PRINTING PROCESS

General Overview of the Printing Process

- Prepress
  - Introduction
  - Typesetting and composition
  - Copy assembly and process photography
  - Image Carrier Preparation
- Printing processes
  - Lithography
    - Prepress
    - Fountain solution
    - Inks
    - Press types and processes
      - Non-heatset Sheet fed
      - Heatset web
      - Non-heatset web
  - Flexography
    - Prepress
    - Inks
    - Press types and processes
  - Gravure
    - Prepress
    - Inks
    - Press types and processes
      - Gravure - web fed
      - Gravure - sheet fed
  - Screen printing
    - Inks
    - Press types and processes
    - Screen Reclamation
  - Letterpress
  - Plateless printing processes (e.g., digital printing)
- Post-press and finishing

"Print - It’s everywhere! It’s on your coffee table; in your freezer; on the bumper of your car. It can be found on your walls, your doorstep, and on your clothes. It’s on your mail, in your wallet, and most often in your hands." The commercial printing industry is one of the largest industries in the United States. According to 1999 data the printing industry employs 1,173,393 people among approximately 50,000 establishments with annual sales totaling over $155,771 million in annual shipments.

While the industry accounts for a significant portion of the nations' total volume of goods and services, it also represents the largest conglomeration of small businesses in the domestic manufacturing sector. Seventy nine percent of the plants in the industry employ 19 people or less (PIA 1999 Report to Congress). Most firms in the industry serve local or regional markets, though some printers and many publishers reach national and international markets (USIO 1992).

The industry is dominated by five separate and distinct processes, lithography, letterpress, flexography, gravure, and screen-printing. However some of the newer plate-less technologies are beginning to take hold in the market. Based on 1997 sales figures lithography accounted 68.5% of the market; screen 9.0%; flexographic 6.4%; quick printing 5.7%; gravure 5.4%; letterpress 4.5%, and digital printing 0.6%. The market share is drastically changing as indicated by comparing 1990 sales figures with these current figures. In 1990 the market share was broken down to lithography 47%, gravure 19%; flexography 17%; letterpress 11%; and screen-printing 3%. (1999 US Economic Census Report)

Print Technology	1990	1997
Lithography	47 %	68.5 %
Gravure	19 %	5.4 %
Screen	3 %	9.0 %
Flexography	17 %	6.4 %
Quick Printing	N/A	5.7 %
Letterpress	11 %	4.5 %
Digital	N/A	0.6 %

The introductions of plateless printing processes are beginning to significantly impact the printing industry. Based on 1991 projections the plateless technologies include electronic printing such as xerography and laser printing; ink jet printing; magnetography; thermal printing; ion deposition printing; direct charge deposition printing; and the Mead Cucolor Photocapusle process.

While most printing facilities utilize primarily one process or type of printing press, it is not uncommon to see multiple processes or types of printing presses at a printing facility. For example a newspaper publishing company may be utilizing both offset lithographic printing presses as well as flexographic printing presses. At many smaller printing facilities, which print a variety of products such as business cards, stationary, advertisements, etc., it is not uncommon to find both offset lithographic printing presses as well as letterpress printing.

General Overview of Printing Process

The five major printing processes are distinguished by the method of image transfer and by the general type of image carrier employed. Depending upon the process, the printed image is transferred to the substrate either directly or indirectly. In direct printing the image is transferred directly from the image carrier to the substrate, examples of direct printing are gravure, flexography, screen-printing and letterpress printing processes. In indirect, or offset, printing, the image is first transferred from the image carrier to the blanket cylinder and then to the substrate. Lithography, currently the dominant printing technology, is an indirect (offset) process.

Image carriers (or plates) can generally be classified as one of four types: relief, planographic, intaglio, or screen. In *relief printing*, the image or printing area is raised above the non-image areas. Of the five major printing processes, those relying on relief printing are letterpress and flexography. In *planographic printing*, the image and non-image areas are on the same plane. The image and non-image areas are defined by differing physiochemical properties. Lithography is a planographic process. In the *intaglio process*, the nonprinting area is at a common surface level with the substrate while the printing area, consisting of minute etched or engraved wells of differing depth and/or size, is recessed. Gravure is an intaglio process. In the *screen process* (also known as porous printing), the image is transferred to the substrate by pushing ink through a porous mesh, which carries the pictorial or typographic image.

Each printing process can be divided into three major steps: prepress, press, and post press.

Prepress operations encompass that series of steps during which the idea for a printed image is converted into an image carrier such as a 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. Post press primarily involves the assembly of printed materials and consists of binding and finishing operations.

Within each process, a variety of chemicals are used, depending on the types of operation involved. Prepress operations typically involve photo processing chemicals and solutions. Inks and cleaning solvents are the major types of chemicals used during press operations. Depending on the finishing work required, post press operations can use large amounts of adhesives. This is especially true 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 used in the largest quantities. Many of the chemicals used in the printing industry are potential hazards to human health and the environment.

Prepress Operations

Introduction

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

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 paste-ups 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 pre typed material and photographic images can easily be incorporated into the document being composed. With the systems now 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 (letterpress), 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 are used extensively in-plant printing applications.

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.

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. 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. Forcing ink through the stencil openings and onto the substrate prints the image. The stencil openings determine the form and dimensions of the imprint produced.

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.

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 within the gravure process description.

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.

Light-sensitive Coatings

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

Photo polymeric Coatings

Most image carriers (printing plates) are made using any of a number of different types of photo polymeric coatings. These coatings are characterized by the type of reaction they undergo upon exposure to UV light: photo polymerization, photocrosslinking, photo arrangement, and photo degradation. A well known example of a photopolymer coating is Kodak Photo Resist (KPR), a photo cross-linking 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 wear ability, 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.

Diazos Coatings

Diazos Coatings, introduced in the printing industry around 1950, are used primarily for coating both pre-sensitized and wipe-on lithographic surface plates. For pre-sensitized plates, a machine called a whirler, which spreads the coating on the rotating plate, applies the diazos coating.

With wipe-on plates the plate maker with a sponge or a roller applicator instead of applies the coating by the usual whirler method. Diazos 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 diazos plates have negative-process coatings, though positive process coatings are also used. Diazos coatings are used to pre-sensitized deep-etch and bi-metal plates. Additionally, diazos is used to sensitize some colloid coatings.

The diazos resin most often used for plates is the condensation product of 4-diazodiphenylamine salt with formaldehyde. Diazos 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.

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. Colloid ions 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.

