyl ketone, ethyl acetate, isopropyl acetate, n-butyl acetate, ethylene glycol monoethyl ether, methanol, ethanol, isopropanol, tri-decanol
Wash solvent	Aliphatic and aromatic hydrocarbons, ethanol,mineral spirits, acetone, toluene, isopropanol
Postpress	
Glue, adhesive	Paraffin wax, toluene, 1,1,1-trichloroethane, isopropanol

Figure 19. Product Gravure (continued) (Source: Mathtech)

C. Flexography

1. Flexographic Platemaking

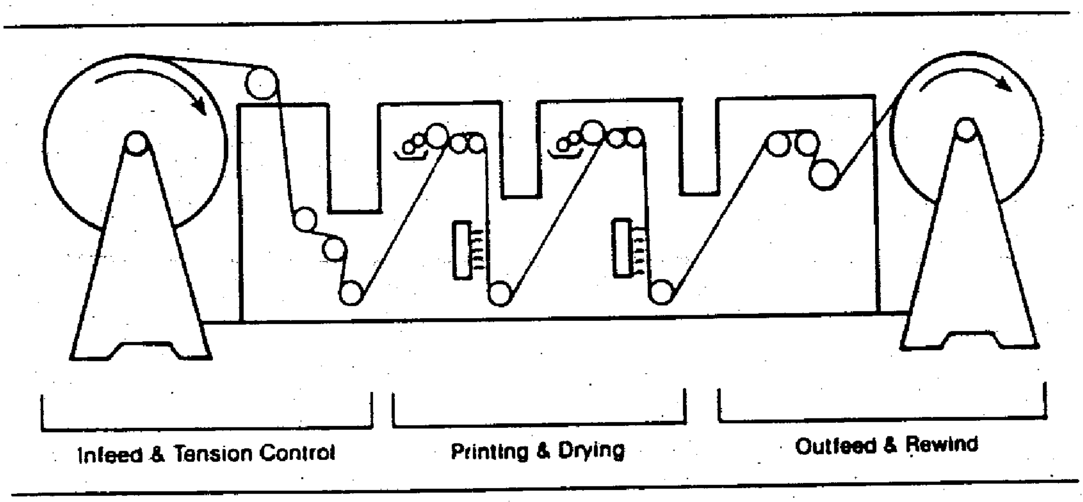
Flexographic plates are relief plates made of either rubber or ultraviolet light sensitive polymers (i.e., photopolymers). The first step in making a rubber flexographic plate is the production of an engraving of the job using a photomechanical process. Once finished, the engraving is placed in a mold press. The mold is produced by pressing the mold material, which can be either plastic or glass, against the engraving under controlled temperature and pressure. The resulting mold is then used to make a rubber flexographic plate; a rubber sheet is pressed into the mold under pressure and elevated temperature.

The production of photopolymer flexographic plates is a direct-to-plate process that does not require an original plate or mold. The process differs depending on whether solid sheets of photopolymer or liquid photopolymer are used, though the two processes are similar in general outline. In both processes the plates are made in ultraviolet exposure units. A negative of the job is placed between the photopolymer and the ultraviolet light source. The photopolymer sheet or liquid is then exposed to ultraviolet light, hardening the image area. Lastly, the plate is processed to remove the unhardened non-image area. Photopolymer plates are replacing rubber plates because they offer superior quality and performance at a lower cost.

2. Flexographic Presses and Printing

Flexographic presses combine features of both letterpress and rotogravure printing. Like letterpress, the process uses relief plates and, like rotogravure, it uses low-viscosity, fast-drying inks. Typically, the plates are made of low-cost rubber or photopolymer. Inexpensive, durable plates coupled with simple printing techniques and the use of a two roller system to distribute ink onto the plate cylinder allow for easy makeup and cleanup. As a result, flexography is one of the least expensive printing processes. Flexographic presses are capable of producing good quality impressions on many different substrates. Figure 20 presents schematics of a web-fed rotary press and a three roller ink system typical of those used in flexographic printing.

The five types of printing presses used for flexographic printing are the stack type, central impression cylinder (CIC), in-line, newspaper unit, and dedicated 4-, 5-, or 6-color unit commercial publication flexographic presses. All five types employ a plate cylinder, a metering cylinder known as the anilox



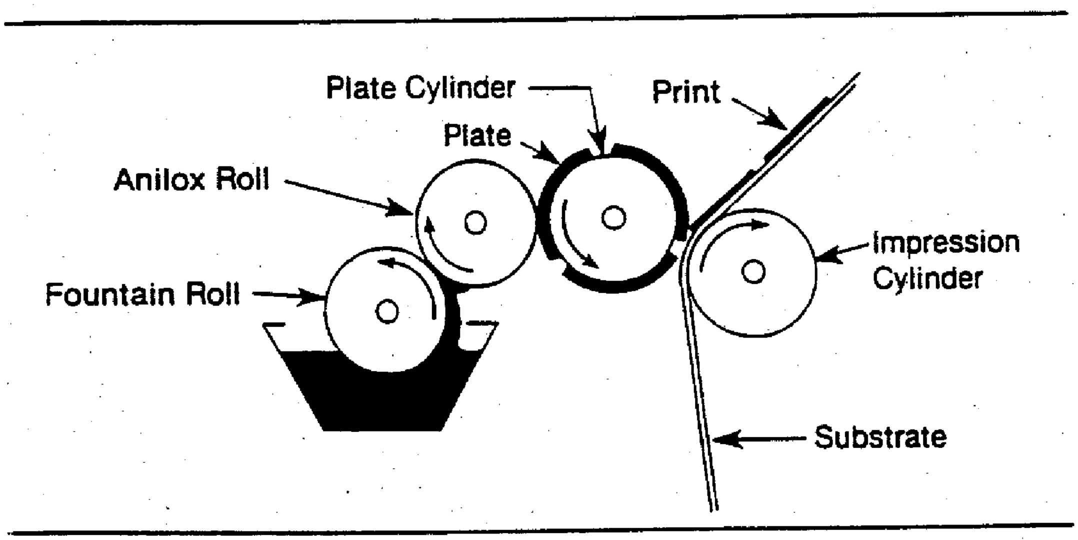


Figure 20. Web-fed Rotary Flexographic Press (top) and Three Roller Ink System (Source: Adams 1988. Reproduced by permission. Printing Technology, 3rd Edition by J. Michael Adams, David D. Faux and Lloyd Reiber, Delmar Publishers, Inc., Albany, New York, Copyright 1988)

roll that applies ink to the plate, and an ink pan. Some presses use a third roller as a fountain roller and, in some cases, a doctor blade for improved ink distribution.

The stack press is characterized by one or more stacks of printing stations arranged vertically on either side of the press frame. Each stack has its own plate cylinder which prints one color of a multicolor impression. All stations are driven from a common gear train. Stack presses are easy to set up and can print both sides of the web in one pass. They can be integrated with winders, unwinders, cutters, creasers, and coating equipment. They are very popular for milk carton printing. A drawback of stack presses is their poor registration; the image position on every printed sheet is not as consistent as in many other printing processes.

Central impression cylinder (CIC) presses use a single impression cylinder mounted in the press frame. Two to eight color printing stations surround the central impression cylinder. Each station consists of an ink pan, fountain roller, anilox roll, doctor blade, and plate cylinder. As the web enters the press it comes into contact with the impression cylinder and remains in contact until it leaves the press. The result is precise registration which allows CIC presses to produce very good color impressions.

The in-line flexographic press is similar to the stacked press except the printing stations are arranged in a horizontal line. They are all driven by a common line shaft and may be coupled to folders, cutters, and other postpress equipment. These presses are used for printing bags, corrugated board, folding boxes, and similar products.

A newspaper flexographic press consists of multiple printing units, each unit consisting of two printing stations arranged back-to-back in a common frame. The use of paired stations allows both sides of the web to be printed in one pass. Multiple printing stations are required to print the many pages that make up a typical newspaper. Single and double color decks, stacked units, or 4-, 5-, or 6-color units are sometimes positioned above those units where the publisher wants to provide single or multiple spot color, spot color for both sides of the web, or process color, respectively (Buonicore).

Commercial publication flexographic presses are compact high-speed presses with wide web capability that utilize dedicated 4-, 5-, or 6-color units. Typically, two four-color units are paired in one press to allow printing on both sides of the web. Publication flexographic presses generally incorporate infrared dryers to ensure drying of the waterborne ink after each side of the web is printed (Buonicore).

There are two primary reasons why flexography is gradually becoming a major player in the printing industry: 1) it is a relatively simple operation; and 2) it is easily adapted to the use of water-based inks. The widespread use of water-based inks in flexographic printing means a large reduction in VOC emission compared to the heatset web or gravure printing processes. Publication flexography is used mainly in the production of newspaper, comics, directories, newspaper inserts, and catalogs. Packaging flexography is used for the production of folding cartons, labels, and packaging materials. Large quantities of inks are used during normal runs on flexographic presses; however, some printers are able to recycle a majority of their spent inks and wash waters.

Major chemicals used in flexography include platemaking solution, water and solvent based inks, and blanket/roller cleaning solvents. Figure 21 presents a process flow diagram as well as information on the chemicals used in publication flexography. Figure 22 presents this information for packaging flexography (GATF 1992b).

3. Volume of Output and Percentage of Total Market

In 1991, flexographic printing accounted for 17 percent of the total value of U.S. printing industry output (excluding instant and in-plant printing). Between 1991 and 2025, however, flexography's share of the market is expected to increase to 21 percent. Growth areas for flexography which recently replaced letterpress as the major relief printing process, are expected to be preprinted labels for corrugated boxes, pressure sensitive labels, newspaper inserts, comic books, and directories and catalogs (Bruno 1990, 1991).

4. Number and Relative Size of Printing Companies

Of a total of 59,636 plants with printing presses, only 1,587, or 2.7 percent, have flexographic presses. Flexographic printers, however, tend to be larger than printers using other processes. Almost 55 percent of plants with flexographic presses have 20 or more employees compared to less than 16 percent in the printing industry as a whole (A.F. Lewis 1991).

D. Letterpress

1. Letterpress Platemaking

Letterpress and flexographic plates are made using the same basic technology. The two basic types of plates used in letterpress printing are original plates and duplicate plates. Only duplicate plates are used in flexography.

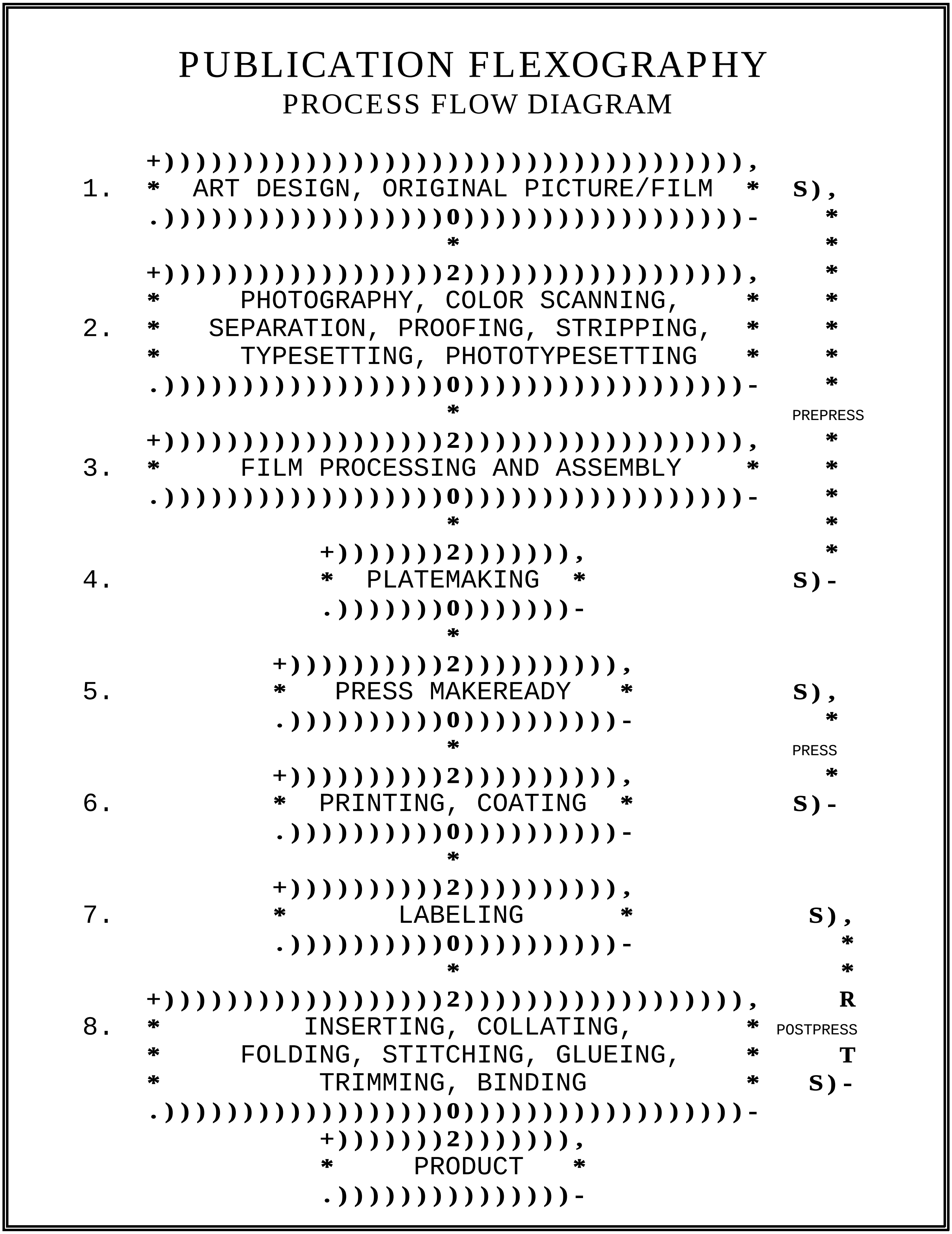


Figure 21. Publication Flexography (Source: GATF 1992b).

PUBLICATION FLEXOGRAPHY (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Glue, cleaning solvent, class cleaner
2. Glue
3. Film fixer, film developer, film cleaner, antistatic spray
4. Platemaking photopolymer, plate washing, defoamer, plate etching compound, plate cleaning liquid, isopropyl alcohol
5. Microbial agent
6. Flexo ink (solvent- or water-based), varnish blanket and roller wash, ink cleaner/remover, plate preserver
7. Adhesive
8. Adhesive

Figure 21. Publication Flexography (continued).

PUBLICATION FLEXOGRAPHY (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1-trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Flexoplatemaking solution	Methacrylate monomer, organic phosphorous compounds, petroleum distillates, anionic surfactants, potassium hydroxide
Press	
Ink	Benzisothiazolinon, ethylenediamine, ammonium hydroxide, antimicrobial agents, isopropanol, toluene
Wash solvent/plate cleaner	Aliphatic and aromatic hydrocarbons, ethanol, mineral spirits, acetone, toluene
Wash solution	Ethylene glycol monoethyl ether, amines, ammonia
Postpress	
Glue, adhesive	Paraffin wax

Figure 21. Publication Flexography (continued).

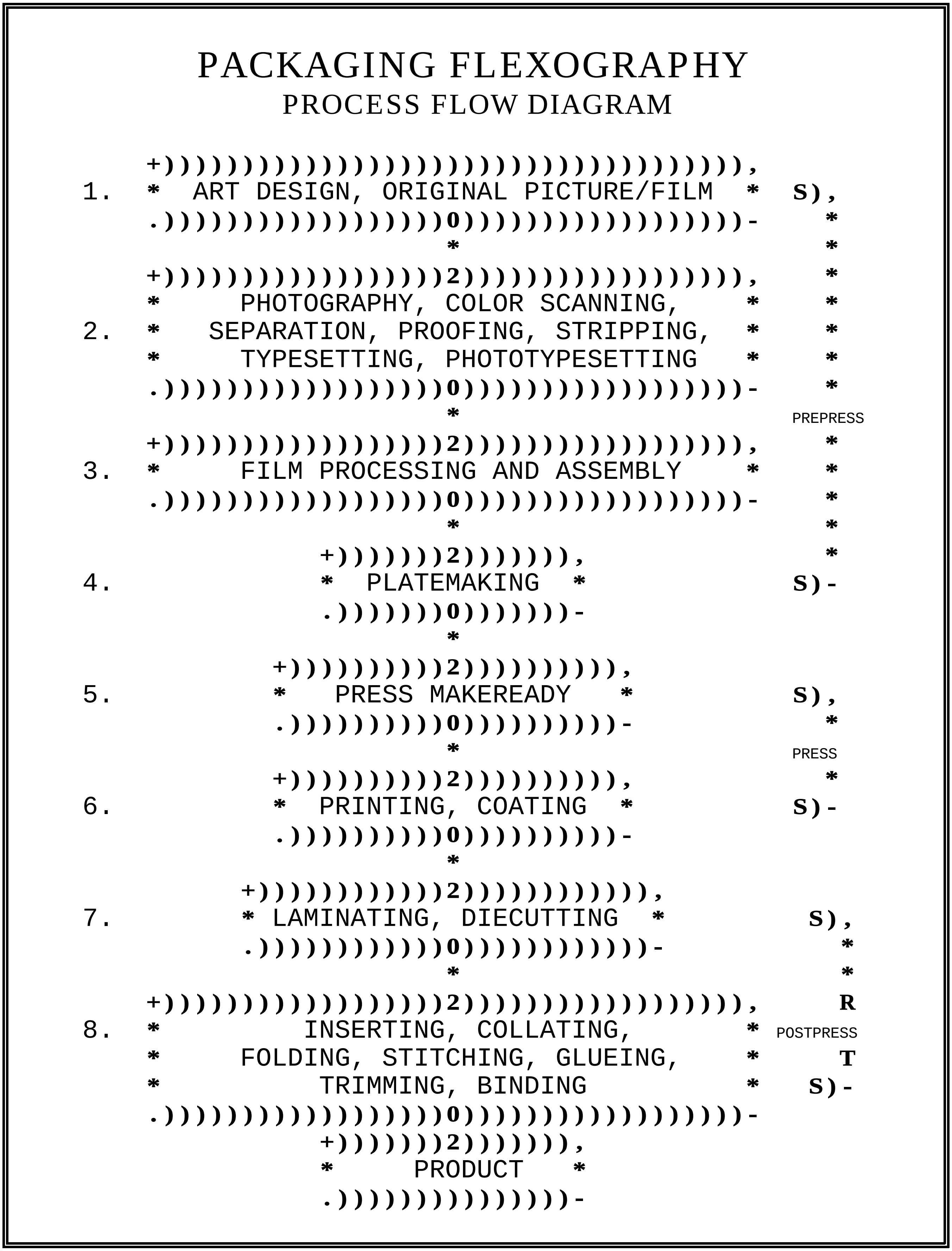


Figure 22. Packaging Flexography (Source: GATF 1992b).

PACKAGING FLEXOGRAPHY (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive
2. Cleaning solvent, adhesive
3. Film fixer, film developer, film cleaning solvent
4. Platemaking fluid, spent platemaking fluid neutralization compound, muriatic acid
5. Plate cleaning solvent, ink, plating cleaning solution
6. Plate cleaner, plate preserver, flexo ink, varnish, roller cleaning solvent
7. Adhesive, adhesive remover
8. Adhesive, adhesive remover

- Specialty operations:

  Lamination (glue)

Figure 22. Packaging Flexography (continued).

PACKAGING FLEXOGRAPHY (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1-trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Flexoplatemaking solution	Methacrylate monomer, organic phosphorous compounds, petroleum distillates, anionic surfactants, glycol ethers, sodium hydroxide
Press	
Ink	Benzisothiazolinon, ethylenediamine, ammonium hydroxide, antimicrobial agents, isopropanol, toluene, n-propanol, n-propyl acetate, ethyl alcohol, n-heptane
Wash solvent/plate cleaner	Aliphatic and aromatic hydrocarbons, ethanol, mineral spirits, acetone, toluene, isopropanol, methyl isobutyl ketone, diethylene glycol ether, methyl ethyl ketone
Wash solution	Ethylene glycol monoethyl ether, amines, ammonia
Postpress	
Glue, adhesive	Paraffin wax, toluene, 1,1,1-trichloroethane, isopropanol

Figure 22. Packaging Flexography (continued).

Original plates are made by photomechanical means from artwork or photographs that have been converted to either line or half-tone negatives. The negatives are used to produce either a photoengraved or photopolymer plate. When the original plates themselves are used for printing, they are called direct plates. Generally, direct plates are used for very short press runs. Duplicate plates, cast in molds made from original plates, are used for longer press runs.

a. Original Plates

Today, original plates are made either from a variety of metals by acid etching methods or from photopolymer plastics. Metal plates are commonly referred to as photoengravings or engravings. The three types of engravings used, line, half-tone, and combination, are dependent on the type of film negative used to expose the plate prior to engraving. Photoengravings are made in units smaller than the size of the press cylinder allowing several to be mounted on the cylinder to produce a complete image. Because rotary presses dominate the market, letterpress printing generally requires curved plates.

A second type of letterpress plate, the wraparound plate, is made using the same general process as used for photoengraving. However, letterpress wraparound plates are mounted in one piece and cover the entire surface of the cylinder. Wraparound letterpress plates are used for both dry offset and direct printing.

Photoengraved plates are produced on 16 gauge zinc, copper, or magnesium. Copper is usually used for halftone plates and zinc and other metals for line engravings. Photosensitive coatings used in plate preparation are bichromated shellac for zinc and magnesium plates and bichromated glue for copper plates. Photocrosslinking polymers are also used for some plates. After exposure, the metal plates are subjected to an acid bath where the non-printing areas are etched away by the acid. Large non-printing areas may be removed by mechanical routing. Nitric acid is frequently used to etch zinc and magnesium plates while a ferric chloride solution is used for copper plates.

A major problem during etching is undercutting, the unwanted sideways etching that can undercut the resist and adversely effect dot size and line width on the plate. Today a technique known as powderless etching is used to prevent this problem. In powderless etching, the etching bath consists of an emulsion of nitric acid, oils, and a wetting agent. As the acid attacks the plate, the wetting agent and oil form a banking agent that clings to the sides of the etched areas and prevents sideways etching. This system has been adopted for use on zinc, magnesium, copper and aluminum plates. Chemically, the emulsions used for etching copper and aluminum plates are quite different from those used for zinc and magnesium plates. Powderless etching can be used for original photoengraved plates as well as wraparound plates.

Photopolymer plates can be used for original and wraparound applications or for making duplicate plates. The photopolymer plates in use today are typically proprietary products and include Dycril, Nyloprint, Letterflex, Dynaflex, NAPP, and Merigraph plates.

Du Pont Dycril plates, introduced in 1959, are used in a wide variety of flat, rotary, and wraparound letterpress applications as well as letterset applications. These plates also serve as patterns for making duplicate plates. Dycril plates consist of a layer of light-sensitive plastic bonded to a metal or film substructure. When the plate is exposed to UV light through a halftone or line type negative, the exposed areas of the plastic coating is polymerized and becomes hardened. The unexposed coating can be washed away using an alkaline spray.

Nyloprint plates, produced by BASF, Corp., are made of a photosensitive nylon layer bonded to a backing material, usually aluminum, steel, or distortion resistant foil. These plates are used on cylinder presses for printing magazines and other long run jobs.

Letterflex plates, manufactured by W. R. Grace & Co., are used extensively in newspaper and book printing. They consist of a liquid photosensitive prepolymer applied as a coating to a polyester sheet. A machine performs both the coating and exposure process in one operation. The liquid prepolymer is converted to a solid polymer on exposed areas of the sheet. The liquid prepolymer remaining on the unexposed areas is then removed. Used on cylinder presses, Letterflex plates are very durable.

Dynaflex plates, used primarily by the newspaper industry, consist of a dry prepolymer photosensitive coating on a metal substrate. Once exposed, processing is similar to other photopolymer plates. The unexposed areas of the plate is easily removed by water.

NAPP plates, developed in Japan but manufactured in the U.S. by Lee Enterprises, Inc., use a denatured polyvinyl alcohol coating bonded to a steel or aluminum backing. The plates are delivered to the printer in a presensitized state that are ready for exposure without any other processing. After exposure, the plate is washed in water to remove the unexposed material. These plates are used primarily for letterpress applications but they can be easily adapted to gravure and lithographic operations.

Merigraph plates, developed in Japan but manufactured in the U.S. by Hercules, Inc., use a liquid unsaturated polyester photopolymer similar to that found on the Letterflex plate. A machine is used to coat the plate just prior to exposure.

b. Duplicate Plates

A duplicate is a plate cast in a mold made from an original plate. Duplicate plates are used because they can be made from a number of durable materials resulting in plates with longer service lives than is possible with original plates. Furthermore, if a duplicate plate is damaged, a new duplicate can quickly be produced from the original. Curved duplicate plates are produced to fit modern press cylinders.

Duplicate plates fall into four general categories: stereotype, electrotype, plastic, and rubber. Each of these types of plates are described in greater detail below.