Press Operations

Offset Lithographic Printing

Applications

Lithographic printing is well suited for printing both text and illustrations in short to medium length runs of up to 1,000,000 impressions. Typical products printed with offset printing processes include:

- General commercial printing Quick printing
- Newspapers Books
- Business Forms Financial and Legal Documents
- Offset Lithographic Printing Process Overview

Lithography is an "offset" printing technique. Ink is not applied directly from the printing plate (or cylinder) to the substrate as it is in gravure, flexography and letterpress. Ink is applied to the printing plate to form the "image" (such as text or artwork to be printed) and then transferred or "offset to a rubber "blanket". The image on the blanket is then transferred to the substrate (typically paper or paperboard) to produce the printed product. On sheet-fed presses, the substrate is fed into the press one sheet at a time at a very high speed. Web fed presses print on a continuous roll of substrate, or web, which is later cut to size. There are a total of 3 types of offset printing: non-heatset sheet fed, heatset, and non-heatset web offset. The difference between heatset and non-heatset is primarily dependent on the type of ink and how it is dried.

Offset Lithographic Printing Process

All offset presses have three printing cylinders, as well as the inking and dampening systems. The plate cylinder, the blanket cylinder and the impression cylinder.
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 deferring physiochemical properties.
Lithography is based on the principal that oil and water do not mix (hydrophilic and hydrophobic process). 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, fountain (dampening) solution, which consists primarily of water with small quantities of isopropyl alcohol and other additives to lower surface tension and control pH, is first applied in a thin layer to the printing plate and migrates to the hydrophilic non-image areas of the printing plate. Ink is then applied to the plate and migrates to the oleophilic image areas. Since the ink and water essentially do not mix, the fountain solution prevents ink from migrating to the non-image areas of the plate.

As the plate cylinder rotates, the plate comes in contact with the dampening rollers first. The dampening rollers wet the plate so the non-printing areas repel ink. Then the inking rollers transfer ink to the dampened plate, where ink only adheres to the image areas. The inked image is transferred to the rubber blanket, and the substrate is printed as it passes between the blanket and impression cylinder.

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. 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).

The major unit operations in a lithographic printing operation include:

- Image preparation
- Processing printing plates
- Printing
- Finishing
- Image Preparation of Lithographic Printing Plates

Image preparation begins with camera-ready (mechanical) art/copy or electronically produced art supplied by the customer. Images are captured for printing by camera, scanner or computer. Components of the image are manually assembled and positioned in a printing flat when a camera is used. This process is called stripping. When art/copy is scanned or digitally captured the computer with special software assembles the image. A simple proof (brown print) is prepared to check for position and accuracy. When color is involved, a color proof is submitted to the customer for approval.

Processing of Lithographic Printing Plates

There are eight different types of litho plates common to the commercial printing industry: Diazos, Photopolymer, Silver Halide, Electro photographic (Electrostatic), Bimetal, Waterless, Thermal, and Ablation. The predominant surface plate in use today is termed a "pre-sensitized" plate. Most printers will primarily use one or two types of plates. It is highly unlikely that you would encounter a printer that could use a few of each type of plate nor is it easy for them to switch to a different type of plate due to equipment, expense and application reasons.

Offset Lithographic Plate Making

Diazos plates are coated with organic compounds and are developed with a special solvent. They have a shelf life of about one year. These are used for print runs of about 150,000 impressions.
Photopolymer plates are coated with organic compounds which are very inert and abrasion resistant. This makes them last much longer than diazos plates. They are used for print runs of up to 250,000 impressions

Silver halide plates use photosensitive coatings similar to photographic film, except that the silver halide emulsions are slower and for color reproduction are coated on anodized aluminum. The processing solutions contain silver which must be recovered with the proper equipment before being discharged to the sewer. Film based silver halide plates are used for single color printing and metal-based silver halide plates are used in computer-to-plate systems.
Electrostatic plates are based on the principle of the electrostatic copier. There are two types, inorganic photoconductors on a drum and the second is organic photo conductor on a substrate. These are used mostly in quick printing jobs of 100,000 impressions or less.
Bimetal plates use pre-sensitized polymer coatings. There are two types of bimetal plates; copper plated on stainless steel or aluminum and chromium plated on copper. These are the most expensive, but rugged plates and are used for very long print runs. In fact they are capable of print runs in the millions.
Waterless plates, used on waterless presses only, consist of ink on aluminum for the printing areas and a silicone rubber for the non-image areas. These systems require special inks and high-grade paper to avoid debris accumulating on the blanket.
Ablation plates are imaged by digital data and require no chemical processing. These plates are digitally imaged by selectively burning tiny holes in thin coatings of a polyester or metal base. These types of plate are used on the new computer to plate imaging systems and the brand new computer to press system. The cost of equipment and materials is high and the technology is relatively new.
Heat sensitive plates are exposed by infrared diodes in special image setter and processed in water based chemistry. This a relatively new technology and requires the printer to invest in new equipment that can be quite costly.

Offset Lithographic Inks:

- Petroleum Based
- Vegetable Oil Based
- UV & EB Curable
- Heatset

There are four common types Lithographic inks, unlike Gravure, Flexo, and Screenise very viscous to the point they are paste-like. Litho inks are generally very strong in color value to compensate for the lesser amount applied. Sheet fed litho inks are similar to oxidizing types of letterpress inks. To accelerate drying and control ink flow characteristics litho inks contain solvents (or drying oils) which result in some VOC emissions from the ink.

Offset Lithographic Inks

Linseed and rapeseed (canola) oil have been added to litho inks for years, but other vegetable oils like soybean oil are more frequently being used because because of their lower VOC content, which helps eliminate smudging.
Heatset Inks are completely different from non-heatset inks and cannot be interchanged between the two types of presses. Heatset inks are quick drying inks for web printing.

The solvents are vaporized as they pass through resins fixed to the paper in such a way that there is no chance for the ink to spread, smear, or soak into the paper. Heatset presses are equipped with a drier, and a chilling system to cool the heated resins and set the image. Heatset inks emit a significantly greater amount of VOC as compared to non-heatset lithographic inks. Therefore most heatset presses are also equipped with pollution control equipment such as a thermal oxidizer or after burner to destroy the high volumes of VOCs that are being emitted from these inks.
Ultraviolet (UV) and Electron Beam (EB) curable inks are also available for litho printing, but the press must be properly equipped to run these types of inks. The use of UV curable inks is on the rise, particularly for the application of overprint coatings.
One advantage of low VOC content is the ability to operate presses at comparable speeds to conventional inks, versus the slow drying and slow press speeds associated with water-based coatings.
One disadvantage is equipment can be costly and is still in the development stage, and the inks and coatings may cost as much as three times the price of conventional coatings.
Electron beam curing inks make a good alternative to U.V. inks because they are less costly and less reactive materials can be used. They also require less energy than U.V. curing inks. The down side of E.B. curing inks is the capital costs to outfit a press. Additionally, EB inks, like UV inks, can be a skin irritant. The inks, if exposed to sensitive skin or left on skin, may cause dermatitis and could even cause chemical burns.

Fountain Solutions & Dampening System

Traditionally, isopropyl alcohol was used to control surface tension in the fountain solution, but in recent years its use has been reduced, and in many cases eliminated by using alcohol substitutes. The reason for this shift is due to the VOC emissions attributed to the evaporation of isopropyl alcohol and the level of environmental regulation this lead to. Alcohol substitutes may use glycol ethers such as butyl cellosolve (2-butoxy ethanol) or other glycols to control surface tension.

- Direct Feed Continuous Integrated System
- Direct to Plate

Fountain solutions are applied to enhance the non-image areas ability to repel ink. Some newer fountain solutions have been developed with oxidizing chemicals which accelerate the setting and drying of inks and reduce the need for anti-set off sprays.
Anti-Set Off Sprays are fine corn starch powders sprayed on the sheets to prevent the ink from smearing and sticking onto the back of the top sheet as the printed material is stacked.
There are two common types of dampening systems; the direct feed continuous integrated system and direct to plate dampening system. Direct to plate dampening systems apply the fountain solution directly to the plate. Direct feed continuous integrations systems meter the fountain solution, which contains alcohol or an alcohol substitute, through the inking system. Direct feed can also act as a direct to plate dampening system and apply

the fountain solution directly to the plate. This system generally uses less water, reduces make ready time and paper waste at start up.
The inking system, which has several rollers, is designed to work the ink so that it will be evenly distributed across the blanket. The rollers also aid in evaporating some of the water from the dampening system.
The fountain solution acts as the water solution for the hydrophilic process of lithographic printing. Fountain solution also helps to cool the press and facilitate the ink drying. Fountain solution is applied to the dampening roller to repel ink in the non-image areas of the plate.

Sheet fed Offset Lithographic Printing

The sheet fed offset process is used mainly for relatively short runs in the production of commercial and packaging products. In sheet fed lithography, the paper or paperboard substrate is normally delivered to the facility in sheets. If rolls are supplied, the paper or paperboard must be sheeted (cut into sheets and trimmed before printing.

Major categories of chemicals used in the sheet fed offset process include film developers and fixers, inks, blanket and roller washes, and fountain solution concentrate. Isopropyl alcohol and glycol based, lower VOC, products are widely used in fountain solutions.

Sheet fed lithographic inks are paste inks primarily composed of petroleum products, a portion of vegetable oils and pigments, that dry by oxidative polymerization and adsorption into the substrate, rather than evaporation, and therefore do not generate large amounts of VOC emissions. The majority of VOC emissions come from isopropyl alcohol used in the fountain solution and cleanup solvents used to clean ink fountains (trays that hold ink), rollers, blankets and other press components.

Heatset Web Offset Lithographic Printing

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.

In heatset web lithography, the paper substrate is delivered to the facility in rolls. The paper is fed directly into the press and is termed a "Web" since it is a continuous feed of paper as opposed to individual sheets. After printing, the paper is folded and/or cut "in-line" with the printing units.

Heatset web lithographic inks are paste inks that dry through evaporation of the ink oils contained in the ink this is usually accomplished with a re-circulating hot air system (normally fueled by natural gas) although direct flame impingement and infrared drying systems are in limited use (Buonicore). Ink oil evaporated and emitted through dryer stacks is a potentially significant source of VOC emissions. Because of this many heatset web lithographic presses require an emission control device (such as a catalytic or thermal oxidizer) to reduce VOC concentrations in the dryer exhaust air stream. VOC emissions also occur from isopropyl alcohol used in fountain solution and cleanup solvents used to clean ink fountains (trays that hold ink), rollers, blankets, and other press components. Major chemicals used are quite similar to those used in sheet fed offset

Non-heatset Web Offset Lithographic Printing

The non-heatset web offset process is a high speed process used largely in the production of newspapers, journals, directories, and forms. In non-heatset web lithography, the paper or paperboard substrate is delivered to the facility in rolls. The paper is fed directly into the press from the roll and is termed a "Web" since it is a continuous feed of paper as opposed to individual sheets. After printing, the paper is folded and/or cut "in-line" with the printing units.

Non-heatset lithographic inks are paste inks that dry by oxidative polymerization and adsorption into the substrate, rather than evaporation therefore they typically do not require mechanical, and thus, 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, such as fountain solution cleaning solvents, etc. are quite similar to those used in heatset web offset.

Finishing:

After printing, the substrate may run through a number of operations to be "finished and ready for shipment to the customer. Finishing may include operations such as coating, cutting, folding, binding, stitching, embossing, and die cutting.

Flexographic Printing

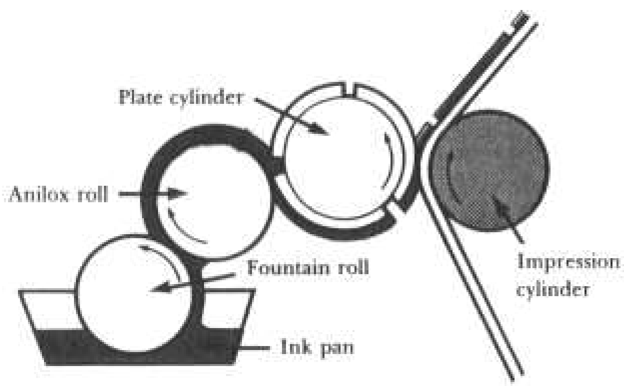
Applications:

Flexography is the major process used to print packaging materials. Flexography is used to print corrugated containers, folding cartons, multi wall sacks, paper sacks, plastic bags, milk and beverage cartons, disposable cups and containers, labels, adhesive tapes, envelopes, newspapers, and wrappers (candy and food).

Flexographic presses are capable of producing good quality impressions on many different substrates and is the least expensive and simplest of the printing processes used for decorating and packaging printing. The use of flexographic printing presses is on the rise. There are two primary reasons for this: 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 plate making solution, water and solvent based inks, and blanket/roller cleaning solvents.