Stereotype plates are used only for letterpress newspaper printing. A stereotype plate is prepared by first making a paper-mache mat or mold from the original plate. Molten metal is then poured into the paper-mache mold to form the press plate. The metal used depends on the length of the press run. For long runs nickel, chromium, or iron are used.

Electrotype plates are used in letterpress operations where high quality is required. This includes commercial printing, books, and magazines. An impression or mold of the original is made using hot plastic. The mold is then plated with silver to make it conductive. The coated mold is then electroplated with a thin layer of copper or nickel. The resulting shell is removed from the mold and backed with molten metal to give it strength. The face can then be plated with nickel, iron, or chromium for long press runs.

Plastic and rubber plates are prepared in a process similar to the one used to make electrotype plates. The use of plastic or rubber makes the plates very lightweight and low-cost. Plastic plates are made from thermoplastic vinyl resins. Currently, however, use of this type of plate is not widespread due largely to the toxicity of the vinyl monomers used.

Rubber plates can be molded from either natural or synthetic rubber or some combination of the two. These plates are used on flexographic presses for printing wrapping paper, bags, envelopes, corrugated boxes, milk cartons, and any application where the flexible characteristics of rubber assist printing on irregular and rough surfaces. These plates are also used for special "central impression presses" used to print flexible films used in packaging.

2. Letterpress Presses and Printing

Letterpress printing dates back to the earliest methods for applying an image to paper. The three types of letterpress presses in use today are platen, flat-bed, and rotary presses. Schematic representations of two of the most common types of letterpress presses, the unit-design perfecting rotary press and the rotary letterpress typically used for magazine printing, are shown in Figure 23.

Platen presses have been in continuous use since Gutenberg first invented the printing press. A platen press is made up of two flat surfaces called the bed and the platen. The plate containing the image is placed on the bed and locked down. The platen provides a smooth backing for the paper or other substrate that is to be printed. The plate is inked and then the platen presses the substrate against the plate producing the impression. Some platen presses are arranged with the bed and platen in the vertical plane.

The plate is inked with an inking roller that transfers ink from an inking plate to the image carrier. Ink is placed on the inking plate by an ink fountain roller. The platen style press has been widely used in printing small-town newspapers since the late 1800s. The printing area is usually limited to a maximum of 18 inches by 24 inches. These presses are also used to print letterhead, billheads, forms, posters, announcements, and many other types of printed products, as well as for imprinting, embossing, and hot-leaf stamping.

Flat-bed cylinder presses use either vertical or horizontal beds. These presses can print either one or two-color impressions. Flat-bed cylinder presses, which operate in a manner similar to the platen press, will print stock as large as 42 inches by 56 inches. The plate is locked to a bed which passes over an inking roller and then against the substrate. The substrate passes around an impression cylinder on its way from the feed stack to the delivery stack. Ink is supplied to the plate cylinder by an inking roller and an ink fountain. Flat-bed cylinder presses are slow, having a production rate of not more than 5,000 impressions per hour. As a result, much of the printing formerly done on this type of press is now done using rotary letterpress or lithography. The horizontal bed press, the slower of the two types of flat-bed cylinder press, is no longer manufactured in the United States.

Rotary presses are currently the most popular type of press used in letterpress operation. They can be either sheet-fed or web-fed and, in construction, are similar to other sheet-fed and web-fed presses. Like all rotary presses, rotary letterpress requires curved image carrying plates. The most popular types of plates used are stereotype, electrotype, and molded plastic or

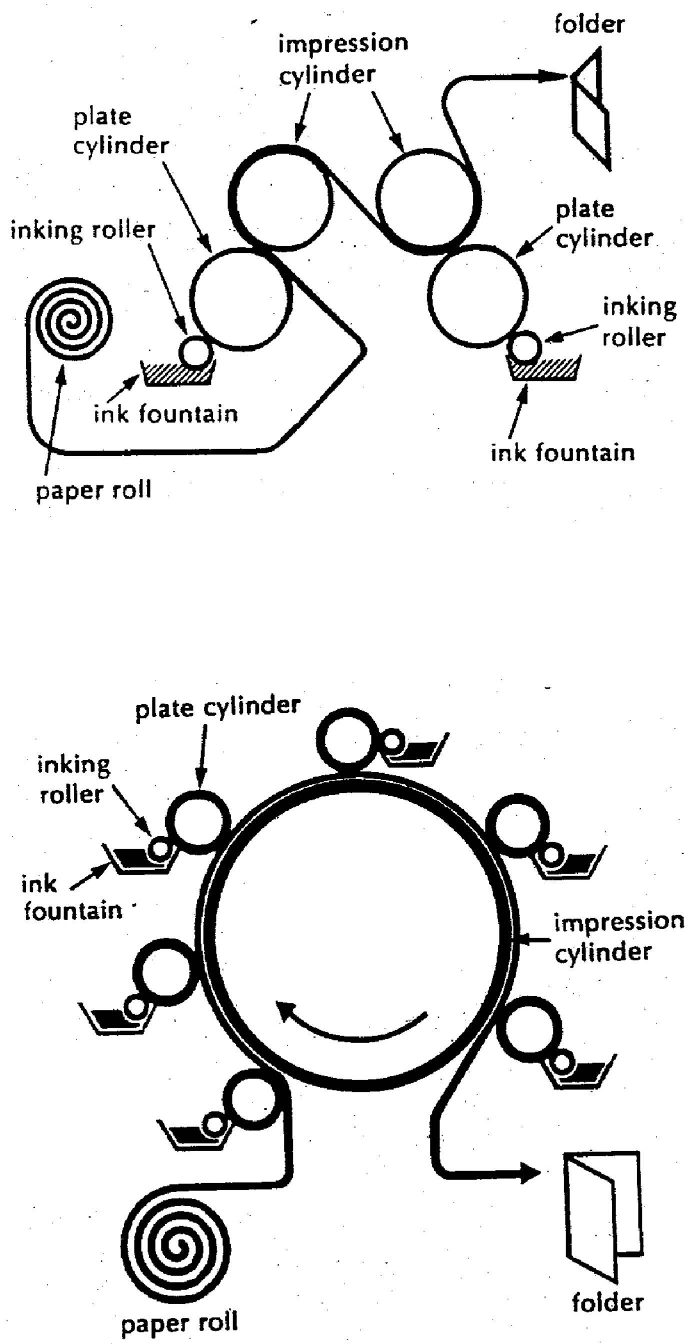


Figure 23. Unit-design Perfecting Rotary Press (top) and Rotary Letterpress Typically Used for Magazine Printing (Source: Field 1980. Reproduced by permission of Ayer Company Publishers, Inc.)

rubber. When printing on coated papers, rotary presses use heat-set inks and are equipped with dryers, usually the high-velocity hot air type.

Web-fed rotary letterpress presses are used primarily for printing newspapers. These presses are designed to print both sides of the web simultaneously. Typically, they can print up to four pages across the web; however, some of the new presses can print up to six pages across a 90-inch web. Rotary letterpress is also used for long-run commercial, packaging, book, and magazine printing.

Major chemicals used in letterpress printing, very similar to those used in lithography, include film developers and fixers, inks, and blanket and roller washes (GATF 1992b). A process flow diagram as well as information on the chemicals used in this process are presented in Figure 24.

3. Volume of Output and Percentage of Total Market

Prior to the Second World War letterpress was the dominant printing process, but since the mid-1940s it has been gradually replaced by other printing processes. In 1991, letterpress printing accounted for 11 percent of the total value of U.S. printing industry output (excluding instant and in-plant printing). However, between 1991 and 2025, letterpress' market share is expected to decline dramatically to only four percent of the total U.S. market. By 2025, letterpress will no longer rank as a major printing process. Gravure has largely replaced letterpress in the printing of long-run magazines and catalogs while flexography is replacing it for printing paperbacks, labels, business forms, newspapers, and directories (Bruno 1990, 1991).

4. Number and Relative Size of Printing Companies

In 1982, the latest year for which data are available, 20,786 plants used letterpress presses. More recent data was available on the number of plants with sheetfed letterpress presses; in 1988, there were 18,961 plants with this type of press. In 1982, over 83 percent of plants with letterpress presses had fewer than 20 employees and almost 46 percent had fewer than five. In 1988, almost 85 percent of plants with sheetfed letterpress presses had fewer than 20 employees and 44 percent had fewer than five (A.F. Lewis 1991).

LETTERPRESS
PROCESS FLOW DIAGRAM

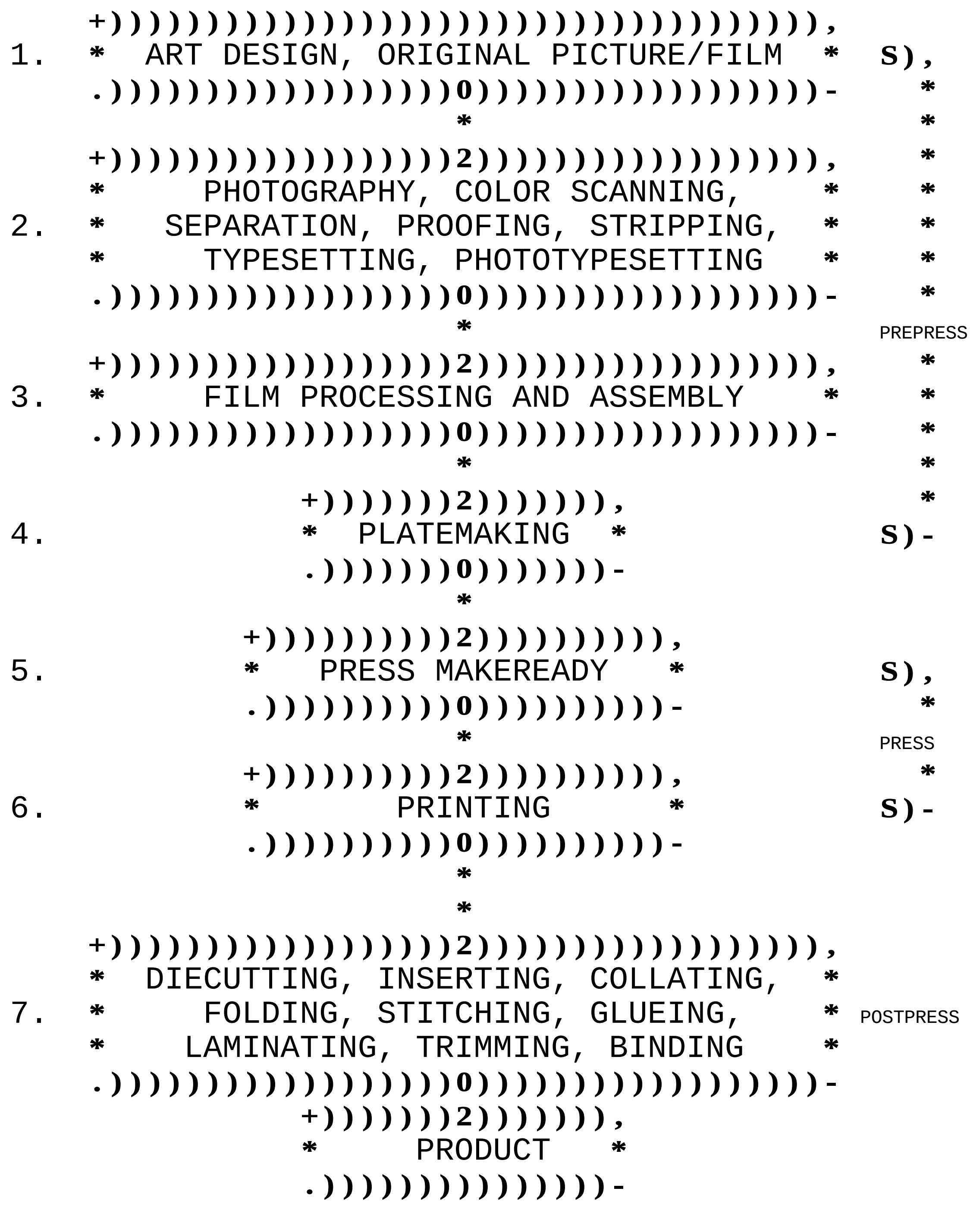


Figure 24. Letterpress (Source: GATF 1992b).

LETTERPRESS (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive, cleaning solvent

2. Color scanner cleaner, deletion fluid

3. Film developer and fixer, film cleaner, film system cleaner, image cleaner/preserver, antistatic spray, adhesive

4. Plate developer and finisher, plate toner, plate system cleaner

5. Letterpress ink, blanket wash, roller wash, copperizing solution, anti-setoff powder

6. Adhesive, ink

7. Adhesive

- Specialty operations:

  Lamination (glue, varnish, plastics)
  Cellophane window (glue)

Figure 24. Letterpress (continued).

LETTERPRESS OPERATION (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film/glass cleaner	Acetone, hexane, 1,1,1-trichloroethane, ethanol, n-propanol, perchloroethylene, 2-butoxy ethanol, isopropanol
Equipment cleaner	Isopropanol, hexane, acetone
Film developer	Sodium sulfite, sulfosalicyclic acid, hydroquinone, potassium sulfite, potassium hydroxide, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Plate developer	Surfactant, Benzyl alcohol, diethanolamine, polyvinyl alcohol, ethylene glycol, thiol compounds, acetic acid
Plate	Photosensitive polymers
Press	
Ink, varnish	Petroleum distillates, vegetable oil, resin, rosin, toluene, isopropanol, xylene, pigments containing barium and copper
Ink thinner	Hydrotreated or solvent extracted naphthenic distillates
Wash solvent	Aliphatic and aromatic hydrocarbons, ethanol, turpentine, acetone
Linotype	Lead, zinc, tin
Postpress	
Glue	Paraffin wax, methanol, hexane, acetone, ethylene dichloride, methyl ethyl ketone, polyglycol dimethacrylates, methyl cyanoacrylates, toluene

Figure 24. Letterpress (continued).

E. Screen Printing

1. Screen Preparation

A typical image carrier used in screen printing consists of a screen made from a very finely woven fabric. The image is defined by a stencil or mask which is adhered to the fabric screen. Ink will pass through the fabric except where the stencil is applied, thus forming an image on the printing substrate. The fabric is typically stretched taught over a wooden or metal frame. The resulting shallow container formed by the frame will hold a quantity of ink which is pressed through the fabric by a squeegee that is drawn across the screen by the printing press.

a. Screen Fabrics

Silk was the original material used to make screens for screen printing. Today, various synthetic material are the dominant screen materials. By far the most widely used fabric is monofilament polyester followed by multifilament polyester and nylon. Other screen materials include: calendared monofilament polyester, metallized monofilament polyester, carbonized polyester, glass, wire mesh, and stainless steel. Screens made of the same material can differ in thread diameter, number of threads-per-inch, and choice of mono- or multifilament fibers. Need for various characteristics such as wearability and dimensional stability will help determine the fabric selected for a particular screen printing job. Diameter of mesh thread and number of threads per inch determine the amount of ink transferred to the substrate during the printing process (Buonicore and SPAI 1991).

b. Stencils

The stencil, used to cover the non-printing area of the screen, must be of a material that is impermeable to the screen printing ink. Materials used for stencils include plain paper, shellac or lacquer coated paper, lacquer film, photographic film, and light-sensitive emulsions. Stencil types available include: hand-cut film, photographic film, direct coating, direct/indirect photostencil, and wet-direct photostencil.

A hand-cut film stencil is made by hand cutting the image areas from a lacquer film sheet on a paper backing. A liquid adhesive is then used to bond the stencil to the screen fabric. Once the adhesive has dried, the film's paper backing sheet is removed.

Two types of photographic film, presensitized and unsensitized, are available for use in the preparation of stencils. Presensitized film is ready to use as purchased, while unsensitized film must first be treated with a photosensitization solution. In preparing the stencil, the film is exposed to a positive film image in a vacuum frame. It is then developed in a solution that renders the unexposed image areas soluble in water. The soluble areas are removed and the remaining film is bonded to the screen fabric.

In the direct coating process, a light-sensitive emulsion is applied to the entire screen and allowed to dry. The screen is then exposed to a film positive image. The non-image areas of the emulsion harden upon exposure. However, the coating in the unexposed image areas remains soluble and is removed with a spray of warm water. Several coats of the light-sensitive material are applied and smoothed to achieve a long wearing screen.

The preparation of direct/indirect stencils combines elements of both the photographic film and the direct coating methods. An unsensitized photographic film is laminated to the screen and then sensitized by the direct application of a photosensitive emulsion. The exposed stencil is processed in a manner similar to that used in the preparation of stencils produced by the photographic film and the direct coating methods. The direct/indirect process produces highly durable stencils that are used in applications where high print quality is required.

A recent development in stencil preparation is the wet-direct photostencil process. To prepare a stencil using this process, a film positive is held in direct contact with a wet photopolymer emulsion. The emulsion hardens when exposed to UV light. The unexposed areas of emulsion are then removed yielding a very durable, high quality screen.

2. Screen Presses and Printing

Reduced to its basics, screen printing consists of three elements: the screen which is the image carrier; the squeegee; and ink. The screen is placed in a wooden, steel, or aluminum frame and pulled taught. Proper tension is essential to accurate color registration. The stencil is then applied to the non-image areas of the screen to render them impervious to ink. The image areas remain porous.

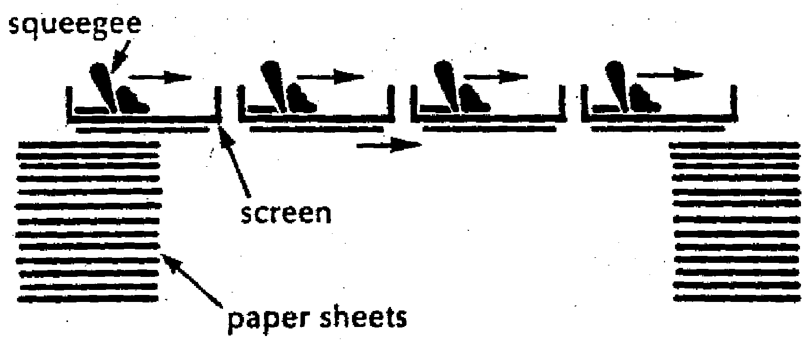
The squeegee is a blade that is drawn across the screen to force ink through its porous image areas and onto the substrate. Many factors such as composition, size and form, angle, pressure, and speed of the blade determine the quality of the impression. At one time most blades were made from rubber which, however, is prone to wear and edge nicks and has a tendency to warp and distort. While blades continue to be made from rubbers such as neoprene, most are now made from polyurethane which can produce as many as 25,000 impressions without significant degradation of the image.

A significant characteristic of screen printing is that a greater thickness of the ink can be applied to the substrate than is possible with other printing techniques. This allows for some very interesting effects that are not possible using other printing methods. Because of the simplicity of the application process, a wider range of inks and dyes are available for use in screen printing than for use in any other printing process.

Until relatively recently all screen printing presses were manually operated. Now, however, most commercial and industrial screen printing is done on single and multicolor automated presses. Three types of presses are used by the screen printing industry: flat-bed (probably the most widely used), cylinder, and rotary. Flat-bed and cylinder presses are similar in that both use a flat screen and a three step reciprocating process to perform the printing operation. The screen is first moved into position over the substrate, the squeegee is then pressed against the mesh and drawn over the image area, and then the screen is lifted away from the substrate to complete the process. With a flat-bed press the substrate to be printed is positioned on a horizontal print bed that is parallel to the screen. With a cylinder press the substrate is mounted on a cylinder (Field and Buonicore).

Rotary screen presses are designed for continuous, high speed web printing. The screens used on rotary screen presses are seamless thin metal cylinders. The open-ended cylinders are capped at both ends and fitted into blocks at the side of the press. During printing, ink is pumped into one end of the cylinder so that a fresh supply is constantly maintained. The squeegee is a free floating steel bar inside the cylinder and squeegee pressure is maintained and adjusted by magnets mounted under the press bed. Rotary screen presses are most often used for printing textiles, wallpaper, and other products requiring unbroken continuous patterns. Figure 25 depicts two types of screen presses, flat-bed and rotary.

Screen printing is arguably the most versatile of all printing processes. It can be used to print on a wide variety of substrates, including paper, paperboard, plastics, glass, metals, fabrics, and many other materials. The major chemicals used include screen emulsions, inks, and solvents, surfactants, caustics and oxidizers used in screen reclamation. The inks used vary dramatically in their formulations (GATF 1992b). A process flow diagram as well as information on the chemicals used in this process are presented in Figure 26.



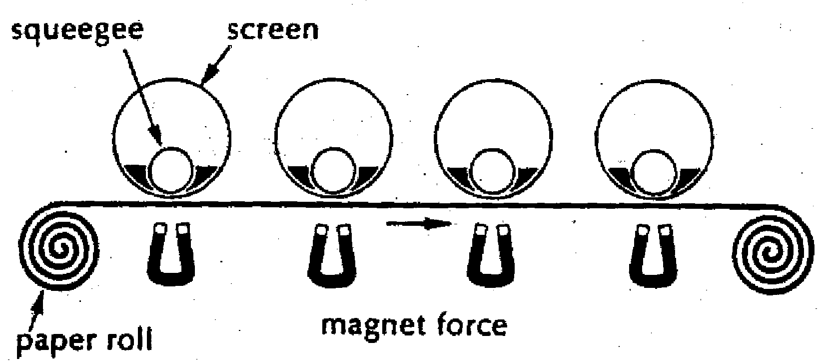


Figure 25. Flat-bed Screen Press (top) and Rotary Screen Press (Source: Field 1980. Reproduced by permission of Ayer Company Publishers, Inc.)

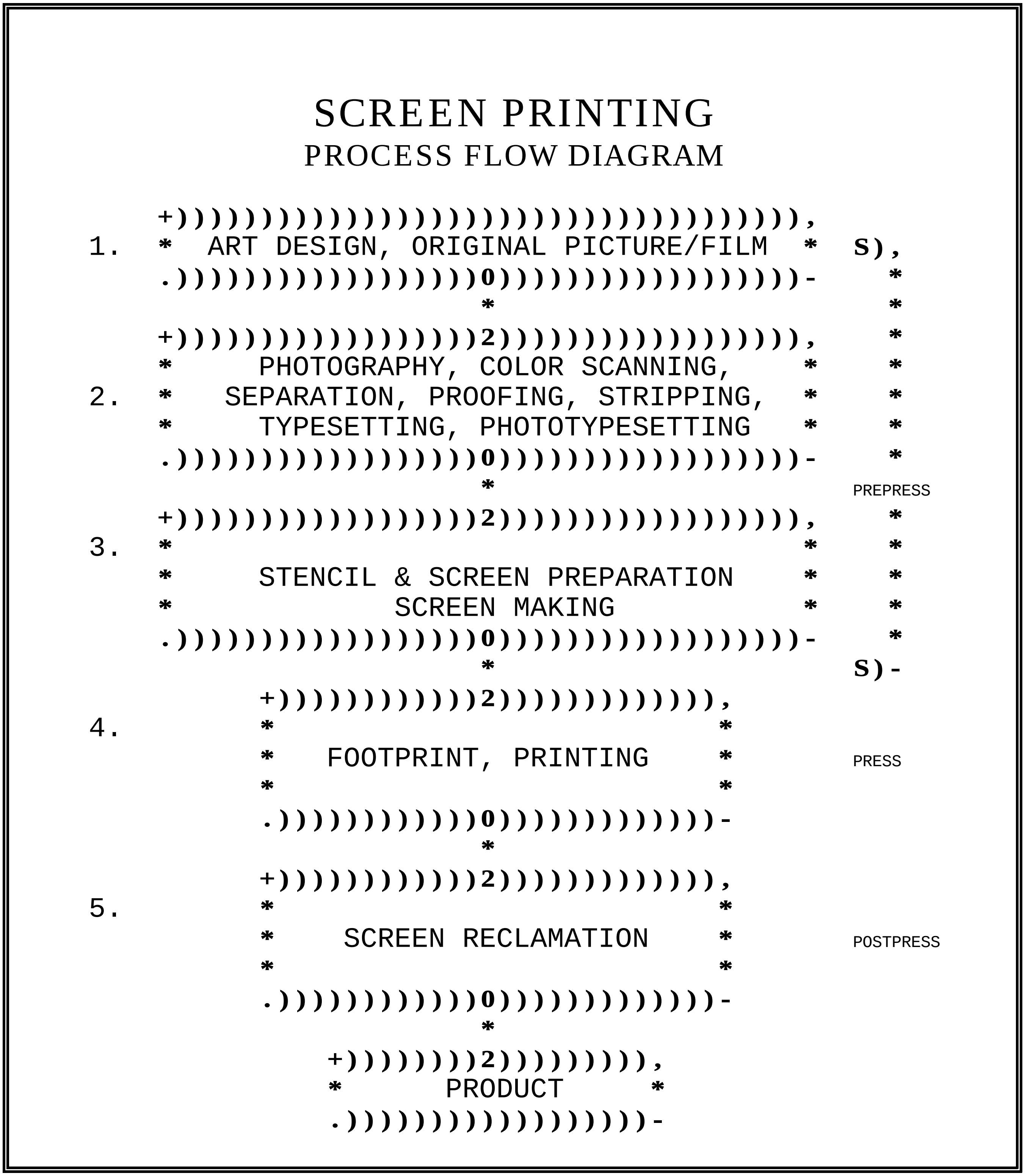


Figure 26. Screen Printing (Source: GATF 1992b).