Flexography is a form of rotary web letterpress, combining features of both letterpress and rotogravure printing, using relief plates comprised of flexible rubber or photopolymer plates and fast drying, low viscosity solvent, water-based or UV curable inks fed from an "anilox" or two roller inking system. The flexible (rubber or photopolymer) plates are mounted onto the printing cylinder with double-faced adhesive. Plates are sometimes backed with thin metal sheets and attached to the cylinder with fastening straps for close register or ink alignment. This adds additional cost to the plate and requires more make ready time, but when quality printing is critical this type of plate can make the difference.



Process Overview

In the typical flexo printing sequence, the substrate is fed into the press from a roll. The image is printed as substrate is pulled through a series of stations, or print units. Each print unit is printing a single color. As with Gravure and Lithographic printing, the various tones and shading are achieved by overlaying the 4 basic shades of ink. These are magenta, cyan, yellow and black. Magenta being the red tones and cyan being the blue.

The process of printing each color on a flexo press consists of a series of four rollers:

- Ink Roller
- Meter Roller
- Plate Cylinder
- Impression Cylinder

The first roller transfers the ink from an ink pan to the meter roller or Anilox Roll, which is the second roller. The Anilox roller meters the ink to a uniform thickness onto the plate

cylinder. The substrate then moves between the plate cylinder and the impression cylinder, which is the fourth roller.
The impression cylinder applies pressure to the plate cylinder, thereby transferring the image onto the substrate. The web, which by now has been printed, is fed into the overhead dryer so the ink is dry before it goes to the next print unit.
After the substrate has been printed with all colors the web MAY be fed through an additional overhead tunnel dryer to remove most of the residual solvents or water. The finished product is then rewound onto a roll or is fed through the cutter.

The major unit operations in a flexographic printing operation are:

- Image preparation
- Plate making
- Printing
- Finishing

Image Preparation

Image preparation begins with camera-ready (mechanical) art/copy or electronically produced art supplied by the customer. Images are captured for printing by camera, scanner or computer. Components of the image are manually assembled and positioned in a printing flat when a camera is used. This process is called stripping. When art/copy is scanned or digitally captured the computer with special software assembles the image. A simple proof (brown print) is prepared to check for position and accuracy. When color is involved, a color proof is submitted to the customer for approval.

Flexographic Plate Making

Flexographic and letterpress plates are made using the same basic technologies utilizing a relief type plate. Both technologies employ plates with raised images (relief) and only the raised images come in contact with the substrate during printing. Flexographic plates are made of a flexible material, such as plastic, rubber or UV sensitive polymer (photopolymer), so that it can be attached to a roller or cylinder for ink application. There are three primary methods of making flexographic plates; photomechanical, photochemical and laser engraved plates.

Prepress - Plate making

The photomechanical plate making method begins with making an engraving. Exposing a metal plate through a negative and processing the exposed plate in an acid bath accomplish this. The metal engraved plate is used to make a master which is molded out of Bakelite board. The engraving is placed in a mold press. The mold is produced by applying heat & pressure to the mold material (bakelite board), which can be either plastic or glass, against the engraving under controlled temperature and pressure. The

Bakelite board fills the engraving on the metal plate. When its cooled you end up with a master mold for the plastic or rubber compound that will be pressed into the mold under pressure and elevated temperature to produce the flexible printing plate with raised areas that will transfer the ink.
The second method of flexo plate making is relief plates. This utilizes a solid or liquid photopolymer. The sheet of photopolymer is exposed to light through a negative. The unexposed areas are then washed away with solvent or water wash. This is fast becoming the most common method of making plates.
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.
Flexographic printing plates may be made by laser engraving, which is called direct digital plate making. In this process an image is scanned or computer generated. Then a computer-guided laser etches the image onto the printing plate.

Flexographic Printing Presses

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 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.

Flexographic Printing Press Types

Stack Type

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)

Central impression cylinder (CIC), like the common impression rotary letterpress, 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. CIC presses are used extensively for printing flexible films.

In Line

In Line flexo printing is similar to a unit type rotary press or 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 post press equipment. These presses are used for printing bags, corrugated board, folding boxes, and similar products.

Newspaper Flexographic Presses

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

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).

Flexographic Inks

Flexographic inks are very similar to packaging gravure printing inks in that they are fast drying and have a low viscosity. The inks are formulated to lie on the surface of nonabsorbent substrates and solidify when solvents are removed. Solvents are removed with heat, unless U.V. curable inks are used.

These inks consist of colorants, which may be pigments and soluble dyes along with a binder and various solvents. Both Solvent based and water based inks commonly contain various types alcohol as the primary solvent or drier. Alcohol rapidly dries through evaporation and contributes to VOC emissions. The inks may also contain glycol ether and/or ammonia which facilitate drying.

Types:

- Water Based

- Solvent Based
- U.V. Curable

Water based flexo inks dry through evaporation and absorption on paper. This evaporation requires a greater amount of fuel or energy to dry the ink. Coated papers may be used to control the absorption through the paper. Due to the speed of the presses and volume of inks consumed daily a pollution control system may be necessary, especially if the printer is using solvent based inks. If the product allows, the printer may avoid pollution control equipment if they convert to water based inks or UV curable inks. The cost of Pollution control equipment for a small Flexo or gravure printer will cost approximately $400,000 (1998 estimate) for the equipment and approximately $50,000 for testing and certification. The price increases as the size and/or volume of the operation increases.
UV flexo inks are commonly used for top coats and lacquers and are responsible for many improvements in image quality of flexographic printing. The use of UV curable colored inks is rising within the flexographic printing industry, but product concerns and equipment investment are obstacles. Note, water based or UV curable inks may not be an option for some printers due to the substrate being printed or design of the product.

Finishing

After printing, the substrate may run through a number of operations to be "finished" and ready for shipment to the customer. Finishing may include operations such as coating, cutting, folding and binding.

Gravure Printing

Applications:

Typical gravure printed products include:

- Food packaging
- Wall paper
- Wrapping paper
- Furniture laminates
- Paneling
- Greeting cards
- Magazines

Process Overview
Gravure printing is characteristically used for long run, high quality printing producing a sharp, fine image. The number of gravure printing plants in the U.S. is significantly lower than other printing processes. This is due, in part, to the cost of presses and components. While a lithographic press will cost in the range of $100,000 the cost of gravure press

will be in the range of $1 million. Additionally a single gravure cylinder will cost around $5000 versus around $15 for a lithographic plate. Additionally, the gravure cylinder has a long service life and will yield a very large number of impressions without degradation.

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.

Currently, the dominant gravure printing process, referred to as rotogravure, employs web presses equipped with a cylindrical plates (image carrier). 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.