SCREEN PRINTING (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. Adhesive, cleaning solvent

2. Cleaning solvent, film fixer and developer

3. Mesh preparation compounds, abrading compounds, degreasers, adhesives, stencil/emulsion systems, blockout solution

4. Screen printing ink, haze remover

5. Ink remover, stencil remover

Figure 26. Screen Printing (continued).

SCREEN PRINTING OPERATION (cont'd)

MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
Film developer	Sodium sulfite, sulfosalicyclic acid, potassium hydroxide, potassium sulfite, hydroquinone, butyl-diethanolamine
Film fixer	Ammonium thiosulfate, sodium acetate, acetic acid, aluminum sulfate
Stencil emulsion	Polyvinyl alcohol, polyvinyl acetate, benzoate esters, citrate esters, trihexyl ester acetate, trimethylolpropane triacrylate, pentaerythritol tetracrylate, sodium citrate, phthalocyanine pigments, diazonium salts
Press	
Ink	Glycol ethers, aromatic and aliphatic petroleum distillates, ketones, esters, mono- and multifunctional acrylate monomers, acrylate oligomers, isocyanates, acrylic, vinyl, urethane, styrene, cellulosic, polyamide, epoxy, polyester and melamine resins, silicones, amines, pigments containing lead, chromium, and cadmium
Postpress	
Screen reclamation solvents	Mineral spirits, toluene, xylenes, limonenes, terpenes, acetone, methyl ethyl ketone, cyclohexanone, butyrolactone, ethyl acetate, butyl acetate, ethylene glycol mono butyl ether acetate, propylene glycol mono methyl ether acetate, propylene glycol mono ethyl ether acetate, diethylene glycol mono butyl ether acetate, dipropylene glycol mono methyl ether acetate, isopropanol, diacetone alcohol, benzyl alcohol, terpineol, ethylene glycol mono methyl ether, ethylene glycol mono ethyl ether

Figure 26. Screen Printing (continued).

SCREEN PRINTING OPERATION (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Postpress (cont.)	
Screen reclamation solvents (cont.)	Ethylene glycol mono butyl ether, propylene glycol mono methyl ether, propylene glycol mono ethyl ether, propylene glycol mono butyl ether, diethylene glycol mono ethyl ether, diethylene glycol mono butyl ether, dipropylene glycol mono methyl ether, dipropylene glycol mono ethyl ether, dipropylene glycol mono butyl ether, N-methylpyrrolidone,
Screen reclamation surfactants	Alkybenzene sulphonates, alkyl sulphates, alkyl ether sulphates, aliphatic phosphate esters, alkyl sulphosuccinates, alkyl phenol ethoxylates, ethoxylated fatty alcohols, EO-PO block copolymers, tetra alkylammonium halides/phosphates, betaines, alkylimidazoline carboxy acids
Screen reclamation caustics	Sodium hydroxide, potassium hydroxide, sodium carbonate, trisodium phosphate
Screen reclamation oxidizers	Sodium metaperiodate, sodium hypochlorite, periodic acid, enzymes

Figure 26. Screen Printing (continued).

3. Volume of Output and Percentage of Total Market

In 1991, screen printing accounted for less than three percent of the total value of U.S. printing industry output (excluding instant and in-plant printing). Between 1991 and 2025, screen printing market share is expected to show little or no growth (Bruno 1991).

4. Number and Relative Size of Printing Companies

The Screen Printing Association International estimates that there are at least 40,000 plants in the U.S. with screen presses (Kinter 1993). This estimate does not include an unknown number of electronics plants that use screen printing in the production of electronic circuitry (Kinter 1992). The majority of screen printing plants are small businesses with fewer than 20 employees (Kinter 1993).

F. Plateless Processes

1. Description

The various plateless printing processes are quite different from the five major conventional printing processes described above. Unlike traditional processes, the new processes do not use printing plates or any other type of physical image carrier. Instead, they rely on sophisticated computer software and hardware to control the printing elements. Currently, however, the plateless processes are restricted largely to in-plant and quick printing applications.

In terms of chemical use, the plateless processes have a number of advantages over traditional printing processes. Typically, make-ready preparations are done electronically so the various chemicals associated with prepress operations are largely avoided. Plateless processes do not require solvent washes and with a few exceptions (e.g., ink jet printers) dry (solventless) inks are used. Though the chemicals used in plateless processes depends on the particular process involved, important chemicals include Freon 11, inks, and hydrocarbon based solvents (GATF 1992b). A process flow diagram for electronic printing as well as information on the chemicals used are presented in Figure 27.

2. Specific Plateless Processes

A number of commercial plateless printing technologies were identified including: electronic printing, ink jet printing, magnetography, ion deposition printing, direct charge deposition printing, and the Mead Cycolor Photocapsule process. Each of these systems is discussed briefly below.

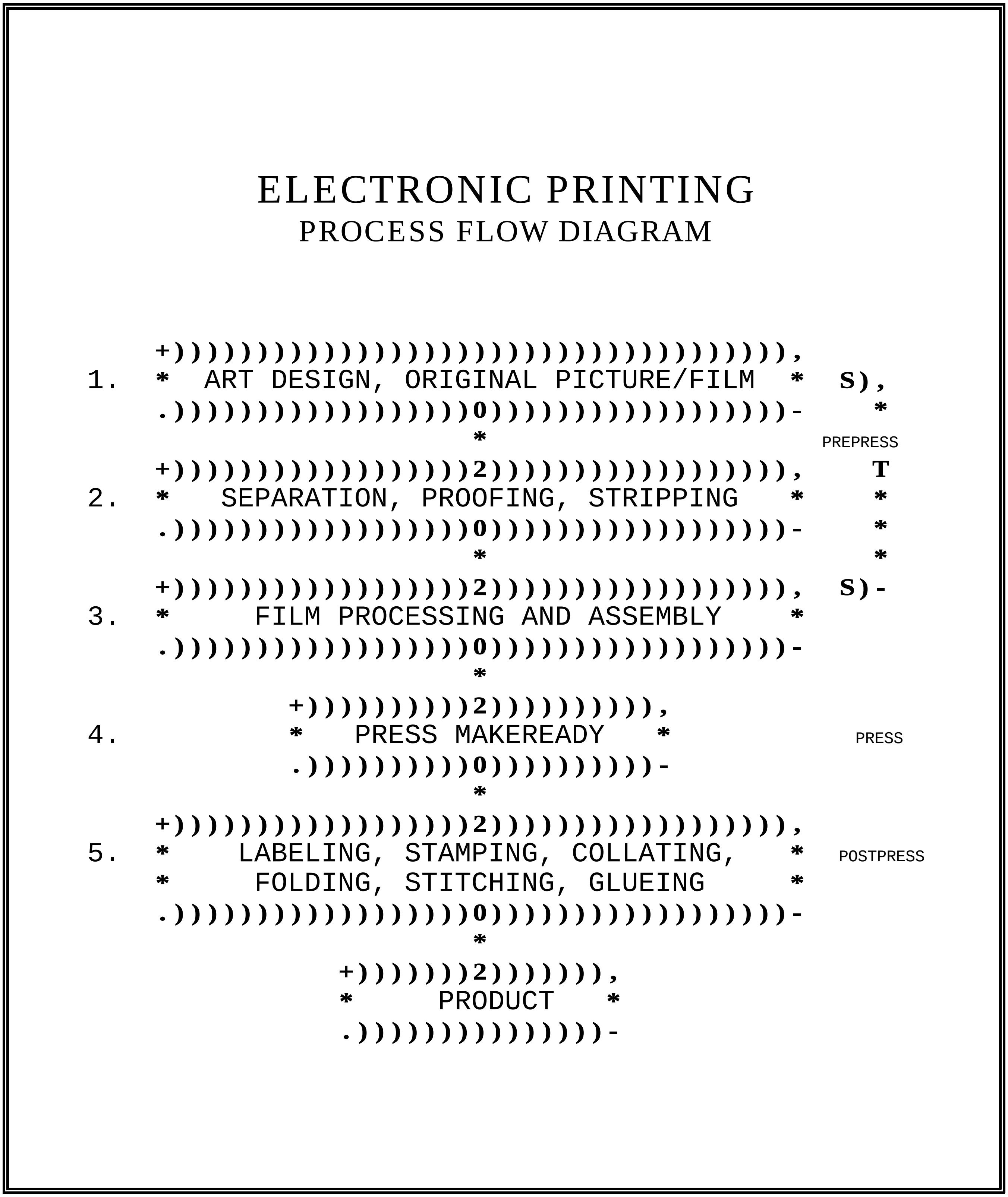


Figure 27. Electronic Printing (Source: GATF 1992b).

ELECTRONIC PRINTING (cont'd)
CHEMICAL/CHEMICAL COMPOUND USAGE

In reference to each step in the process flow diagram:

1. None

2. None

3. Cleaning solvent

4. Water and solvent based inks, petroleum hydrocarbon additives, ink depositing solvents

5. Adhesive

\- Specialty operations:

  Ink jet (water and solvent based inks),
  Laser printer (freon and acetone),
  Electropress (solvent based inks and petroleum based ink solvents)

Figure 27. Electronic Printing (continued).

ELECTRONIC PRINTING (cont'd)
MAJOR CHEMICALS USED

Operation/Process	Major Chemicals Used (Volumes of Individual Chemicals Used Vary Greatly)
Prepress	
None	None
Press	
Ink	Petroleum distillates, isopropanol, aliphatic and aromatic hydrocarbons, pigments
Processing material	Freon 113, acetone, petroleum hydrocarbons,
Wash solvent	Aliphatic and aromatic hydrocarbons, ethanol, mineral spirits, acetone, isopropanol
Postpress	
Glue	Paraffin wax

Figure 27. Electronic Printing (continued).

a. Electronic Printing

The most important electronic processes are xerographic and laser printing. With one major exception, xerographic and laser printers operate on similar principals. In both processes an image is recorded on a drum in the form of an electrostatic charge. The electrostatic charge is then transferred to a sheet of some material, generally paper. A conductive fine dry powder, the toner, is then spread on the paper. The toner is attracted to the electrostatically charged areas of the paper, thereby converting the electrostatic image into a visual one. The paper is then heat treated to melt and affix the toner to the paper (Adams 1988; Bruno 1990; Hawley 1981).

Laser printing and xerography differ in how the image is inputted and how the electrostatic image is formed on the drum. In xerography, light reflected off a hard copy of the text or pictorial image (e.g., a printed or illustrated page) is projected on to the drum though a camera lens. In laser printing the image is inputted in digital form from a computer. A laser is then used to project the image onto the drum (Adams 1988; Bruno 1990; Hawley 1981).

The input and output capabilities of electronic printing continue to improve. For example, raster image processing has made the integration of text and graphic images much easier. (Until recently, most computer output devices formed text and graphic images as a series of dots. With raster image processing, the image is formed as a series of lines.) The resolution of laser printers is good but still falls far short of the resolution achieved with phototypesetters. To produce high quality reproductions of fine type and halftone screen images, a resolution of at least 1,500 line per inch is required. However, in 1990, the highest resolution laser printers could achieve was a density of 1,200 X 600 dots per inch (dpi) while most achieved resolutions of only 300 X 300 dpi.

Currently, electronic printing is used primarily for short-run in-plant and quick printing. Another use is for the production of proof copies of printed materials which will be printed using one of the traditional printing technologies. These proof copies are much less expensive than phototypeset proofs. In desktop publishing, electronic printing is often used to produce a camera ready copy of a document that is then printed using one of the traditional printing technologies. According to Michael Bruno, the current markets for desktop publishing include demand publishing, book review copies, college texts, workbooks, technical manuals, and parts catalogs (Adams 1988; Bruno 1990).

b. Ink-jet Printing

Ink-jet printers operate by spraying a pattern of individual ink droplets onto a substrate. The application of the dot matrix image is controlled by computer input. The two types of ink-jet printers differ in whether the "jet" of ink droplets is continuous or occurs only when a drop of ink is needed to form part of the dot matrix image. In continuous spray systems, an electric charge is used to deflect ink drops not needed to form the image to an ink recycling unit. In a drop-on-demand system, drops of ink are produced only when they are needed to form part of the image. Drop-on-demand systems are less complicated than continuous systems and use less ink; however, they print much more slowly (Adams 1988).