Today almost all gravure printing is done using engraved copper cylinders protected from wear by the application of a thin electroplate of chromium. The cylinders (image carrier) 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. The basics of Gravure printing is a fairly simple process which consists of a printing cylinder, a rubber covered impression roll, an ink fountain, a doctor blade, and a means of drying the ink.

Gravure printing is an example of intaglio printing. It uses a depressed or sunken surface for the image. The image areas consist of honey comb shaped cells or wells that are etched or engraved into a copper cylinder. The unetched areas of the cylinder represent the non-image or unprinted areas. The cylinder rotates in a bath of ink called the ink pan.

As the cylinder turns, the excess ink is wiped off the cylinder by a flexible steel doctor blade. The ink remaining in the recessed cells forms the image by direct transfer to the substrate (paper or other material) as it passes between the plate cylinder and the impression cylinder.

The major unit operations in a gravure printing operation are:

- Image preparation
- Cylinder preparation
- Printing
- Finishing

Gravure Inks - Solvent Based, Water Based
Gravure inks are fluid inks with a very low viscosity that allows them to be drawn into the engraved cells in the cylinder then transferred onto the substrate. In order to dry the ink and drive off the solvents or water, which essentially replaces most of the solvent, the paper is run through Gas fired or electric fired driers. 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 can be recovered using this process (Buonicore). The solvents can either be reused or destroyed by incineration.
Water based inks, especially used for packaging and product gravure, require a higher temperature and longer drier exposure time in order to drive off the water and lower vapor pressure constituents. As mentioned subsequent sections, Flexo and Gravure inks are very similar and the constituents are essentially the same. Again, a pollution control device may be needed.
Gravure Press Design and Equipment
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.
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.

Web Fed Gravure

There are several types of web presses used in gravure printing, including publication presses, packaging presses, product presses, label presses, and folding carton presses. The printing process is basically the same regardless of which press is used.

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.

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 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).

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).

Image Preparation

Image preparation begins with camera-ready (mechanical) art/copy or electronically produced art supplied by the customer. Images are captured for printing by camera, scanner, or computer. Components of the image are manually assembled and positioned in a printing flat when a camera is used. This process is called stripping. When art/copy is scanned or digitally captured, the computer with special software assembles the image. A proof is prepared to check for position and accuracy. When color is involved, a color proof is submitted to the customer for approval.

Cylinder Preparation

The gravure cylinder is composed of a steel or aluminum base, is copper plated and then polished to a predetermined diameter. Precise diameter of gravure cylinders in a set is critical. Any variances in diameter, as little as 2 thousandths of an inch can significantly affect the print registration. These cylinders are extremely sensitive to scratches and abrasions. Extreme care is taken when handling and storing the cylinders.

Because copper is so soft the image areas quickly wear. Cylinders that are used for press runs of a million impressions or more are chromium plated. Some gravure printers "Double Chrome" cylinders in order to run them even longer. When the chromium begins to wear or the image is no lit is stripped off and the cylinder is re-chromed. This is much cheaper (and environmentally responsible) than etching a new cylinder. Once the cylinder has degraded or the image is no longer needed the image can be stripped off and the base cylinder can be reused for other printing jobs unlike other printing processes.

Gravure Cylinder Imaging:

- Chemical Etching
- Electromechanically Engraved
- Direct Digital Engraving.

There are three processes used for making gravure cylinders. The first is for conventional gravure using chemical etching that produces cells of the same size or area with varying depths. The second is Electromechanically engraved cylinders.
In electromechanically engraved cylinder making, the image or copy is wrapped around a scanning cylinder. The scanning head moves across the scanning cylinder which sends impulses to a computer. The computer signals a pneumatic head, which contains a diamond stylus, when and where to make a cell in the copper cylinder. The diamond

stylus cuts an inverted pyramid shaped cell into the copper cylinder. Engraved cells may be up to 200 microns wide and up to 50 microns deep.
Chemical etching is hardly used now, but the process involves applying iron chloride solution of varying strengths over carbon tissue that has been sensitized to light by submerging it in a bath of potassium bichromate and water. The carbon tissue is a water-sensitive, fibrous paper that has been coated with a smooth gelatin resist.
In summary the gelatin resist is made to adhere to the cylinder. The cylinder is then exposed to UV light to harden the gelatin resist and then rinsed with plain water. Finally the etching technician applies the ferric chloride etchant which creates the printing cells on the cylinder.
Electromechanically engraved cells hold a lot less ink, yet print quality is equal to or better than chemically etched cylinders. In fact, an Electromechanically engraved cell holds approximately 30% less ink than a chemically engraved cell.
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).

Web Gravure Printing

The Doctor Blade and Impression Cylinder

The doctor blade is a simple device used to shear the ink from the surface of the plate cylinder. Pressure is applied to the doctor blade to assure uniform contact along the length of the cylinder. The blades must be angled to cut the surface of the ink, but pressure and angle must be carefully adjusted to prevent premature wear on the cylinder. The doctor blade also oscillates back and forth to prevent a flat surface being worn into the cylinder.

The rubber coated impression roll brings the substrate in contact with the engraved cylinder resulting in proper ink transfer. The impression roll also acts to adjust the tension between print units and helps move the substrate through the press.

The impression roll is made of a tubular sleeve coated with a rubber compound. The cover material is determined by the press conditions. Typically the coating is made of natural rubber, neoprene, nitrile or polyurethane. These impression rolls are typically purchased from an outside vendor rather than made on site.

Sheet-fed Gravure

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).

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).

Another type of offset gravure press, the flexo-gravure press, is currently used for printing clear film over wraps 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).

Process Overview

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 with a gripper to hold the plate in place during printing.

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 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.

Currently, the dominant gravure printing process, referred to as rotogravure, employs web presses equipped with a cylindrical plates (image carrier). 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.

Today almost all gravure printing is done using engraved copper cylinders protected from wear by the application of a thin electroplate of chromium. The cylinders (image carrier) 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. The basics of Gravure printing is a fairly simple process which consists of a printing cylinder, a rubber covered impression roll, an ink fountain, a doctor blade, and a means of drying the ink.

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).

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, and 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.

Screen Printing

Applications

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. including paper, plastics, glass, metals, nylon and cotton. Some common products from the screen printing industry include posters, labels, decals, signage, and all types of textiles and electronic circuit boards. The advantage of screen printing over other print processes is that the press can print on substrates of any shape, thickness and size.

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.

Utilization of screen printing presses has begun to increase because production rates have improved. This has been a result of the development of the automated and rotary screen printing press, improved dryers, and U.V. curable ink. 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).

Screen Printing Process Overview

Screen printing consists of three elements: the screen which is the image carrier; the squeegee; and ink. The screen printing process uses a porous mesh stretched tightly over a frame made of wood or metal. Proper tension is essential to accurate color registration. The mesh is made of porous fabric or stainless steel mesh. A stencil is produced on the screen either manually or photo chemically. The stencil defines the image to be printed in other printing technologies this would be referred to as the image plate.

Screen printing ink is applied to the substrate by placing the screen over the material. Ink with a paint-like consistency is placed onto the top of the screen. Ink is then forced through the fine mesh openings using a squeegee that is drawn across the screen, applying pressure thereby forcing the ink through the open areas of the screen. Ink will pass through only in areas where no stencil is applied, thus forming an image on the printing substrate. The diameter of the threads and the thread count of the mesh will determine how much ink is deposited onto the substrates.

Many factors such as composition, size and form, angle, pressure, and speed of the blade (squeegee) determine the quality of the impression made by the squeegee. 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.

If the item was printed on a manual or automatic screen press the printed product will be placed on a conveyor belt which carries the item into the drying oven or through the UV curing system. Rotary screen presses feed the material through the drying or curing system automatically. Air drying of certain inks, though rare in the industry, is still sometimes utilized.

The rate of screen printing production was once dictated by the drying rate of the screen print inks. Do to improvements and innovations the production rate has greatly increased. Some specific innovations which affected the production rate and have also increased screen press popularity include:

1. Development of automatic presses versus hand operated presses which have comparatively slow production times
2. Improved drying systems which significantly improves production rate
3. Development and improvement of U.V. curable ink technologies
4. Development of the rotary screen press which allows continuous operation of the press. This is one of the more recent technology developments

Screen Preparation

Screen (or image transfer) preparation includes a number of steps. First the customer provides the screen printer with objects, photographs, text, ideas, or concepts of what they wish to have printed. The printer must then transfer a "picture" of the artwork (also called "copy") to be printed into an "image" (a picture on film) which can then be processed and eventually used to prepare the screen stencil.

Once the artwork is transferred to a positive image that will be chemically processed onto the screen fabric (applying the emulsion or stencil) and eventually mounted onto a screen frame that is then attached to the printing press and production begins.

Screen Materials and Preparation Overview

Frames

There are two types of screen frames, metal and wood. Metal frames, both static (solid) and retention able, have become the industry standard. Retentionables do not require the use of adhesive products.

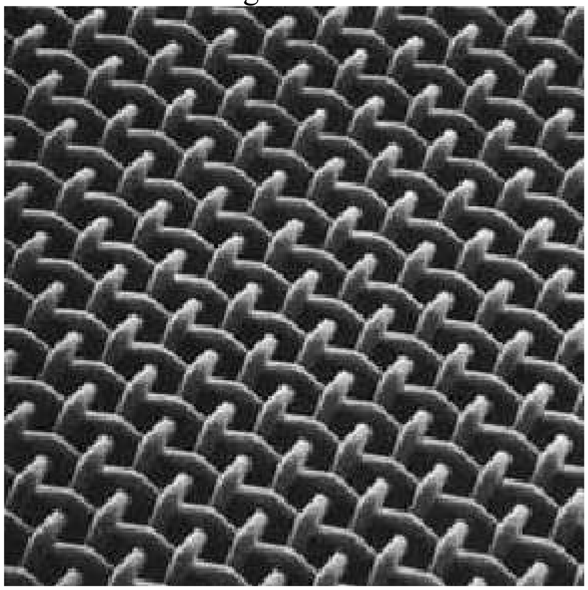
Metal frames have been replaced by wood because they do not warp from water like wood frames do. The most commonly used types of wood are cedar and pine. Pine is preferred because it is more water resistant while it is light weight.

Metal screens are made out of aluminum or steel. Aluminum is commonly preferred because it is light weight, yet sturdy. There are some applications where steel is preferred such as very large printing frames used for long printing runs.

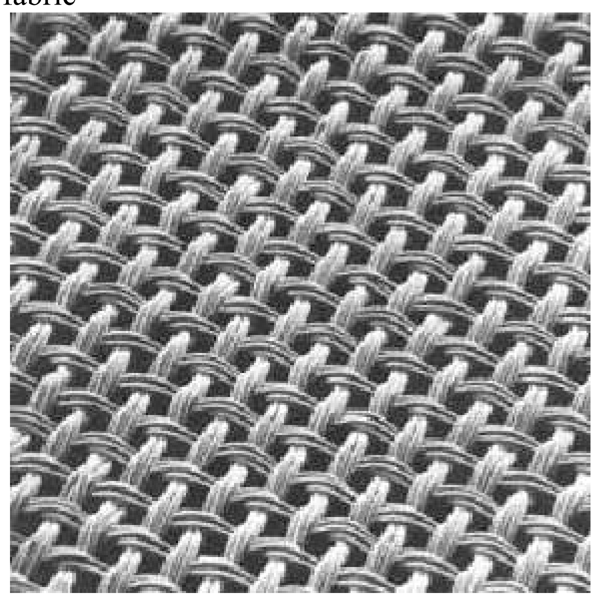
Fabric

Screen making - there are two types of threads for screen fabric:

- Monofilament - single strands weaved into fabric



  - primarily used in commercial printing and other applications
  - Advantage: Monofilament is easier to clean than multifilament
- Multifilament - multiple strands wound together like a rope, then weaved into fabric



  - primarily used in textile printing.
  - Disadvantage: ink tends to build up on screen, more difficult to clean Monofilament mesh has become the industry standard

Fabric Types

Today commercial screen printing primarily uses 4 types of fabric for making screens, silk, cotton organdie, nylon, and polyester. Silk was the original material used to make screens for screen printing. By far the most widely used fabric is monofilament polyester followed by multifilament polyester and nylon.

- Silk - multifilament weave
    - loses taughtness with frequent use
    - reclaiming chemicals containing bleach or chlorinated solvents destroy the silk
    - today silk is primarily used for printing art, not commercial use as before
- Cotton Organdie - multifilament weave
    - same disadvantages as silk
- Nylon - multifilament or monofilament
    - good for stretching
    - compared to polyester, lacks stability
    - less rigid than polyester
    - unsuitable for closely registered colors
- Polyester - multifilament or monofilament (calendared monofilament polyester, metallized monofilament polyester)
    - primary material used in commercial screen printing
    - Polyester is strong and stable when stretched
- Other screen materials - carbonized polyester
    - glass
    - wire mesh
    - 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. The need for various characteristics such as wear ability 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).