The advantage of ink-jet printing is the speed with which it can do addressing and print variable information on repetitive forms. For these reasons ink-jet printers are credited with revolutionizing the direct mailing business. Other applications include printing bar and batch codes and printing variable information on computer letters, sweepstakes forms, and other personalized direct mail advertising as well as on payroll checks and other business forms. Furthermore, because it is a non-impact printing process, jet-printers can be used to print on almost any surface despite the material, texture, shape, or resistance to surface pressure. Because of this versatility, ink-jet printing is used to print on substrates as varied as plastics, sandpaper, and pills (i.e., pharmaceuticals) (Adams 1988; Bruno 1990).

The major disadvantage of ink-jet printers is the low resolution of the images produced. The poor resolution is the result of at least three factors: even on the best machines no more than 300 dots per square inch are possible; a certain percent of the dots applied are misdirected; and the dots of inks used tend to spread as they dry (Adams 1988).

c. Magnetography

Magnetography is similar to electronic printing except that a magnetic, and not an electrostatic, photoconductor is used. The toner must, of course, be magnetic material. Magnetographic printing is competitive with traditional printing methods, such as lithography, for small runs of up to about 1,500 copies. Drawbacks include slow speed, high toner costs, and the inability of currently available printers to do color process printing (Bruno 1990).

d. Thermal Printing

In thermal printing, an image is formed by a chemical reaction that occurs when portions of a thermal-coated paper are subjected to heat. The printing element consists of one or more heated pins or nibs. Currently thermal printers find use in facsimile machines and other office applications. A shortcoming of thermal print is that it tends to fade over time. In certain applications such as fax machines, thermal printers are being replaced by electronic printers using plain paper (GATF 1992b).

e. Ion Deposition Printing

The ion deposition process is similar to electronic printing and other electrostatic processes. The four basic steps of the process are: 1) an electrostatic image is generated on a rotating drum using a directed array of ions; 2) toner is attracted to the latent image on the drum; 3) the toned image is transferred to plain paper by cold pressure fusion; 4) toner residue is removed from the drum by a doctor blade and the drum is ready for re-imaging (Bruno 1990).

Ion deposition printers are used in various business applications such as printing invoices, reports, manuals, forms, letters and proposals as well as in specialty printing applications such as tags, tickets, and checks (Bruno 1990).

f. Direct Charge Deposition Printing

In direct charge deposition printing, the image is generated by a direct voltage carried by ionized air. The process differs from ion deposition printing in that the image is projected on to a dielectric belt and not a drum. A major advantage of the direct charge deposition printers is the durability of both the dielectric belt and the imaging head which can produce up to 200,000 pages and five million pages, respectively, before replacement. This technology is used primarily for printing business forms (Bruno 1990).

g. Mead Cycolor Photocapsule Process

The Mead Cycolor Photocapsule Process combines microencapsulation technology used in carbonless copy paper with photopolymerization technology found in UV curable inks. The process uses two coated materials, the Cycolor film and the Cycolor receiver sheet. The coating on the Cycolor film is embedded with millions of microcapsules that contain a liquid acrylic monomer, a yellow, cyan, or magenta leuco dye base, and one of three photoinitiators. Each of the photoinitiators is sensitive to the spectrum of visible light corresponding to the final color of the leuco dye itself. Leuco dyes are dyes which have been rendered colorless by the addition of a chemical group referred to as a color block. The color block can be removed and the appropriate color developed by reacting the dye with an acid. When the Cycolor film is exposed to colored light, the photoinitiators sensitive to the particular color cause the monomer to polymerize and harden. The contents of the unexposed microcapsules remain in a liquid state (Bruno 1990).

The Cycolor receiver sheet is coated with an acid resin that, during processing, reacts with the leuco dyes in the film to remove the color blocks and form color dyes. The receiver sheet can be either paper or a transparency. To print the receiver sheet, it and the exposed Cycolor film are brought into contact under pressure by feeding them between two rollers. The pressure breaks the unexposed microcapsules on the film, releasing the colorless leuco dyes, monomer, and photoinitiator. Subsequently, the leuco dyes react with the coating on the receiver sheet to form colored dyes and the monomer hardens as well. The result is a continuous tone color image (Bruno 1990).

Currently, the Cycolor process is used for color copiers, 35mm slide printers, color computer printers for desktop printing, and color video output for electronic imaging (Bruno 1990).

3. Volume of Output and Percentage of Total Market

In 1991, the various plateless printing processes accounted for only three percent of the total value of U.S. printing industry output (excluding instant and in-plant printing). However, plateless printing is expected to experience explosive growth over the next 35 years and is forecast to account for 21 percent of the market by 2025 (Bruno 1991).

4. Number and Relative Size of Printing Companies

No information was found on the current number or relative size of companies or plants using plateless printing processes. However, many of these processes, especially xerographic, electronic, and ink-jet printers, are widely used by thousands of "quick" printing services, the majority of which are small businesses. These printing technologies are also used on an enormous scale in the office environment and their use in the home is becoming commonplace.

IV. POSTPRESS OPERATIONS

A. Introduction

Postpress operations consist of four major processes: cutting, folding, assembling, and binding. Not all printed products, however, are subjected to all of the processes. For example, simple folded pamphlets do not undergo binding.

There are many additional lesser postpress finishing processes such as varnishing, perforating, drilling, etc. Some types of greeting cards are dusted with gold bronze. Printed metal products are formed into containers of various sizes and shapes. Many metal toys are prepared in the same manner. Containers may also be coated on the inside to protect the eventual contents. Other substrates may be subjected to finishing processes that involve pasting, mounting, laminating, and collating. There are also a number of postpress operations unique to screen printing including die cutting, vacuum forming, and embossing.

A limited number and volume of chemicals are used in postpress operations. The major type of chemicals used in postpress are the adhesives used in binding and other assembly operations. Because chemical usage is limited, only a brief overview of each of the four major postpress operations is provided in the following sections. In-line finishing, an automated process that links the press directly with postpress operations, is also discussed.

B. Cutting

The machine typically used for cutting large web-type substrates into individual pages or sheets is called a guillotine cutter or "paper cutter". These machines are built in many sizes, capacities, and configurations. In general, however, the cutter consists of a flat bed or table that holds the stack of paper to be cut. At the rear of the cutter the stack of paper rests against the fence or back guide which is adjustable. The fence allows the operator to accurately position the paper for the specified cut. The side guides or walls of the cutter are at exact right angles to the bed. A clamp is lowered into contact with the top of the paper stack to hold the stack in place while it is cut. The cutting blade itself is normally powered by an electric engine operating a hydraulic pump. However, manual lever cutters are also still in use.

To assist the operator in handling large reams of paper which can weigh as much as 200 pounds, some tables are designed to blow air through small openings in the bed of the table. The air lifts the stack of paper slightly providing a near frictionless surface on which to move the paper stack.

The cutter operator uses a cutting layout to guide the cutting operation. Typically, the layout is one sheet from the printing job that has been ruled to show the location and order of the cuts to be made.

Though cutting is generally considered a postpress operation, most lithographic and gravure web presses have integrated cutters as well as equipment to perform related operations such as slicing and perforating.

C. Folding

Folding largely completes postpress operations for certain products such as simple folded pamphlets. Other products are folded into bunches, known as signatures, of from 16 to 32 pages. Multiple signatures are then assembled and bound into books and magazines. Though folding is generally considered a postpress operation, most lithographic and gravure web presses are equipped with folders.

Three different folders are used in modern print shops. They range in complexity from the bone folder to the buckle folder. Bone folders have been used for centuries and are made of either bone or plastic. These folders are simple shaped pieces of bone or plastic that are passed over the fold to form a sharp crease. Today, they continue to be used, but only for small, very high quality jobs.

Knife folders use a thin knife to force the paper between two rollers that are counter-rotating. This forces the paper to be folded at the point where the knife contacts it. A fold gauge and a moveable side bar are used to position the paper in the machine before the knife forces the paper between the rollers. The rollers have knurled surfaces that grip the paper and crease it. The paper then passes out of the folder and on to a gathering station. Several paper paths, knives and roller sets can be stacked to create several folds on the same sheet as it passes from one folding station to another.

Buckle folders differ from knife folders in that the sheet is made to buckle and pass between the two rotating rollers of its own accord. In a buckle folder, drive rollers cause the sheet to pass between a set of closely spaced folding plates. When the sheet comes in contact with the sheet gauge, the drive rollers continue to drive the paper causing it to buckle over and then pass between the folding rollers.

D. Assembly

The assembly process brings all of the printed and non-printed elements of the final product together prior to binding. Assembly usually includes three steps: gathering, collating, and inserting.

Gathering is the process of placing signatures next to one another. (A signature is a bunch of printed sheets ranging from 16 to 32 pages.) Typically, gathering is used for assembling books that have page thicknesses of at least 3/8 inch.

Collating is the process of gathering together individual sheets of paper instead of signatures.

Inserting is the process of combining signatures by placing or "inserting" one inside another. Inserting is normally used for pieces whose final thickness will be less than one-half inch.

Assembly processes can be manual, semiautomatic or fully automatic. In manual assembly operations, workers hand assemble pieces from stacks of sheets or signatures laid out on tables. Sheets or signatures are picked up from the stacks in the correct order and either gathered, collated, or inserted to form bindery units. Some printers use circular revolving tables to assist in this process. However, due to the high cost of labor, manual assembly is used only for small jobs.

Semiautomatic assembly is completely automated except that stacks of sheets or signatures must be manually loaded into the feeder units. During semiautomatic inserting, operators at each feeder station open signatures and place them at the "saddlebar" on a moving conveyer. The number of stations on the machine is determined by the number of signatures in the completed publication. Completed units are removed at the end of the conveyer and passed on to the bindery.

Automatic assemblers are similar to semiautomatic units except that a machine and not a person delivers the sheets or signatures to the feeder station and places them on the conveyor. In order to improve efficiency, automatic assemblers are typically placed in line with bindery equipment.

E. Binding

Binding is categorized by the method used to hold units of printed material together. The three most commonly used methods are adhesive binding, side binding, and saddle binding. Three types of covers are available to complete the binding process: self-covers, soft-covers, and casebound covers.

1. Binding Methods

Adhesive binding, also known as padding, is the simplest form of binding. It is used for note pads and paperback books, among other products.

In the adhesive binding process, a pile of paper is clamped securely together in a press. A liquid glue is then applied with a brush to the binding edge. The glue most commonly used in binding is a water-soluble latex that becomes impervious to water when it dries. For note pads, the glue used is flexible and will easily release an individual sheet of paper when the sheet is pulled away from the binding. Adhesive bindings are also used for paperback books, but these bindings must be strong enough to prevent pages from pulling out during normal use. For paperback book binding, a hot-melt glue with much greater adhesive strength than a water-soluble latex is applied. A piece of gauze-like material is inserted into the glue to provide added strength.

In side binding, a fastening device is passed at a right angle through a pile of paper. Stapling is an example of a simple form of side binding. The three other types of side binding are mechanical, loose-leaf, and side-sewn binding.

A common example of a form of mechanical binding is the metal spiral notebook. In this method of binding, a series of holes are punched or drilled through the pages and cover and then a wire is then run through the holes. Mechanical binding is generally considered as permanent; however, plastic spiral bindings are available that can be removed without either tearing the pages or destroying the binding material. Mechanical binding generally requires some manual labor.

Looseleaf bindings generally allow for the removal and addition of pages. This type of binding includes the well known three-ring binder.

Side-sewn binding involves drilling an odd number of holes in the binding edge of the unit and then clamping the unit to prevent it from moving. A needle and thread is then passed through each hole proceeding from one end of the book to the other and then back again to the beginning point. This type of stitch is called a buck-stitch. The thread is tied off to finish the process. Both semiautomatic and automatic machines are widely used to perform side-stitching. The main disadvantage of this type of binding is that the book will not lie flat when opened.

In saddle binding one or more signatures are fastened along their folded edge of the unit. The term saddle binding comes from an open signature's resemblance to an inverted riding saddle. Saddle binding is used extensively for news magazines where wire stitches are placed in the fold of the signatures. Most saddle stitching is performed automatically in-line during the postpress operations. Large manually operated staplers are used for small printing jobs.

Another saddle binding process called Smythe sewing is a center sewing process. It is considered to be the highest quality fastening method used today and will produce a book that will lie almost flat.

2. Covers

Self-covers are made from the same material as the body of the printed product. Newspapers are the most common example of a printed product that uses self-covers.

Soft covers are made from paper or paper fiber material that is somewhat heavier or more substantial than the paper used for the body of the publication. This type of cover provides only slight protection for the contents. Unlike self-cover, soft covers almost never contain part of the message or text of the publication. A typical example of the soft cover is found on paper-back books. These covers are usually cut flush with the inside pages and attached to the signatures by glue, though they can also be sewn in place.