Screen mesh

Screen mesh refers to the number of threads per inch of fabric. The more numerous the threads per inch the finer the screen.

Finer mesh will deposit a thinner ink deposit. This is a desirable affect when printing a very fine detail and halftones. Typically a fabric should be 200-260 threads per inch. Water based inks work best on finer mesh. These are generally used in graphic and industrial printing.

Course mesh will deposit a heavier ink deposit. This type of screen is used on flatter, open shapes. Typically a course screen mesh will be 160-180 threads per inch. These are generally used in textile printing.

"Emulsion" or "Stencils"

The words emulsion and stencil are used interchangeably in screen printing.

Applying the emulsion is the chemical process of transferring image to a screen. The function of the emulsion (or stencil) is to cover the non-printing area of the screen. The stencil process works due to the use of a light sensitive material that hardens when exposed to ultraviolet light. The stencil material 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 photo stencil, and wet-direct photo stencil.

The stencil is composed of either a liquid product that is poured onto the screen mesh or a film product. There are two types of photographic film, pre-sensitized and unsensitized, available for use in the preparation of stencils. Pre-sensitized 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.

There are four stencil application processes, hand cut, direct stencil and indirect stencil (application of a film):

Hand Cut

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.

Direct Stencil

In the direct coating process, a light-sensitive emulsion is applied to the entire screen using a scoop coater 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.

Some of the characteristics of direct stencils are:

- Most are water soluble
- Wear better than indirect stencils
- Cheaper to produce than indirect stencils
- Two different types of direct stencil solution
    - Water-resistant stencil solution
    - Solvent-resistant stencil solution

Within direct stencil processes yellow and orange colored fabric is used for the screen mesh. The color prevents light from bouncing when the stencil is exposed to UV. If light bounces or scatters the exposure is uneven.

Indirect Stencil

The preparation of 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 indirect process produces highly durable stencils that are used in applications where high print quality is required.

Indirect Stencil process consists of using a coated acetate film which is cut into the exact shape of the artwork and adhered to the screen using water then is dried by heat. Some of the characteristics of Indirect Stencils are:

- Produce excellent definition & finer detail
- Best for Water-based ink printing
- More difficult to remove from screen mesh, requires high pressure water rinse.

Wet-Direct Photo stencil
A recent development in stencil preparation is the wet-direct photo stencil 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.

Screen Printing Prepress - Screen Making - Emulsion Application

- Clean & Degrease Screen Mesh
  - putting tooth on mesh

The screen must first be thoroughly cleaned and degreased prior to applying emulsion (stencil). If not, the film stencil will not properly adhere to the screen resulting in parts of the stencil coming loose during printing and thus spoiling the finished product. The screen is then cleaned with warm water and cleaner/degreaser. Then, a pumice-based abrasive is used. These steps act to remove grease from the surface and roughen it so that the film stencil adheres well. This is called "putting tooth" on the mesh.

- Apply emulsion/stencil

The process of exposing indirect and direct stencils is the same. A light-proof positive is made on a sheet of clear acetate to act as the positive image area of the screen. This is placed over the light-sensitive coating. A timed exposure to UV light is then made. The UV light hardens only the exposed parts of the film coating (negative areas); the areas of emulsion concealed beneath the positive image remain soft. A simple developer is then used to further harden the exposed parts of the film stencil. On washing the emulsion with warm water, the soft areas of film emulsion start to dissolve, finally disappearing to leave a negative stencil that is the exact opposite of the positive image. When printed, the result will be the exact likeness to the original positive image / artwork.

Emulsion Types

- Water resistant emulsions
  - Solvent based ink
  - UV curable ink
  - Water based ink - w/ chemical curing
- Solvent resistant emulsions
  - Water based ink
  - UV curable ink

Water resistant emulsions are used in Direct Stencil processes and capillary film processes. Stencil or emulsion which is water-soluble is incompatible with water based ink. Solvent-based and UV curable inks can be used with water-resistant emulsions

Chemical curing of water-resistant emulsions using a HCl based solution can improve resistance to water and therefore can be used with water based inks. Screens made with water resistant emulsions are more difficult to reclaim/remove the stencil than solvent-resistant, but are very inexpensive. It also adds an extra step and use of additional chemicals.
Solvent resistant emulsions cam be used along with water based inks. Although solvent resistant emulsions are most compatible with water based ink systems, the use of solvent-resistant emulsions and water based inks cause the emulsion to quickly erode and create pin-holes. In order to avoid this problem screen printers can opt for water resistant emulsions with chemical curing.
There are no VOC or HAP emissions from screen emulsion products or the process of applying the emulsion to the screen.

Screen Printing Presses

There are three types of screen printing presses. The flat-bed (probably the most widely used), cylinder, and rotary.

Flat-bed and Cylinder Presses

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

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.

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.

Screen Reclamation (post-press)

Why reclaim screens?

Polyester fabric costs $10-40 per square yard.

Failure to reclaim screens and ruined screens cost on average $5,000-$10,000 per year. The average monthly fabric cost $360. One study showed chemical reclamation cost between 2 and 10 dollars per average screen, while screen disposal cost just shy of 50 dollars.

The process of reclaiming screens generates solvent waste and waste water. Solvent waste generated from screen cleaning and waste water is generated through the process of emulsion removal. The waste water will contain particulates comprised of ink pigment, emulsion and emulsion remover (periodate).

Reclaiming screens involves 2 to 3 steps.

1. Remove the ink:

Any and all excess ink in the screen should be "carded off" for reuse on another job. The screen must then be washed to remove any remaining ink because the ink will interfere with the process of removing the stencil. Screen cleaning solvents are a source of VOC emissions.

2. Emulsion removal:

The stencil or emulsion is removed by spraying the screen with a solution of water and emulsion remover chemicals which is comprised mainly of sodium metaperiodate. Then rinsing the solution away with fresh water.

The emulsion remover solution should not be permitted to dry on the surface of the screen. The emulsion and remover will become virtually impossible to remove if allowed to dry. Repeated rinsing will result in excess waste water that must be disposed of as a regulated waste and will not significantly improve the situation.

3. Haze or ghost image removal:

Finally, if any haze or "ghost image" remains, a haze remover must be applied. Some haze remover products are caustic and can damage or weaken the screen. Haze removers make screens brittle and tear easily, therefore only small amounts should be used. Ghost image is a shadow of the original image that remains on the screen caused by ink or stencil caught in the threads of the screen.