Casebound covers are the rigid covers generally associated with high-quality bound books. This method of covering is considerably more complicated than any of the other methods. Signatures are trimmed by a three-knife trimming machine to produce three different lengths of signature. This forms a rounded front (open) edge to give the finished book an attractive appearance and provides a back edge shape that is compatible with that of the cover. A backing is applied by clamping the book in place and splaying or mushrooming out the fastened edges of the signatures. This makes the rounding operation permanent and produces a ridge for the casebound cover. Gauze and strips of paper are then glued to the back edge in a process called lining-up. The gauze is known as "crash" and the paper strips are called "backing paper." These parts are eventually glued to the case for improved strength and stability. Headbands are applied to the head and tail of the book for decorative purposes.

The case is made of two pieces of thick board, called binder's board, that is glued to the covering cloth or leather. The covering material can be printed either before or after gluing by hot-stamping or screen methods.

The final step in case binding consists of applying end sheets to attach the case to the body of the book.

F. In-Line Finishing

Historically, the finishing operations described above were labor-intensive operations handled either in-house or by trade shops. Even when performed in-house, finishing operations generally were not integrated with the presses or with each other. Today, web presses are often linked directly to computer controlled in-line finishing equipment. Equipment is available to perform virtually all major post-press operations including cutting, folding, perforating, trimming, and stitching (Adams).

In-line finishing equipment can also be used to prepare materials for mailing. The computer can store and provide addresses to ink-jet or label printers, which then address each publication in zip code order (Adams).

One of the most important results of computer in-line finishing is the introduction of demographic binding, the selective assembly of a publication based on any one or more of a number of factors including geographic area, family structure, income, or interests. For example, an advertisement will appear only in those copies of a magazine intended for distribution in the advertisers selling area. Demographic binding has proven to be a successful marketing tool and is already widely used, especially by major magazines (Adams).

One comparison found that the use of in-line finishing equipment can reduce the number of operators and helpers required for an off-line finishing operation by almost half, while at least doubling the rate of production (Adams).

V. TECHNOLOGICAL TRENDS

The printing industry has been experiencing a period of change that promises to be greater than any it's experienced since the introduction of automated printing presses. Much of the change is being fueled by the already widespread and still rapidly growing application of computers to the printing industry. Major trends include:

Prepress

- o Continued rapid development in computer-based front-end platforms that allow users to create, manipulate, and store text, graphic images, and entire documents prior to printing;
- o Improved telecommunications and introduction of digital data exchange standards that will allow the exchange of text, graphics, and entire documents between different press systems;
- o Development of direct-to-plate and direct-to-press technologies;

Press

- o Increasing automation of press operations;
- o Introduction of waterless lithographic plates that do not require a dampening system;
- o Introduction of a new generation of low- or no VOC non-alcohol fountain solutions and of low-VOC press cleaners;
- o Growing use of low- or no VOC ink technologies such as vegetable oil- and water-base inks, high-solids inks, ultraviolet and electron beam curable inks, and chemically reactive inks;
- o Overall trend toward reduction or replacement in the press room of chemicals that pose a potential hazard to human health or the environment;
- o Increased recycling of ink;
- o Major growth in market for plateless printing technologies;

Postpress

- o Increasing automation of postpress operations;
- o Growing use of in-line finishing; and
- o Increasing use of water-base adhesives.

TECHNOLOGICAL TRENDS IN THE PRINTING INDUSTRY

- PREPRESS
  - Rapid development in computer-based front-end platforms (e.g. desktop publishing)
  - Improved telecommunications and introduction of digital data exchange standards
  - Direct-to-plate and direct-to-press technologies
- PRESS
  - Automation
  - Waterless lithographic plates that do not require dampening systems
  - New generation of non-alcohol fountain solutions and low-VOC press cleaners
  - Low- or no VOC ink technologies such as vegetable oil- and water-base inks, high-solids inks, ultraviolet and electron beam curable inks, and chemically reactive inks
  - Ink recycling
  - Plateless printing technologies
  - Reduction in the use of materials that pose a potential hazard to human health or the environment
- POSTPRESS
  - Automation
  - In-line finishing
  - Water-base adhesives

Figure 28. Technological Trends in the Printing Industry

In the following sections, new products, emerging technologies, and other factors affecting the printing industry are explored in more detail.

A. Trends in Prepress Technology

Prepress technologies made major strides in the late 1980s and early 1990s and rapid progress will continue throughout the current decade. Most of the prepress tasks at both prepress shops and printers are now performed using a combination of computer hardware and software commonly referred to as a front-end platform (Bruno 1990; SRI 1990).

1. Front-End Platforms (Desktop Publishing)

Front-end platform (FEP) is a term used by the industry to describe the combination of desktop computer hardware and peripherals and sophisticated software that allow users to create, manipulate, and store text, graphic images, and entire documents prior to printing. These systems are found not only in the printing industry but in literally thousands of homes and offices across the country. FEPs and desktop publishing will continue to develop and grow in importance well into mid-decade (SRI 1990).

Using FEPs, the lay person can perform many prepress operations and produce a high quality copy ready for printing. When used properly, a primary benefit of this emerging technology will be a significant reduction in the cost of producing lay-outs ready for the plate maker. This, in turn, will make it profitable for printers to accept shorter-run jobs. According to the Graphic Arts Technical Foundation (GATF), however, lay persons rarely use FEPs properly when preparing materials for printing. Instead their limited knowledge of the printing process often creates more work for the printer (Jones 1993).

Important new products available for prepress functions include:

- **Graphics-oriented Workstations.** FEPs, now based largely on low-cost personal computers, will evolve toward graphics-oriented workstations running production-level software. The software will be based on products originally developed for CAD/CAM applications (Bruno 1990; SRI 1990).

- **Color Electronic Prepress Systems (CEPS).** CEPS provide the capability to perform complete color page makeup including color balancing and correction. Newer systems will be priced economically thus reducing the price-per-printed-page. CEPS will be capable of performing integrated text and graphics functions in both black and white and color. It will be possible to fully network CEPS with other digital equipment including, for example, modems for telecommunications and directly-driven image carrier preparation systems (Bruno 1990; SRI 1990).

- **Digital Scanners.** Lower cost flat-bed scanners are expected to largely replace the drum scanners in new systems by 1994. These systems use charge-coupled device (CCD) technology as the primary imaging element. Flat-bed scanners will be used in both color and black and white work and will be capable of scanning a complete page at a time. These systems will be driven by either personal computers, graphics workstations, or CEPS. Initially, the cost of these systems will be high, but will probably decline to levels affordable to the small to medium size print shop by mid-decade (SRI 1990).

2. Telecommunications

According to a report prepared for the Printing 2000 Task Force, by 1995 prepress systems will be able to transmit text, graphic images, and even entire documents between different printers' hardware systems (SRI 1990). Already, two ANSI standards for digital data exchange in the printing industry have been published and four additional standards are under development (Bruno 1990).

Continuing improvements in high-speed/high volume telecommunications coupled with the growing use of front-end platforms will lead to the increasing globalization of the printing and publishing industries. More and more frequently customers will use printers located at great distances or even in foreign countries (SRI 1990).

3. Proofing

The increasing use of telecommunications and local area networks, coupled with workstations, will result in faster, more accurate proofing of materials being readied for the press at a significant reduction in cost. Remote or "soft" proofing (i.e., proofing from an electronic medium as opposed to a hardcopy), will be used in initial checking of materials.

During the 1990s it will become possible to produce high-quality color proofs from digital inputs. Advances in digital proofing will be facilitated by the continuing development of high quality ink-jet printers to produce color and black-and-white proofs. The ink-jet technology will be particularly useful to textile houses, architectural firms, and advertisers (SRI 1990).

4. Direct-to-Plate and Direct-to-Press Technologies

A variety of techniques that allow the direct application of an image to a printing plate or other image carrier without various intermediate steps are under development or just entering commercial use.

Direct-to-plate (or computer-to-plate) technology is expected to play a major role in offset printing by the mid-1990s. The introduction of direct-to-plate processes in offset printing does not require additional technological breakthroughs. Instead, it calls for the integration and refinement of existing technologies. Image laser setters are available as are silver and zinc oxide plates sufficiently sensitive for use in the direct-to-plate process. Additional refinements required include modification of laser image setters to accommodate a wider range of materials, greater laser power, and increased plate coating sensitivities. These improvements coupled with photopolymer plates will allow the introduction of digital-to-plate technology to traditional commercial printing operations (SRI 1990). Large and medium size printers are expected to move rapidly to the use of direct-to-plate technologies. The trend will then slow significantly as smaller printers (20 or fewer employees), which account for the majority of printing plants, make the transition (Purcell).

In addition to direct-to-plate technologies, direct-to-press (or computer-to-press) systems are now becoming available. In these systems, computer controlled equipment allow the application of the image directly to the printing cylinder while the cylinder is mounted on the press. For example, Heidelberg USA has a press that includes an imaging system that will create a waterless plate directly on the press unit. The use of this and similar systems are reported to result in major reductions in plate preparation time as well as press downtime (Petersen 1992).

By the mid-1990s, as much as 7 percent of all printed material will be produced using direct-to-plate systems. Some industry analysts expect this to increase to as much as 50 percent by 2000 (SRI 1990). However, as noted above, other analysts are less optimistic because they expect the transition to direct-to-plate technology to be slow among the large number of small printers (Purcell).

B. Trends in Press Technology

1. General Press Trends

a. Inks

The major environmental factor driving the development of new ink technologies is the need to reduce VOC emissions which are subject to increasingly stringent state and Federal regulations. In response to VOC requirements and other health, safety, and environmental concerns with solvents and pigment systems, new and improved vegetable oil-based and water-based inks will appear during the 1990s and currently available ultraviolet and electron-beam curable inks will be widely used by all the major printing technologies. In general, the new inks will resist smearing, emit fewer volatile organic compounds, and make the use of color in new markets possible (Bruno 1990; SRI 1990).

Inks based on soybean oil are increasingly popular in the U.S., where they are currently used mainly in nonheatset web offset printing. In 1987, five newspapers were experimenting with soy-based inks in the U.S.; by 1990 these inks were being used by over 1,000 newspapers. Newspapers use primarily color soy-based inks, replacing inks based on petroleum distillates (Bruno 1990).

Water-based inks generally contain small amounts of solvents, typically an alcohol. Water-based screen printing inks, however, do not contain alcohols. Although water-based inks are now used primarily in flexographic and gravure packaging printing, their use is spreading to other areas of printing except lithography. Water-based inks can not be used in lithographic printing because the process depends on the affinity of the image area of the plate for oil-based inks and of the non-image area for water (Branco; Centaur; Kinter 1993; SRI 1990).

Another approach being taken by industry in reducing VOCs is the use of high solids ink, particularly for certain products printed using heatset lithography. By increasing the solids (i.e., pigment and/or resin) content of the ink, the solvent level can be reduced from as much as 45 percent by weight to 30 percent (Centaur; McGraw-Hill).

A number of no-solvent technologies that emit no VOCs are also available including ultraviolet (UV) and electron beam (EB) curable inks. UV and EB inks polymerize or "cure" upon exposure to the energy source indicated by their names. In general these inks consist of an oligomer, a reactive diluent (usually a multifunctional acrylate), and a pigment. UV inks also require a photoinitiator. A number of health risks are associated with exposure to the multifunctional acrylates found in these inks. UV and EB inks are generally more expensive than conventional inks and the capital costs of the curing equipment is high. However, the curing systems use much less energy than the drying systems often required for conventional inks. Additionally, UV and EB inks dry almost instantaneously so their use can increase productivity. These inks provide high gloss print that is both chemical and abrasion resistant. UV and EB inks are used in lithography, screen printing, letterpress, and flexography (Centaur; GCIU; McGraw-Hill; SRI 1990).

Another no-solvent technology is chemically reactive inks. Typically, these are two component systems that polymerize upon mixing. To date, however, chemically reactive inks have found only very limited commercial use (McGraw-Hill).

b. Dampening Systems

Since the 1950s, isopropyl alcohol (IPA) has been widely used in fountain solutions for dampening systems on lithographic presses. However, due to increasingly strict state and Federal control of VOCs, the trend is towards the use of alcohol-free fountain solutions. Glycol ethers have been the primary replacement for alcohols in fountain solutions. 2-Butoxy ethanol, a glycol ether, is currently the major substitute for IPA; however, its use requires process changes (Branco; Petersen 1991).

Another alternative is waterless plates that do not require the use of dampening systems. Waterless plates are discussed in more detail in section IV.B.2.a of this report.

c. Press Cleaners

Currently, there are three primary categories of press cleaners: chlorinated solvents, aromatic petroleum distillates, and aliphatic petroleum distillates. Potential substitutes include: 2-butoxy ethanol; N-methylpyrrolidone; D-limonene; and low vapor pressure mixtures of aliphatic and aromatic petroleum distillates (Branco). Others consist of surfactants, surfactant and solvent mixtures, or non-volatile oils such as vegetable oil (Hicks; Petersen 1991).

Traditionally, presses have been cleaned manually. Today, however, automatic press cleaning systems are widely available. Compared to manual cleaning of presses, these systems shorten press down-time and reduce (though do not eliminate) solvent use (Hicks).

Most newspapers now use dry-type (i.e., solventless) automatic blanket washers. According to industry sources, while dry systems do not clean as well as manual or automatic systems using solvents, they are viable substitutes (Hicks).

d. Process Color

Process color techniques allow the creation of virtually any color by overprinting some combination of translucent inks of only four colors: cyan, magenta, yellow, and black. Improvements in turnaround time and quality will cause the use of process color to grow in the 1990s. This growth will be fed by the continued preference of consumers for color images in daily newspapers and news magazines. Other factors include: technological developments that allow economies in short-run offset color printing, new prepress systems for processing color images, and the availability of acceptable quality from laser printers and color copiers. Other factors that will contribute to the growth of process color including: the development of water-based and vegetable oil-based inks suitable for use in all major printing processes and the introduction of integrated prepress systems that simplify the preparation of color pages and reduce color processing costs (SRI 1990).

2. Offset Printing

In the 1990s, there are expected to be modest improvements in offset platemaking and ink technology. The major trend in lithographic printing, however, will be in the automation of printing press operations (SRI 1990).

Microcomputer technology will be employed in the areas of data collection and process control. Microcomputers now available run at the speeds required to monitor and adjust the operation of high-speed presses. Furthermore, extremely sensitive and responsive sensors are now available that are capable of monitoring the performance of printing presses in real-time. These two technologies have been integrated to create closed-loop control systems that can monitor and control nearly every aspects of the modern high-speed press (SRI 1990).

During the 1990s, the increasing application of automation to offset printing will increase speed, reduce waste and improve quality as well as reduce labor requirements. Areas where automated monitoring or control are either being implemented or studied include (SRI 1990):

- Plate changing and unloading;
- Paper roll replacement;
- Inking control;
- Temperature control of inks, water, press dryers, and chill rollers;

- Registration;
- Paper speed and tension control;
- Press cleaning;
- Web tear detection; and
- In-line finishing.

Waterless plates, an important development in lithographic plates, are discussed below. Other changes in offset technology will include modest improvements in plate technology, including the commercial introduction of laser-exposed plates and wider presses that will allow faster printing speeds (2500 to 3000 feet per minute) and signatures of up to 72 pages (SRI 1990).

a. Waterless Plates

Waterless plates are a type of lithographic plate that requires no water to prevent the non-image areas of the plate from accepting ink. The non-image areas of waterless plates are coated with silicone rubber which has such low surface energy that it will not be wet by ink. However, early waterless plates, introduced in the U.S. in 1970, had poor scratch resistance and durability. Furthermore, they were sensitive to heat, and elevated temperatures caused toning of non-image areas. These plates were withdrawn from the market in 1977. A second generation of plates was introduced in Japan in the late 1970s that largely overcame these problems. Today waterless plates are in widespread use in Japan and are beginning to achieve commercial acceptance in the U.S. (Bruno 1990; Stanilus).

Waterless plates require the use of special waterless inks based on high viscosity modified phenolic or modified hydrocarbon resins and high boiling point nonaromatic or alpha-olefin hydrocarbon solvents. The inks are higher viscosity than conventional offset inks. Because of their special rheological properties, the inks need to be maintained within a narrow range of temperatures during printing. For this reason presses using waterless plates must be equipped with chillers (cooling systems) or printers must stock a variety of inks designed for use under different temperature conditions (Lustig and Stanulis). Cooling systems are optional on most new presses and retrofitting of existing units is usually possible (Toray).

There are disadvantages to using waterless plates: the plates are more expensive and less durable than conventional lithographic plates and processors for waterless plates run about $40,000. The inks used are also more expensive. Furthermore, chillers for presses using waterless plates cost between $60,000 and $100,000 (American

Printer and Branco). This technology has increased energy requirements over traditional technology. Plate and ink chemistry differences also need to be examined (Kalima 1993).

From an environmental and health and safety standpoint, the advantage of waterless plates is they do not require dampening and, therefore, print without the alcohol and other chemicals used in dampening systems (Stanilus). However, the plate developing chemistry is solvent based (Jones 1993).

3. Rotogravure Printing

A steady decrease in the time required for cylinder preparation as well as increasing automation will keep rotogravure competitive with both lithographic offset and flexographic printing.

Historically, the major disadvantage of the gravure process in comparison to other printing processes has been the substantially greater amount of time required for cylinder preparation. Automation and the development of a number of direct-to-cylinder preparation techniques have reduced the time required for cylinder preparation; however, gravure still remains uneconomical for smaller press runs. The minimum number of impressions is usually dictated by economics and the type of product. U.S. publication gravure printers seldom print below 500,000 copies while in other parts of the world publication print orders of 100,000 to 200,000 copies are not uncommon. On the other hand, a specialty gravure (i.e., wall covering) run may total only a few hundred yards of printed material (Tyszka 1993).

During the 1990s, a number of direct-to-cylinder techniques currently either under development or in the early stages of commercialization promise to decrease gravure cylinder preparation time significantly. For example, a computer-to-cylinder system that uses a laser to carve cells in a polymer coated gravure cylinder has recently been installed in a number of U.S. printing plants. German companies are leading in the development of photopolymer cylinders for gravure presses (Adams 1988; Bruno 1990; SRI 1990).

Automation of rotogravure presses will occur at a slower rate than for offset presses due primarily to the very large size of rotogravure presses. However, widespread automation of cylinder changeover and of paper roll transport and loading has already occurred. The introduction of fully automated presses controlled by a single operator is expected by the late 1990s (Bruno 1990; SRI 1990).

A number of other significant changes are anticipated in rotogravure printing during the next few years. Special polymers and other new materials will partially replace copper and steel in cylinders thereby reducing weight and making higher press operating speeds possible. Although gravure remains heavily dependent on solvent-base inks, a growing amount of water-based and ultraviolet-curable inks will be used; however, acceptable water-based publication gravure inks have yet to be identified. Wider presses will be introduced, allowing increased output (Bruno 1990; Jones 1993; SRI 1990).

4. Flexographic Printing

Important improvements will occur in both flexographic plates and inks. The use of photopolymers in plate manufacture will both lower the cost and improve the quality of flexographic plates. Edge sharpness will improve approaching that achieved with offset. Improvements in the density and consistency of the water-based color inks used in flexography are also expected (SRI 1990).

A major problem in flexographic printing has been so-called plate or image plugging. However, this problem will be largely overcome as a result of improved wash-up devices and inking systems. This will result in black-and-white halftone quality approaching that achieved with offset printing (SRI 1990).

Continuing improvements in process color printing by flexography will make the process increasingly competitive with lithography in the medium-quality magazine market (Bruno 1990).

5. Plateless Printing

A variety of plateless technologies are currently in use. These processes, expected to undergo continuing improvements and refinements during the 1990s, include: electronic printing; ink-jet printing; thermal printing; ion deposition printing; and magnetography. Anticipated market trends for these processes are discussed below. The technologies themselves are described in Section III.F.2 of this report.

Plateless technologies are currently important primarily in the office, in-plant, and quick printing markets. They are also important in direct mailing and personalized advertising. These markets are expected to be the growth leaders in the printing industry during the 1990s. As plateless technologies improve and become widely available, a growing share of the business that would formerly have been done by small- to medium-size commercial printers using traditional technologies will instead be done in the office or at the quick printer (Bruno 1990; SRI 1990).

In 1990, plateless processes accounted for only about three percent of the total value of the output of the U.S. printing market. However, these processes' market share will grow explosively in the next 35 years, accounting for 11 percent of the market by the year 2000 and 21 percent by 2025 (Bruno 1990).

a. <u>Electronic Printing</u>

Electronic printing is used primarily for short-run office, in-plant, and quick printing. Quick printing is expected to be one of the fastest growing segments of the printing industry in the foreseeable future and its growth will be fueled in part by the continuing increase in the quality and economy of electronic printing technologies (SRI 1990). For example, there have been dramatic improvements in the quality of color copiers. These copiers are soon expected to be competitive with traditional printing methods in the short-run (500 to 10,000 copies) color market (GATF 1992a).

Laser printers, connected to personal computers in both the office and home environments, will become widespread. Currently, prices are falling and low-end laser printers are available for as little as $600. More sophisticated printers capable of using the Postscript page definition language are available for well under $2,000 (SRI 1990).

Use of high dot-density color electrophotography machines with dot densities ranging from 400 dots per inch (DPI) to 2000 DPI will become more widely used in the office, in-plant, and fast-services environments. The quality of the printed output will increase during the 1990s but printing speed will continue to be very slow when compared to other methods (SRI 1990).

Another growth area for electronic printing is in the production of relatively inexpensive proof copies of printed materials that will be printed using one of the traditional printing technologies (Adams 1988; Bruno 1990).

b. <u>Ink-jet Printing</u>

Continued technological improvements will stimulate the increased use of ink-jet printers in the printing industry. The ink-jet printer's speed in addressing and printing variable information on repetitive forms is credited with revolutionizing the direct mailing business as well as personalized direct mail advertising (Adams 1988; Bruno 1990). The principle use for this technology, however, is expected to remain in the office environment. Ink-jet printers fall between dot-matrix and laser printers both in cost and quality of printed output. However, ink-jet printers have the capability to produce both graphics and text in a variety of colors on plain paper and transparencies. These capabilities will ensure broadening use in the office environment for engineering graphics and other business applications. Higher quality color ink-jet printers will be developed in response to the growing amount of sophisticated graphics software available for personal computers (SRI 1990).

c. Thermal Printing

Thermal printers will continue to enjoy a limited increase in market share during the 1990s. This growth will be stimulated by improvements in resolution, color capability, and reduced paper cost. However, a number of drawbacks remain, including the need for special papers, a low rate of output, and, despite improvements, comparatively poor image quality. Thermal printing is currently used in facsimile machines and other office applications (SRI 1990).

d. Ion Deposition

Ion deposition printing, an emerging technology similar to electronic printing and other electrostatic processes, will show marked improvement during the mid-1990s. Currently, this technology is used primarily in the office environment where it is used to print forms, reports, and other business documents. One area where this technology is expected to be applied in the 1990s is in multiple-color printing. However, ion deposition printing will require considerable development and refinement before it can compete with laser printing (Bruno 1990; SRI 1990).

e. Magnetography

Magnetography is similar to electronic printing except that a magnetic, and not an electrostatic, photoconductor is used. The use of magnetography is limited to a few specialty printing markets such as printing identifier labels, bar codes, pressure sensitive labels, and glossy substrates. No major improvements in this technology are expected in the 1990s. Furthermore, due to shortcomings such as slow speed, high toner costs, and the inability to do color process printing little or no market growth is anticipated (SRI 1990).

C. Postpress Technology

Until recently the automation of postpress operations has been limited, and, for many printers, postpress operations remain labor intensive. One source estimates that nearly 80 percent of the cost of some print jobs is material handling. Because much of the labor in postpress operations involves materials handling, there is the opportunity to decrease postpress costs substantially through further automation (Bruno 1990; SRI 1990).

The major development in postpress technology has been the introduction of computer-controlled in-line finishing systems that directly link the press with postpress operations. In comparison to off-line finishing, these in-line systems can typically finish three to four times the number of units per hour with roughly half the personnel (Adams 1988; SRI 1990).

In addition to traditional binding and finishing operations, some in-line finishing systems can perform a number of specialized operations such as addressing and demographic binding. Demographic binding refers to the selective assembly of a publication based on any of several factors including geographic area, family structure, income, or interests. The technique can be used, for example, to include advertisements only in those copies of a magazine that will be received by persons in the advertisers selling area (Adams 1988). Selective binding techniques used to target printed products to selected geographic areas and markets are widely used today and have been proven to be very effective marketing tools. The use of this technology will continue to expand at a rapid rate due, primarily, to the intense interest shown by advertising agencies and other direct marketing organizations (Bruno 1990; SRI 1990).

Water-based adhesives have long been used in printing facilities operations. However, an important chemical trend in postpress operations is the increasing use water-based adhesives in place of solvent-based adhesives containing toluene and methyl ethyl ketone.

During the 1990s, the introduction of robots for postpress materials tracking and handling is anticipated (Bruno 1990).

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