Screen Printing Inks

Screen printing inks are moderately viscous inks which exhibit different properties when compared to other printing inks such as offset, gravure and flexographic inks though they have similar basic compositions (pigments, solvent carrier, toners, and emulsifiers).

There are five different types of screen ink to include solvent, water, and solvent plastisol, water plastisol, and UV curable.

UV Curable

UV curable inks consist of liquid prepolymers, monomers, and initiators which upon being exposed to large doses of U.V. Radiation instantly polymerize the vehicle to a dry, tough thermosetting resin. They also require less energy, overall, to dry or "cure" compared to gas or electric driers.

The down side of UV inks is they can cost as much as three times that of regular inks and must be handled differently than conventional inks due to safety issues. Additionally, solvents are required for clean-up which results in some VOC emissions.

Plastisol Inks

Plastisol inks (both solvent and water based) are used in textile screen printing.

Solvent Inks & Water Inks

Solvent and water based screen printing inks are formulated with primarily solvent or water. The solvent evaporates and results in VOC emissions. Water based inks, though they contain significantly less, may still emit VOC's from small amounts of solvent and other additives blended into the ink. The liquid waste material may also be considered hazardous waste.

Letterpress Printing

Applications

Typical products printed with letterpress printing processes include business cards, letterhead, proofs, billheads, forms, posters, announcements, imprinting, embossing and hot-leaf Stamping

Offset Letterpress Printing Process Overview

Letterpress is the oldest method of printing with equipment and images printed by the "relief" type printing plates where the image or printing areas are raised above the non-printing areas. The use of letterpresses is on the decline being replaced with faster and more efficient printing presses such as the offset lithographic press or the flexographic press. The amount of setup required to prepare the equipment to print a job is significant. For example, the image must be metal cast prior to print versus offset printing plates which are comparatively cheaper and require less time to make.

How letterpress works: Letter press printing exerts variable amounts of pressure on the substrate dependent on the size and image elements in the printing. The amount of pressure per square inch or "squeeze" is greater on some highlight dots than it is on larger shadow dots. Expensive, time consuming adjustments must be made throughout the press run to make sure the impression pressure is just right. 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).

Image Preparation of Letterpress Printing Plates

Letterpress printing uses type that is raised above (relief) the non-printing areas. In traditional letterpress work, letters were assembled into copy, explanatory cuts were placed nearby, line drawings were etched or engraved into plates, and all these were placed (composed) on a flat marble stone, within a rigid frame (chase) spaced artistically with blocks (furniture) tightened up (locked-up) with toothed angular blocks (quoins).

In the construction of a letterpress "form" older methods of image making involving cast metal, plated molds, and other media have been replaced with photopolymer relief plates in those instances where letterpress equipment is still functional There are a few presses still availing themselves of old type and casts, and using ancient type-making machines (like linotype) but there are few persons alive today who know how to operate, much less keep them in functional repair.

The usage of cast metal type was replaced in some instances with typewriter generated "cold type", by the Varityper, Friden Justowriter, IBM Selectric Composer and these were replaced in part by photographic and then electronic plate making. The development of photopolymer relief plates began to replace all of the above when letterpress hit its prime, and is now the most economical plate making method available.

As letterpress usage grew, it became obvious that for long runs of the same copy, duplicate plates would save time and money. Stereotype, electrotype, rubber and plastic duplicate plate making thrived, but are no longer widely used for letterpress work. The more economical and faster to produce photopolymer plates are extending the life of letterpress printing to some extent.

Photoengraving, at one time thought to be the last word in plate making, is still in use to a limited extent, however photopolymer plates are less expensive, quicker to make, and supply fewer chemical residues, as a result the equipment to make photopolymer plates and the plates themselves provide an undeniable cost saving without jeopardizing the quality of the finished product. Chemical engraving has taken a back seat to mechanical and electronic computer driven engraving methods because of environmental reasons as well as cost and speed. Computers are also doing typesetting, and films, where used, are often laser generated.

Letterpress Equipment Design

There are three different types of letterpress printing devices in use today: platen, flat-bed, and rotary presses. The two most common types of letterpress presses, the unit-design perfecting rotary press and the rotary letterpress typically used for magazine printing.

Platen-type Letterpress Printing

A platen press is made up of two flat surfaces called the bed and the platen. The platen provides a smooth backing for the paper or other substrate that is to be printed. The raised plate (image to be printed) is locked onto a flat surface. The plate is inked, the substrate is then placed on another flat surface called the bed and pressed against the inked plate producing the impression.

The platen and bed carry both the paper and the type form. The press then opens and closes like a clam shell. Platen printing is typically used for short runs such as invitations, name cards, and stationary. Larger platen presses are used for die-cutting and embossing. 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 Letterpress Printing

Flat-bed cylinder presses use either vertical or horizontal beds. 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. Another way of describing this is that a single revolution of the cylinder moves over the bed while in a vertical position so that both the bed holding the substrate and cylinder move up and down in a reciprocating motion. Ink is supplied to the plate cylinder by an inking roller and an ink fountain. The 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.

Flat-bed cylinder presses operate very slowly, 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 Letterpress Printing

There are two type of rotary letterpresses, sheet-fed and web-fed. Sheet fed rotary presses are also declining in use; in fact these presses are no longer manufactured in the U.S. Web-fed rotary presses are the most popular type of letter press printing.

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 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.

Plateless Processes

Applications

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.

Printing Type Process Overview

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 (solvent less) 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).

Equipment

A number of commercial plateless printing technologies exist including: electronic printing, ink jet printing, magnetography, ion deposition printing, direct charge deposition printing, and the Mead Cycolor Photocapsule process.

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).

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).

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. Magneto-graphic 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).

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).

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).

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).

Mead Cycolor Photocapsule Process

The Mead Cycolor Photocapsule Process combines microencapsulation technology used in carbonless copy paper with photo polymerization 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).

Post press Operations

Post press 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 post press 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 post press operations unique to screen printing including die cutting, vacuum forming, and embossing.

A limited number and volume of chemicals are used in post press operations. The major type of chemicals used in post press 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 post press operations is provided.

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 post press operation, most lithographic and gravure web presses have integrated cutters as well as equipment to perform related operations such as slicing and perforating.

Folding

Folding largely completes post press 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 post press 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.

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.

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 case bound covers.

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.

Loose-leaf 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 post press 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.

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.

Case bound 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 case bound 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.

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).

In-line finishing, an automated process that links the press directly with post press operations, is also discussed.